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IN NATURAL SCIENCES

Mediterranean temporary wetlands: Biodiversity, Functioning and Conservation



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Introduction

Temporary wetlands (TWs) are small, shallow wetlands characterised by altering phases of drought and flooding and by very self-contained hydrology. They occur in depressions, which are often endorheic, that are submerged for sufficiently long periods of time to allow the development of hydromorphic soils, aquatic or semi-aquatic vegetation, and specific animal communities (Grillas, 2004). TWs maintain specific communities of both aquatic and amphibious species (Rhazi et al. 2006). However, and equally importantly, they dry out for long enough to exclude the more commonplace plant and animal communities which are characteristics of permanent wetlands (Grillas, 2004). TWs are some of the most remarkable yet most threatened habitats in the Mediterranean region. They comprise an ensemble of highly complex biotopes linked to the major characteristics of the Mediterranean climate typified by a long dry season, in the Mediterranean region and also in various parts of the world subject to more or less arid climates: Mediterranean and arid climate regions of North and South Africa, the Americas (USA, Chile), and Australia (Grillas, 2004). The diversity of vegetation of these habitats has been long recognized in Europe and in North-Africa (e.g. Braun-Blanquet, 1935; Chevassut & Quézel, 1956; Metge, 1986).

At regional level, all the water-body types supported nationally uncommon species but, overall, TWs consistently supported more uncommon species than other types of water-body (Williams, 2003). They often make a greater contribution to biodiversity than any other aquatic habitat (Biggs *et al.*, 2005).

Temporary aquatic ecosystems are useful for studying temporal changes in community organization because the communities inhabiting them change rapidly over time, and they are simple and easily manipulated (Wilbur, 1987; Blaustein, 1997; Schneider & Frost, 1996).

In these habitats the water regime is a major determinant of plant community development and patterns of zonation. A zonation model was proposed for temporary ponds from western Morocco, where three concentric belts were identified: an inner, an intermediate and a peripheral one (Rhazi *et al.*, 2006). In Californian vernal pools a zonation was also recognized (Barbour *et al.*, 2003; Bauder, 2000).

Aquatic and amphibious plants play a key role in wetland ecosystems, as primary producers, providing food and habitat for aquatic and terrestrial organisms. Many contributions to this special issue highlight relationships between species richness of various taxa and environmental variables at regional (Virola *et al.*, 2001; Heino, 2002; Heegaard, 2004; Rolon

& Malchik, 2004) and at local scales (Bornette *et al.*, 1998; Bini *et al.*, 1999; Thomaz *et al.*, 2003; Maltchik *et al.*, 2002; Bertoluci *et al.*, 2004). The predictors for richness and composition of plant in wetlands include factor as, size (Rorslett, 1991; Vestergaard & Sand-Jensen, 2000; Oertli *et al.*, 2002; Jones *et al.*, 2003), altitude (Kotze & O'Connor, 2000; Jones *et al.*, 2003), land use (Smith & Haukos, 2002), water chemistry (Jeppesen *et al.*, 2000, Heegaard *et al.*, 2001; Lougheed *et al.*, 2001) and hydrological fluctuations (Keddy & Reznicek, 1986; Maltchik *et al.*, 2005).

The biological diversity in TWs has been maintained over the centuries by extensive human activities. Although they have significant ecological functions and they recognized social and economics uses are recognized. More recently these habitats have been facing increasing human pressure dues to the urban, industrial and agricultural development (Quézel, 1998). These changes could lead to changes in the plants specie richness (Hill & Keddy, 1992; Rhazi *et al.*, 2001; Crosslé & Brock, 2002) through different mechanisms (e.g. trampling, erosion, filling-in, selective, grazing, nutrient enrichment and pesticide intrusion) and to these threats should also be added at a regional scale the drastic diminution of the number of TWs and also the reduction of connectivity between them (isolation and rupture of migration corridors).

The aims of this research were:

- to define floristic, structural, and syntaxonomical features of plant assemblages within TWs at a small spatial scale and at a short temporal scale (**Chapter 2, 4, 6**).
- to clarify some systematic issues of a flagship species of these habitats, particularly: to assess to what extent this macrospore ornamentation was related to any geographical or ecological trends throughout populations of *I. histrix* from Sardinia, to assess whether the pattern of variation in macrospore features was correlated with karyological, molecular (nuclear ribosomal ITS sequences), macromorphological and micromorphological (microspore ornamentation) discontinuities (**Chapter 9**).
- to characterise the hydrological regimes (water depth and flooding period) in different TW types and to define some phytosociological features from biogeographical and ecological point of view (**Chapter 1**).
- to point out possible relationship between plant and crustacean community parameters and the possible differences in their spatial-temporal dynamics; to identify the influence of environmental parameters, relative to the TWs structure, the water quality and the landscape, on plant and crustacean communities (**Chapter 5**).
- to compare soil and vegetation patterns in TWs (**Chapter 8**).

- to point out useful criteria to facilitate univocal identification of the habitats of Community Interest possibly present in TWs (**Chapter 3**) and to define the conservation status relative to some critical species according to the IUCN criteria (**Chapter 7**).

All manuscripts contribute to build a background of information adequate for conservation efforts.

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Chapter 1

Phytosociological analysis in Sardinian Mediterranean temporary wet habitats

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Phytosociological analysis in Sardinian Mediterranean temporary wet habitats

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Abstract

The aims of this research were to contribute to the knowledge of the Mediterranean temporary wet habitats vegetation and to investigate the spatial distribution and the temporal successions of plant communities under different hydrological regimes in North Western Sardinia. The vegetation was sampled in temporary wet habitats located in large depressions (temporary ponds), in small depressions in patchwork with the vegetation dominated by *Myrtus communis* (waterlogged soils) and in rocky outcrops (rock pools). Three belts were recognized in temporary ponds: a central belt, an intermediate belt, and an outer belt. Overall 11 associations and subassociations were identified, within 4 syntaxonomic classes: *Potametea*, *Isoeto-Nanojuncetea*, *Isoeto-Littorelletea* and *Phragmito-Magnocaricetea*. Four new associations have been described: *Isoeto tiglianae-Callitrichetum brutiae*, *Romuleo requienii-Isoetum histricis*, *Apio crassipedis-Elatinum macropoda*, and *Lythro hyssopifoliae-Crassuletum vaillantii*. Moreover, within the *Preslion cervinae* alliance of the *Isoeto-Nanojuncetea* class, a new Tyrrhenian suballiance *Apionion crassipedis*, has been established, for which the typical association is the *Apio crassipedis-Isoetum tiglianae* Biondi & Bagella 2005 corr. hoc loco. Aquatic vegetation was found in the central and intermediate belt of the temporary ponds and within the rock pools. Late winter-spring amphibious communities were present in almost all temporary wet habitats. Summer plant communities were found exclusively in the central belt of temporary ponds.

Key words: *Apionion crassipedis*, biogeography, hydrological regimes, *Isoeto-Nanojuncetea*, rock pools, temporary ponds, waterlogged soils.

Riassunto

Con questa ricerca si è voluto dare un contributo alla conoscenza della vegetazione che caratterizza gli habitat temporaneamente inondati del Mediterraneo e, in particolare, alla sua distribuzione spaziale e alla sua dinamica temporale in diverse condizioni di inondazione. Le analisi sono state effettuate nella Sardegna Nord occidentale in tre diverse tipologie di habitat umidi: ampie depressioni (stagni temporanei), piccole depressioni a mosaico con la vegetazione arbustiva a dominanza di *Myrtus communis* e cavità rocciose. Solo all'interno degli stagni temporanei è stata riconosciuta una zonizzazione della vegetazione, determinata dalla presenza di tre fasce concentriche: una centrale, una intermedia e una esterna. Le analisi fitosociologiche hanno consentito di individuare 11 associazioni e subassociazioni riferibili a quattro classi: *Potametea*, *Isoeto-Nanojuncetea*, *Isoeto-Littorelletea* e *Phragmito-Magnocaricetea*. Sono state riconosciute e descritte 4 nuove associazioni: *Isoeto tiglianae-Callitrichetum brutiae*, *Romuleo requienii-Isoetum histricis*, *Apio crassipedis-Elatinum macropoda* e *Lythro hyssopifoliae-Crassuletum vaillantii* e una nuova suballeanza a distribuzione tirrenica del *Preslion cervinae*, indicata come *Apionion crassipedis* per la quale è stata indicata come associazione tipo *Apio crassipedis-Isoetum tiglianae* Biondi & Bagella 2005 corr. hoc loco. La vegetazione acquatica è stata rinvenuta nella fascia centrale e in quella intermedia degli stagni temporanei e all'interno delle cavità rocciose. La vegetazione anfibia tardo invernale-primaverile è stata invece rinvenuta in tutte le tipologie di habitat indagati. Infine la vegetazione anfibia a fenologia estiva è stata rinvenuta esclusivamente nella fascia centrale degli stagni.

Parole chiave: *Apionion crassipedis*, biogeografia, *Isoeto-Nanojuncetea*, regime idrologico, stagni temporanei.

Introduction

Temporary wet habitats (TWHs) are shallow wetlands, characterized by alternating phases of drought and flooding and by a very self-contained hydrology. They occur in endoreic depressions that are submerged for sufficiently long periods of time to allow the development of hydromorphic soils, aquatic or semi-aquatic vegetation, and specific animal communities. However, they dry out for a sufficiently long duration to exclude more widespread plant and animal communities, characteristic of permanent wetlands (Grillas, 2004).

The high spatial-time variability of plant and animal communities in TWHs, mostly depends on their hydrological regime (e.g. water-depth dynamics and flooding period), morphology, and size (Fernández-Aláez *et al.*, 1999; Collinson *et al.*, 1995; Oertli *et al.*, 2002; Williams, 2005; Deil, 2005).

From a syntaxonomic point of view, the vegetation that characterizes these habitats is referable not only

to the class *Isoeto-Nanojuncetea* Br.-Bl. & Tüxen ex Westhoff, Dijk, & Passchier 1946, which includes pioneer annual and dwarf perennial ephemeral isoetid communities growing on periodically flooded bare soils, but also to the classes (a) *Isoeto-Littorelletea* (Br.-Bl. & Vlieger in Vlieger, 1937), which includes dwarf helophyte amphibious oligotrophic communities on shores of dystrophic lakes, nutrient-poor standing/slow-flooding water, and (b) *Charetea fragilis* Fukarek ex Krausch 1964, which includes *Charophyte* pioneer communities growing on subaquatic barren soils of pools, lakes, and shallow water courses (Rivas-Martínez *et al.*, 2002). Furthermore, communities belonging to other classes, such as *Potametea* Klika in Klika & Novák 1941, *Phragmito-Magnocaricetea* Klika in Klika & Novák 1941, *Molinio-Arrhenatheretea* Tüxen 1937 and *Helianthemetea guttati* (Br.-Bl. in Br.-Bl., Roussine & Nègre 1952) Rivas Goday & Rivas-Martínez 1963 em. Rivas-Martínez 1978, could be present in a temporal succession at the same sites (Bagella *et al.*, 2007).

Mediterranean temporary wet habitats are considered to be habitats of Community Interest (European Commission, 1992) and are included in the “standing water group”. Following Bagella *et al.* (2007), *Isoetion* communities have to be assigned to the habitat 3170*-Mediterranean temporary ponds; *Preslion cervinae*, *Cicendio-Solenopsision laurentiae* and *Agrostion salmanticae* communities have to be assigned to habitat 3120-Oligotrophic waters containing very few minerals generally on sandy soils of the West Mediterranean with *Isoetes* spp.; *Cyperetalia fusci* and *Littorelletea uniflorae* communities to habitat 3130-Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or *Isoeto-Nanojuncetea*.

The aims of this research were: i) to characterize the hydrological regimes (water depth and flooding duration) in different kinds of Mediterranean temporary wet habitats; ii) to contribute to the phytosociological knowledge, both biogeographical and ecological aspects, of the Mediterranean temporary wet habitats vegetation and iii) to investigate the spatial distribution and the temporal successions of plant communities under different hydrological regimes.

Materials and Methods

The study area, the tableland of Monte Rosso – Monte Miale Ispina (200 m a.s.l.), is located in North-Western Sardinia, in the municipality of Olmedo, province of Sassari, Sardinia (Fig. 1). This tableland, of impermeable ignimbritic rocks of the Oligo-Miocene (Barca *et al.*, 1996), is 430 ha, of which temporary wet habitats occupy 12 ha. Annual mean temperature is 16.7°C and annual rainfall is 573.6 mm (average for the years 1988-99 and 1965-99, respectively). According to the classification by Rivas-Martinez *et al.* (2002), the area is included in the thermo-Mediterranean phytoclimatic belt (Fig. 2).

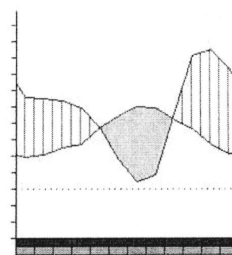
The plant landscape is characterized by the neutro-acidophilic cork-oak series, *Viola dehnhardtii-Quercus suberis myrtetosum communis* sigmetum (Bacchetta *et al.*, 2004), typical of hydromorphic soils with a clay texture and slow drainage. Land use until 20 years ago was mainly based on traditional livestock activities. Subsequently, a strong reduction of the stocking rate occurred, leading to the current total abandoning of the territory.

Regular surveys of vegetation were carried out every month, beginning from March, according to the method of the sigmatist school of Zürich-Montpellier (Braun-



Fig. 1 – Location of the study area

Olmedo (Italia)				50 m
P= 574	40° 39'N	4° 4'W	12/ 35 a	
T= 16.7°	Ic= 15.3	Ip= 2005	Tn= 0	
m= 8.3	M= 11.3	Irc= 363	Io= 2.9	



MEDITERRANEAN PLUVISEASONAL-OCEANIC
UPPER THERMOMEDITERRANEAN UPPER DRY

Fig. 2 – Thermopluviometric diagram for the study area

Blanquet, 1951), until the vegetation was completely withered. The vegetation was sampled in the temporary wet habitats (TWHs) located in large depressions (temporary ponds = TPs), in small depressions in patchwork with the vegetation dominated by *Myrtus communis* (waterlogged soils = WSs), and in rocky outcrops (rock pools = RPs) (Fig. 3). Following the zonation scheme proposed for Moroccan ponds (Rhazi *et al.*, 2006), which is based on water depth at the beginning of the season, morphology of the pond and kind of vegetation present, three belts were recognized in the TPs: a central belt (CB), an intermediate belt (IB), and an outer belt (OB). Water depth was monitored monthly throughout the year in the RPs, in the WSs and in the 3 belts of the TPs.

Phytosociological data were converted according

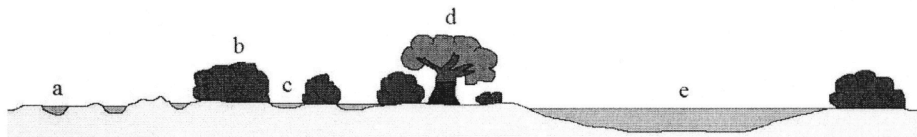


Fig. 3 – Plant landscape of the study area (a = rock pools; b = *Myrtus communis* maquis; c = water logged soils; d = *Viola dehnhardtii-Quercetum suberis myrtetosum*; e = temporary pond).

to the ordinal scale proposed by Van der Maarel (1979). A matrix of similarities between each pair of samples was then calculated using the Bray–Curtis similarity coefficient on untransformed data (Bray & Curtis, 1957). Cluster analysis was used to produce a dendrogram of the surveys with the algorithm of medium linkage (Anderson & Underwood, 1997). Plant communities were identified as homogeneous groups in the dendrogram of the surveys. Formal significance tests for differences between groups were conducted using the one-way analysis of similarities (ANOSIM) permutation/randomization test (Clarke & Warwick, 2001). The phytosociological tables were arranged on the basis of the statistical analysis.

The nomenclature follows Ferrarini *et al.* (1986) for the Pteridophytes and Tutin *et al.* (1964–1980, 1993) and Pignatti (1982) for the Spermatophytes. Life forms were classified according to Raunkiaer (1934), by using types and abbreviations reported by Pignatti (1982). Weighted life form spectra were calculated for each plant community, in addition to the richness and evenness values (Shannon & Weaver, 1949).

For the syntaxonomy were followed the standards contained in the third edition of the International Code of Phytosociological Nomenclature (Weber *et al.*, 2000).

Results

Hydrological regimes

In the TPs, the maximum water depth was reached in February in each belt. Differences in depth between the CB and the IB was 6–11 cm and between IB and OB was 4–12 cm. The flooding period was 8 months in CB, 7 months in IB, and 2 months in OB (Fig. 4).

In the WSs, the flooding period was from January to April, with a maximum water depth of 5 cm in February. RPs were filled in February and completely dry in March.

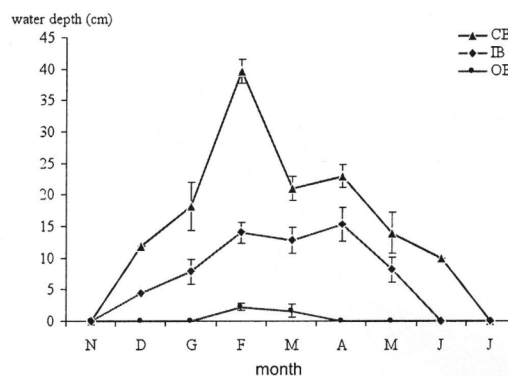


Fig. 4 – Water-depth trend (\pm sd).

Vegetation

Overall, 111 surveys were carried out and 82 taxa recorded. In the dendrogram (Fig. 5), two main clusters were identified: cluster A included late winter–spring vegetation; cluster B included summer vegetation. Within cluster A, sub-cluster a1 included aquatic vegetation, and sub-cluster a2 included amphibious vegetation. On the whole, 11 plant communities were identified (Fig. 5). Differences between the communities were significant by the ANOSIM test (Global R = 0.944; significance level of sample statistic = 0.001; $0.001 < p < 0.029$).

Late winter–spring vegetation

Aquatic vegetation

Aquatic vegetation includes communities of the *Isoeto-Littorelletea*, *Potametea*, and *Phragmito-Magnocaricetea* classes and *Preslion cervinae* alliance of the *Isoeto-Nanojuncetea* class.

ELEOCHARO PALUSTRIS-JUNCETUM HETERO-PHYLLI Paradis & Pozzo di Borgo 2005 (Table 1)

The plant communities referable to this association, originally described in Corse (Paradis & Pozzo di Borgo, 2005) and here indicated for the first time in Sardinia, were located in the CBs of the TPs during

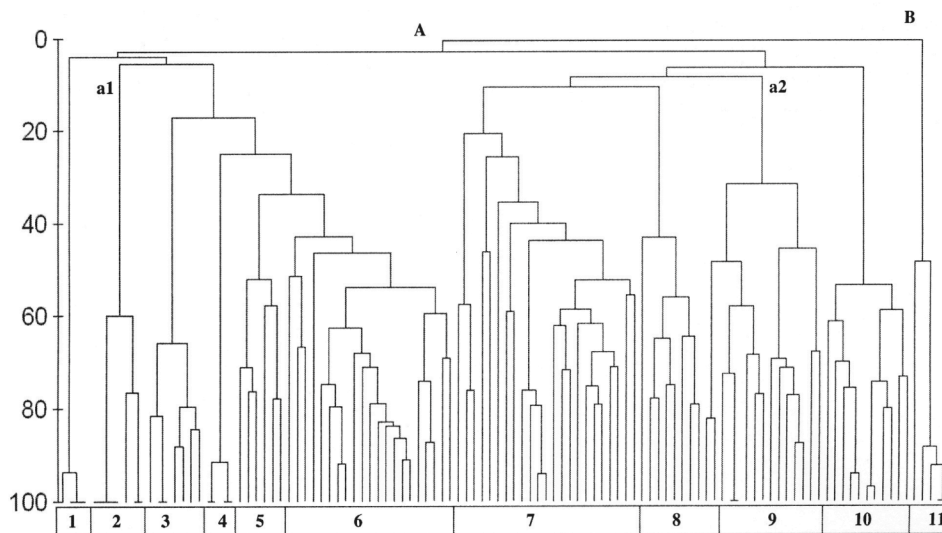


Fig. 5 – Dendrogram of the surveys (1 = *Eleocharo palustris*-*Juncetum heterophyllum*; 2 = *Callitricetum stagnalis*; 3 = *Baldellia ranunculoidis*-*Eleocharitetum palustris*; 4 = *Apio crassipedis*-*Elatinum macropodae*; 5 = *Isoeto tigulianae*-*Callitricetum brutiae*; 6 = *Apio crassipedis*-*Isoetum tigulianae*; 7 = *Romuleo requienii*-*Isoetum histricis*; 8 = *Bellido annuae*-*Cicendietum filiformis* subass. *solenopsidetosum laurentiae*; 9 = *Anthoxantho aristati*-*Agrostietum salmanticae*; 10 = *Lythro hyssopifoliae*-*Crassuletum vaillantii*; 11 = *Mentho pulegii*-*Exaculetum pusilli* subass. *eryngetosum barrelieri*).

flooding and had their maximum development in April-May. Hydrophytes (e.g. *Juncus heterophyllus*, *Baldellia ranunculoides*, *Myriophyllum verticillatum*, and *Ranunculus baudotii*) made up 62% of the cover (Fig. 6). Richness was very low (10 taxa), and evenness was also low (1.8), because of the strong dominance of *Juncus heterophyllus*.

CALLITRICETUM STAGNALIS Segal 1965 (Table 2)

The plant communities referable to this association, present in several sites in Sardinia, e.g. La Maddalena (Biondi & Bagella, 2005), were located in the IB of the TPs, on shallow soils, (rel. 5, 6, 7 in Table 2), where they had their maximum development in March-April and in the RPs (rel. 1, 2, 3, 4 in Table 2), where they were well developed in February and remained so until the end of March.

Hydrophytes (Fig. 6; e.g. *Callitriche stagnalis* and *Ranunculus baudotii*) strongly dominant, representing 84% of the cover. Therefore, evenness and richness were very low (1.5 and 14, respectively).

Tab. 1 - *Eleocharo palustris*-*Juncetum heterophyllum* Paradis & Pozzo di Borgo 2005

Rel. no.	1	2	3	4	P	
TWH	TP	TP	TP	TP	r	
Coverage (%)	100	100	100	100	e	
Area (m ²)	4	4	4	4	s.	
Charact. taxa of the ass.						
I	Juncus heterophyllus Desf.	5.5	5.5	5.5	5.5	4
He	Eleocharis palustris (L.) R. & S.	1.1	1.1	+	1.1	4
Charact. taxa of the upper units						
I	Baldellia ranunculoides (L.) Parl.	1.2	1.1	1.1	1.1	4
Other taxa						
H	Oenanthe fistulosa L.	2.2	3.3	3.3	3.3	4
I	Myriophyllum verticillatum L.	1.1	1.1	+	1.1	4
G	Glyceria spicata Guss.	+	+	+	+	4
H	Lotus uliginosus Schuhr	+	+	+	+	2
H	Mentha pulegium L.	+	+	+	+	2
I	Ranunculus baudotii Godron	+	+	+	+	2

BALDELLIO RANUNCULOIDIS-ELEOCHARITETUM PALUSTRIS Biondi & Bagella 2005 (Table 3)

This association, which has been described in the La Maddalena archipelago (Biondi & Bagella, 2005), included communities that developed in April-June, in both CBs of the TPs. They were dominated by the only helophyte discovered in the area, *Eleocharis palustris*, and included 21 taxa with an evenness value of 2.6.

Tab. 2 - *Callitricetum stagnalis* Segal 1965

Rel. no.	1	2	3	4	5	6	7	P
TWH	RP	RP	RP	RP	TP	TP	TP	r
Coverage (%)	100	100	100	100	90	90	90	e
Area (m ²)	1	2	1	1	1	2	2	s.
Charact. taxa of the ass.								
I Callitriche stagnalis Scop.	5.5	5.5	5.5	5.5	3.4	4.4	4.4	7
Charact. taxa of the upper units								
I Ranunculus baudotii Godron	.	.	.	.	1.1	2.2	2.2	3
Other taxa								
T Ranunculus ophioglossifolius Vill.	.	.	.	.	2.3	1.2	1.2	3
T Crassula vaillantii (Willd.) Roth	+	+	+	.	.	.	.	3
T Trifolium resupinatum L.	+	+	+	.	.	.	.	3
T Bellis annua L.	+	+	.	.	.	.	.	2
G Isoetes histrix Bory	.	+	.	+	.	.	.	2
T Silene laeta (Aiton) Godron	+	.	.	+	.	.	.	2
T Lythrum hyssopifolia L.	.	+	+	.	.	.	.	2
T Plantago coronopus L. subsp. commutata (Guss.) Pilger	.	+	+	.	.	.	.	2
Accidental taxa								
	1	0	1	0	2	0	0	

Tab. 3 - *Baldellia ranunculoidis-Eleocharitetum palustris* Biondi & Bagella 2005

Rel. no.	1	2	3	4	5	6	P
TWH	TP	TP	TP	TP	TP	TP	r
Coverage (%)	100	100	100	100	100	100	e
Area (m ²)	20	7	20	10	6	10	s.
Charact. taxa of the ass.							
He Eleocharis palustris (L.) R. & S.	4.4	3.3	4.4	4.4	3.3	3.3	6
I Baldellia ranunculoides (L.) Parl.	.	.	.	1.1	2.2	2.2	3
Charact. taxa of the upper units							
G Glyceria spicata Guss.	3.3	4.4	1.1	1.1	.	.	4
H Oenanthe fistulosa L.	+	.	.	3.3	.	1.2	3
Other taxa							
I Isoetes tiguliana Gennari	2.2	2.2	3.3	1.2	1.2	1.2	6
H Apium crassipes (Koch) Rehb. fil.	+	1.2	2.2	3.3	3.3	1.2	6
H Lotus uliginosus Scuhr	+	+	+	.	+	r	5
T Polygonum maritimum Willd.	1.1	.	1.1	+	.	+	4
T Ranunculus ophioglossifolius Vill.	+	1.2	1.1	.	.	.	3
H Mentha pulegium L.	.	.	.	+	1.2	+	3
T Trifolium michelianum Savi	1.1	+2	+	.	.	.	3
H Alopecurus bulbosus Gouan	+	+	+	.	.	.	3
T Myosotis sicula Guss.	+	+	+	.	.	.	3
T Illecebrum verticillatum L.	+	.	+	r	.	.	3
H Rumex pulcher L.	.	.	.	.	1.2	+	2
T Agrostis salmantica (Lag.) Kunth	+	.	+	.	.	.	2
I Juncus heterophyllus Desf.	.	.	.	+	.	+2	2
Accidental taxa							
	1	1	0	2	0	0	

APIO CRASSIPEDIS-ELATINETUM MACROPODAE
ass. nova hoc loco (holotypus rel. no. 2, Table 4)

The communities dominated by *Elatine macropoda* were present in the IB of the TPs from March, when water depth was 10–15 cm. They could be considered hydrophytic communities, hydrophytes covering 74% (Fig. 6), and surviving until June on waterlogged areas. The proposal of a new association is based on the fact that these communities present floristic and ecological characteristics different from those of

Elatinetum macropodae Br.-Bl. (1931) 1935 communities. Furthermore because they occur in long-submerged depressions they have to be considered as belonging to the *Preslion cervinae* alliance instead of the *Isoetion* alliance. Richness and evenness showed low values: 8 and 1.8, respectively.

ISOETO TIGULIANAE-CALLITRICETUM BRUTIAE ass. nova hoc loco (holotypus rel. no. 1, Table 5)
isoetetosum tigulianae subass. nova hoc loco (holotypus rel. no. 1, Table 5)
myriophylletosum verticillati subass. nova hoc loco (holotypus rel. no. 6, Table 5)

The communities dominated by *Callitriche brutia* are proposed to be referred to this new association of the *Preslion cervinae* alliance. *Callitriche brutia* geographical distribution includes Western and Southern Europe, eastwards to Italy (Tutin *et. al.*, 1964-80). Two

associations in which this species was dominant were already described: *Myriophyllo alterniflori-Callitricetum brutiae* Cirujano, Pascual & Velayos 1986 for the Iberian peninsula (Cirujano *et al.*, 1986) and *Ranunculo-Callitricetum brutiae* Brullo & Minissale 1998 for Sicily (Brullo *et al.*, 1987, Brullo & Minissale, 1998). The new association proposed is differentiated by the presence of *Isoetes tiguliana* and *Apium crassipes*.

Two subassociations were recognized: *isoetetosum*

Tab. 4 – *Apio crassipedis-Elatineum macropoda* ass. nova (holotypus rel. no. 2)

Rel. no.	1	2*	3	4	P	
TWH	TP	TP	TP	TP	r	
Coverage (%)	90	90	90	90	e	
Area (m ²)	1	1	1	1	s.	
Charact. and diff. taxa of the ass. and of the suball. <i>Apionion crassipedis</i>						
I	Elatine macropoda Guss.	5.5	4.5	4.5	4.5	4
I	Isoetes tiguliana Gennari	2.2	3.2	2.2	2.2	4
H	Apium crassipes (Koch) Rchb. fil.	+2	1.1	+2	+2	4
T	Antinoria insularis Parl.	.	1.2	+	+	3
Charact. taxa of the upper units						
T	Juncus pygmaeus Richard	1.2	1.1	1.1	1.2	4
T	Ranunculus ophioglossifolius Vill.	+	+	1.1	+	4
T	Lythrum borysthenicum (Schränk) Litv.	+	+	1.1	.	3
T	Crassula vaillantii (Willd.) Roth	+	+	.	+	3

Tab. 5 – *Isoetes tiguliana* – *Callitricheum brutiae* ass. nova (holotypus rel. no. 1)
isoetetosum tiguliana subass. nova rel. 1-3 (holotypus rel. no. 1)
myriophylletosum verticillati subass. nova rel. 4-7 (holotypus rel. no. 6)

Rel. no.	1*	2	3	4	6	5	7	P	
TWH	TP	TP	TP	TP	TP	TP	TP	r	
Coverage (%)	90	100	100	100	100	100	100	e	
Area (m ²)	4	1	1	2	2	2	4	s.	
Charact. and diff. taxa of the ass. and the upper units									
I	Callitriche brutia Petagna	4.4	5.5	5.5	4.4	5.5	4.4	5.5	7
I	Isoetes tiguliana Gennari	3.3	1.2	1.2	1.1	.	2.2	1.1	6
H	Apium crassipes (Koch) Rchb. fil.	.	+	+	.	+	+	+	5
Diff. taxa of the subass. <i>myriophylletosum verticillati</i>									
I	Myriophyllum verticillatum L.	.	.	.	3.3	3.3	3.3	2.2	4
I	Ranunculus baudotii Godron	+	.	.	+	.	2.2	1.1	4
Other taxa									
G	Glyceria spicata Guss.	+	.	.	+	+	+	+	5

tiguliana, which represents the typical aspects of the association (rel. 1-3 in Table 5), and *myriophylletosum verticillati* (rel. 4-7 in Table 5), present in deepest water, which represents a transition toward the class *Potametea*.

The communities belonging to this association were located in the CB and IB of the TPs in March-April and were composed nearly exclusively by hydrophytes (Fig. 6), e.g. *Callitriche brutia*, *Myriophyllum verticillatum*, *Isoetes tiguliana*, and *Ranunculus baudotii*. Diversity was low both in terms of richness (6 taxa) and evenness (1.5).

APIO CRASSIPEDIS-ISOETETUM TIGULIANA

Biondi & Bagella 2005 corr. hoc loco (Table 6)
The communities placed in this association, which was also described in the La Maddalena archipelago (Biondi & Bagella, 2005), developed mostly in the IBs of the TPs from March to May. They survived until the substratum was waterlogged and represented a transition between the aquatic and amphibious

vegetation, with 3 codominant life forms (Fig. 6): hemicryptophytes 34%, hydrophytes+helophytes 34%, and therophytes 30%. An increase in the richness and evenness values (34 and 2.7, respectively) was recorded with respect to the communities dominated by hydrophytes+helophytes.

Amphibious vegetation

Amphibious vegetation includes the communities of *Isoetion*, *Cicendio-Solenopsis laurentiae*, according to Brullo & Minissale (1998), and *Agrostion salmanticae* alliances.

ROMULEO REQUIENII-ISOETETUM HISTRICIS

ass. nova hoc loco (holotypus rel. no. 13, Table 7)
The ephemeral dwarf communities dominated by *Isoetes histrix*, were referred to this new association of the *Isoetion* alliance. With respect to the other communities dominated by *Isoetes histrix*, e.g. *Junco capitati-Isoetum histricis* Br.-Bl. 1936, the differential species is the Tyrrhenian endemic *Romulea requienii*.

These communities develop in the OB of the TPs and in the WSs very

early in the season (March-April). The dominant life forms were therophytes (52%): e.g. *Lythrum hyssopifolia*, *Juncus hybridus* and *J. pygmaeus*; and geophytes (39%): e.g. *Ophioglossum lusitanicum*, *Romulea requienii*, and *R. ligustica* (Fig. 6). The level of diversity was the highest in comparison to all the other plant communities present in the TWHs studied in the area (richness: 49 and evenness: 3.3).

BELLIDO ANNUAE-CICENDIETUM FILIFORMIS

De Foucault 1988
solenopsidetosum laurentiae Paradis & Pozzo di Borgo 2005 (Table 8)

Communities dominated by therophytes, which provided 85% of the cover (Fig. 6), were referred to this subassociation, reported in Corsica by Paradis & Pozzo di Borgo (2005), and described here for the first time in Sardinia.

They develop in April-May in the OB of the TPs and in the WSs, and are rich in species characteristic of the class *Isoeto-Nanojuncetea* (e.g. *Cicendia filiformis*,

Tab. 7 - *Romulea requienii*-*Isaetum histricis* ass. nova (holotypus rel. no. 13)

Rel. No.	1	2	3	4	5	6	7	8	9	10	11	12	13*	14	15	16	17	18	19	20	21	22	23	P		
TWH	WS	WS	WS	TP	TP	WS	TP	TP	WS	WS	WS	WS	WS	WS	WS	WS	WS	WS	WS	WS	WS	WS	WS	r		
Coverage (%)	70	70	80	100	90	90	100	100	100	100	100	95	90	90	90	90	90	85	90	100	100	70	100	e		
Area (m ²)	1	1	1	2	1	4.5	1	1	1	1	2	2	14	20	27	12	20	18	8	34	9	1	2	s.		
Character and diff. taxa of the ass.																										
G	1.1	1.1	1.1	4.4	4.4	3.3	3.3	4.4	4.4	2.3	3.3	3.3	4.4	2.3	3.3	4.4	3.3	4.4	4.4	3.3	4.4	4.4	4.4	2.3		
G	r	.	.	+	+	+	1.1	1.1	1.1	1.1	1.1	2.2	2.2	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	2.1		
Character taxa of the upper units																										
T	1.1	+	1.2	+	+	+	1.1	.	.	.	2.3	2.3	1.2	1.1	+	+	+	1.1	+	+	+	1.1	1.1	+	20	
T	2.2	+	+	.	1.2	1.2	1.2	1.2	1.2	+	2.3	1.2	1.2	+	+	1.1	1.1	+	+	18		
T	1.2	.	+	.	.	+	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	18	
T	+	12	
T	11	
T	9	
T	6	
T	5	
T	5	
T	4	
H	4	
H	3	
T	3.4	3.3	3.3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	
T	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	
T	2	
T	2	
T	2	
T	1	
T	2	
Other taxa																										
T	1.2	+	+	1.1	+	+	2.3	+	.	3.3	1.1	1.2	+	.	.	.	.	.	.	.	.	.	.	.	19	
T	2.2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	14
T	+	+	.	+	14
T	1.1	1.1	1.1	.	.	.	.	.	.	.	.	.	.	.	.	.	13
G	12
T	12
T	12
T	11
T	11
H	10
T	9
G	9
H	4
H	3
H	3
H	3
T	3
T	3
G	2
G	2
Accidental taxa																										

Isoetes histrix, *Laurentia gasparrinii*, and *Lythrum hyssopifolia*), in addition to species of the class *Saginetea maritimae* (e.g. *Polypogon maritimus*), and the class *Helianthemetea guttati* (e.g. *Anagallis foemina* and *Oglifa gallica*).

ANTHOXANTHO ARISTATI-AGROSTIETUM SALMANTICAE Biondi & Bagella 2005 (Table 9)

The communities in this association, described initially of La Maddalena (Biondi & Bagella, 2005), develop at the end of spring (May-June), when the OB of the TPs and WSs were completely dry. The dominant life form was that of therophytes, which contribute 75% of the plant cover, followed by hemicryptophytes (Fig. 6). The high level of diversity (richness: 41, and evenness: 3.1) was due to the large number of species of the class *Isoeto-Nanojuncetea* (e.g. *Agrostis salmantica*, *Mentha pulegium* and *Hordeum histrix*),

plus the presence of several uncharacteristic species, such as *Lotus uliginosus*, *Trifolium resupinatum*, and *Polypogon maritimus*.

LYTHRO HYSSOPIFOLIAE-CRASSULETUM VAILLANTII ass. nova hoc loco (holotypus rel. no. 6, Table 10)

The dwarf communities dominated by *Crassula vaillantii* were referred to this new association of the *Isoetion* alliance. No association dominated by *Crassula vaillantii* was indicated until now for Sardinia. The communities of the study area have floristic differences to the other communities already described in the Iberian peninsula: *Damasonio bourgaei-Crassuletum vaillantii* O. Bolòs & Llorens in O. Bolòs 1966 and *Lythro thymifoliae-Crassuletum vaillantii* Rivas Goday ex Ruiz & A. Valdés 1987; and in France: *Isoeto velatae-Crassuletum vaillantii*

Tab. 8 - *Bellis annuae-Cicendietum filiformis* De Foucault 1988
solenopsidetosum laurentiae Paradis & Pozzo di Borgo 2005

Rel. no.	1	2	3	4	5	6	7	8	P
TWH	WS	WS	WS	WS	WS	TP	TP	TP	r
Coverage (%)	80	80	85	90	90	90	80	95	e
Area (m ²)	3	2	3	2	2	2	4	4	s.
Charact. taxa of the ass.									
T	2.2	1.1	2.2	2.3	2.2	1.1	1.1	1.1	8
T	.	r	+2	.	.	.	.	.	2
Diff. taxa of the subass. <i>solenopsidetosum laurentiae</i>									
T	+	1.1	1.2	+	1.2	1.2	1.2	1.2	8
Charact. taxa of the upper units									
T	+2	2.2	2.2	1.2	+	+2	1.1	1.1	8
G	+	+	+	+	+	+	+	+	8
G	+	+	+	+	+	+	+	+	8
T	r	r	r	r	r	r	+	+2	8
T	.	+	+	1.2	1.1	.	r	+	6
T	.	r	1.2	+2	+2	r	+2	+2	7
G	r	.	+2	.	.	+	+	+2	5
T	+2	.	+2	.	r	+2	.	.	4
T	.	.	.	.	.	+	1.2	+2	3
T	.	.	.	r	.	.	r	.	2
T	.	.	.	.	r	r	.	.	2
T	.	+	.	.	.	.	.	.	1
Other taxa									
H	1.1	2.3	2.2	1.1	2.2	1.2	1.1	1.2	8
T	1.2	1.2	1.2	2.2	1.1	2.2	1.1	1.1	8
T	2.2	1.2	1.1	1.1	1.1	1.2	+	+	8
T	+	2.2	1.2	1.2	2.2	+2	+2	1.2	8
T	+	2.2	1.1	1.1	1.2	+	2.2	1.2	8
T	+2	+	1.1	+	+	1.1	1.1	1.1	8
T	+2	+	+2	r	+2	+	+2	+2	8
T	+	1.2	1.1	.	+	+	+	1.2	7
T	.	1.1	.	+2	r	+	+2	+2	6
T	.	r	.	r	+	.	+2	+	5
H	r	.	.	.	r	r	r	r	5
T	.	.	.	+2	+	r	+	+2	5
T	.	1.1	.	.	+	.	.	+	3
G	+	.	r	.	.	.	.	.	2
G	+	.	.	.	r	.	.	.	2
Accidental taxa									
	0	1	1	0	1	0	0	1	

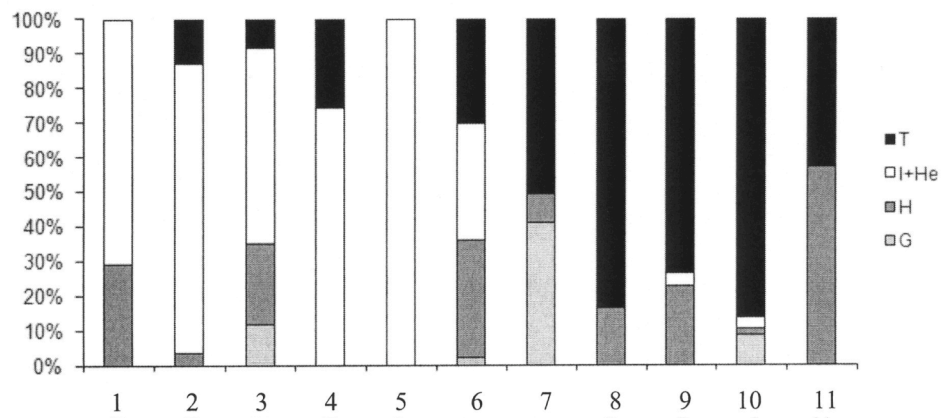


Fig. 6 – Weighted life form spectra of the 11 communities (1 = *Eleocharo palustris*-*Juncetum heterophylli*; 2 = *Callitrichetum stagnalis*; 3 = *Baldellio ranunculoidis*-*Eleocharitetum palustris*; 4 = *Apio crassipedis*-*Elatinetum macropodae*; 5 = *Isoeto tigulianae*-*Callitrichetum brutiae*; 6 = *Apio crassipedis*-*Isoetum tigulianae*; 7 = *Romuleo requienii*-*Isoetum histricis*; 8 = *Bellido annuae*-*Cicendietum filiformis* subass. *solenopsidetosum laurentiae*; 9 = *Anthoxantho aristati*-*Agrostietum salmanticae*; 10 = *Lythro hyssopifoliae*-*Crassuletum vaillantii*; 11 = *Mentho pulegii*-*Exaculetum pusilli* subass. *eryngetosum barrelieri*).

Poiron & Barbero 1965, endemic to Esterel (Poiron & Barbero 1965) and *Myosuro-Crassuletum vaillantii* Br.-Bl. 1935.

In these communities therophytes are the dominant life form, contributing 88% of the total cover (Fig. 6). They are typical of the RPs, where they grow in March-April. The richness value was 22, and evenness 2.5; these values were due to the extensive cover of *Crassula vaillantii*.

Summer vegetation

Summer vegetation includes communities belonging to the order *Nanocyperetalia* of the class *Isoetanojuncetea*, which develop in July-August.

MENTHO PULEGII-EXACULETUM PUSILLI

Paradis & Pozzo di Borgo 2005
eryngetosum barrelieri subass. nova hoc loco (holotypus rel. no. 4, Table 11)

This new proposed subassociation included the only communities present in summer time. The association *Mentho pulegii-Exaculetum pusilli* has been described for Southern Corsica on granitic substrata (Paradis & Pozzo di Borgo, 2005), but communities found in the study area differ because of the consistent presence of *Eryngium barrelieri*. Two subassociations can be recognized: *exaculetosum pusilli*, which represents the holotypus of the association (typus rel. no. 6, Table 21 in Paradis & Pozzo di Borgo, 2005), but which is not found in the study area, and *eryngetosum*

barrelieri. The last subassociation, present in the study area, includes paucispecific communities (richness = 9), which develop in the CB of TPs where water was present until June and where the soils were still waterlogged in July-August. The dominant biological form is that of hemicryptophytes (Fig. 6), which provide 57% of the cover.

Spatial distribution and temporal succession

Spatial distribution and temporal succession of plant communities were related to the different typologies of Mediterranean TWHs and hydrological regimes.

Aquatic vegetation, with a percentage of hydrophytes + helophytes being 34 - 100%, was found in the CBs and IBs of the TPs and within the RPs. Late winter-spring amphibious communities, dominated by therophytes, and with 50 - 87% cover, were present in almost all TWHs. Summer plant communities, with higher percentages of hemicryptophytes (57%), were found exclusively in the CBs of TPs (Fig. 6).

Overall, the CB of TWHs, because of a longer flooding duration, contained a higher number of plant communities in chrono-succession, all with a strong dominance of aquatic ones: *Isoeto tigulianae-Callitrichetum brutiae* subass. *myriophylletosum verticillati*, *Eleocharo palustris-Juncetum heterophylli*, *Baldellio ranunculoidis-Eleocharitetum palustris*, and *Mentho pulegii-Exaculetum pusilli* subass. *eryngetosum barrelieri*. Periods of temporal overlap existed between successional communities (Fig. 7).

Tab. 9 - *Anthoxanthum aristat-Agrostietum salmanticae* Biondi & Bagella 2005

Rel. no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	P
TWH	TP	TP	WS	WS	TP	TP	TP	TP	WS	WS	WS	WS	WS	WS	WS	r
Coverage (%)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	c
Area (m²)	10	10	6	6	6	4	6	4	8	4	4	4	5	4	6	s
Charact. taxa of the ass.																
T	3.3	2	4.4	4.4	3.3	3.3	2.2	3.3	4.4	4.4	4.4	4.4	4.4	4.4	4.4	15
T	+	+	1.1	+	1.1	1.1	+	r	1.1	1.1	1.2	1.2	1.1	+	1.1	14
T	+	+	.	+	1.1	1.1	+	.	1.1	+	.	.	1.1	.	.	9
T	1.1	1.2	.	+	1.1	3.4	4.4	3.3	+	+	+	+	+	3.4	4.4	14
H	+	.	r	1.1	1.1	1.1	1.1	+	+	+	1.1	1.1	1.1	1.1	1.1	14
H	1.2	2.2	.	.	1.2	2.2	1.2	.	2.3	1.2	1.2	4.4	3.3	+	3.3	7
H	.	.	.	.	.	.	.	.	.	+	1.2	1.2	+	+	.	6
H	.	.	.	r	.	.	.	.	.	1.2	1.1	+	+	r	+	6
H	.	.	.	r	.	.	.	.	1.1	.	.	.	.	r	1.2	5
T	.	.	.	1.2	+	1.1	.	.	.	.	.	.	.	+	2	4
T	+	+	.	.	.	.	1.2	.	.	.	.	.	.	.	.	4
T	+	.	.	.	+	+	r	.	.	.	.	.	.	.	.	4
T	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	3
T	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	3
T	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	2
T	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2
T	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
T	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
T	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
T	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Other taxa																
T	3.3	1.2	2.2	2.2	.	1.2	+	.	3.4	.	+	+	+	2.3	+2	12
T	.	1.2	.	.	.	1.2	.	.	3.3	2.2	3.3	3.3	4.4	2.3	1.2	9
H	4.4	3.3	3.3	3.3	3.3	3.4	4.4	4.4	.	.	.	.	.	.	.	8
T	.	.	.	.	.	.	.	.	+	r	+	+	+	+	+	8
T	.	.	.	.	.	.	.	.	.	r	+	+	+	+	+	6
H	.	.	r	+	1.1	.	.	.	.	r	.	+	+	r	.	5
T	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	5
T	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	5
H	.	.	.	.	.	.	.	.	.	1.2	.	.	.	.	.	5
T	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4
T	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4
T	.	.	1.2	.	.	.	.	.	.	.	.	.	.	.	.	4
H	.	+	+	.	.	.	.	.	+	.	.	.	.	.	.	3
H	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2
H	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2
H	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2
G	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2
G	.	.	r	r	.	.	.	.	.	.	.	.	.	.	.	2
Accidental taxa																
	0	0	0	2	0	0	0	0	0	0	0	2	1	0	1	

Tab. 10 - *Lythro hyssopifoliae-Crassuletum vaillantii* ass. nova (holotypus rel no. 6)

Rel. no.	1	2	3	4	5	6*	7	8	9	10	11	P
TWH	RP	RP	RP	RP	RP	RP	RP	RP	RP	RP	RP	r
Coverage (%)	80	80	70	90	70	90	70	100	80	80	60	e
Area (m ²)	1	2	0.5	1	1	2	1	0.5	2	1	1	s.
Charact. taxa of the ass.												
T <i>Crassula vaillantii</i> (Willd.) Roth	3.3	4.5	3.4	5.5	4.4	4.4	3.4	3.4	3.4	3.4	3.3	11
T <i>Lythrum hyssopifolia</i> L.	+	+2	1.1	+	+	1.1	1.1	1.1	1.1	+	+2	11
Charact. taxa of the upper units												
T <i>Juncus hybridus</i> Brot.	1.1	+	+	+	+	1.1	1.1	+	1.1	2.2	1.2	11
T <i>Poa infirma</i> H.B.K.	+	+	+	+	+	1.1	1.1	1.2	1.2	1.2	+	10
G <i>Isoetes histrix</i> Bory	+	+	+	.	.	.	.	+	1.1	2.2	2.2	7
T <i>Silene laeta</i> (Aiton) Godron	+	+2	.	.	.	.	.	.	+	.	.	3
T <i>Juncus pygmaeus</i> Richard	.	.	+	.	.	.	+2	.	.	.	.	2
H <i>Apium crassipes</i> (Koch) Rchb. fil.	1.2	.	.	.	.	.	.	.	.	.	.	1
G <i>Isoetes tiguliana</i> Gennari	.	.	.	.	+	.	.	.	.	.	.	1
Other taxa												
T <i>Plantago coronopus</i> L. subsp. <i>commutata</i> (Guss.) Pilger	.	+	+	+	r	r	r	2.3	2.2	+2	r	10
T <i>Anthemis arvensis</i> L.	+	.	+	.	.	+	+	+	1.2	.	1.2	7
T <i>Sedum caeruleum</i> L.	.	.	.	.	r	+2	.	r	+	1.1	+	6
T <i>Lotus subbiflorus</i> Lag.	.	.	+	.	(+)	.	+	.	+	+	+2	6
G <i>Romulea columnae</i> Seb. & Mauri	.	+2	.	+	.	r	r	.	.	+	.	5
I <i>Callitriche stagnalis</i> Scop.	.	2.3	.	+	.	+	+	.	.	.	.	4
T <i>Bellis annua</i> L.	.	.	+	.	.	.	.	+	+2	+2	.	4
Accidental taxa	0	0	1	0	0	1	0	1	1	2	0	

Tab. 11 - *Mentha pulegii-Exaculetum pusilli* Paradis & Pozzo di Borgo 2005 *eryngetosum barrelieri* subass. nova (holotypus rel. no. 4)

Rel. no.	1	2	3	4*	5	P
TWH	TP	TP	TP	TP	TP	r
Coverage (%)	70	70	70	70	70	e
Area (m ²)	9	10	10	10	10	s.
Charact. taxa of the ass.						
H <i>Mentha pulegium</i> L.	1.2	3.3	3.4	3.4	3.4	5
T <i>Exaculum pusillum</i> (Lam.) Caruel	1.2	1.1	1.2	1.2	1.2	5
Diff. taxa of the subass. <i>eryngetosum barrelieri</i>						
H <i>Eryngium barrelieri</i> Boiss.	3.4	+2	1.1	1.1	1.1	5
Charact. taxa of the upper units						
T <i>Pulicaria vulgaris</i> Gaertner	.	.	1.1	.	.	1
T <i>Agrostis salmantica</i> (Lag.) Kunth	r	.	.	.	.	1
Accidental taxa	2	0	0	0	0	0

The IB of TPs was similar to the CB. Its peculiarity was mainly due to the presence of communities of the association *Apio crassipedis-Isoetum tiguliana*. Usually, the succession proceeded from *Isoeto tiguliana*-*Callitriche brutiae* subass. *isoetosum tiguliana* to *Apio crassipedis-Elatinum macropoda*, and finally to *Apio crassipedis-Elatinum macropoda* (Fig. 7). *Callitriche stagnalis* was present on shallow soils.

In the OBs of TPs and in the WSs, the succession was quicker from *Romuleo requienii-Isoetum histricis* to *Bellido annuae-Cicendietum filiformis* subass. *solenopsidetosum laurentiae*, and finally to *Anthoxantho aristati-Agrostietum salmanticae*.

Two successional communities were found in the RPs, where the flooding period was very brief:

Callitriche stagnalis and *Lythro hyssopifoliae-Crassuletum vaillantii*.

Discussion

This is the first paper specifically reporting on TWHs vegetation of Sardinia. The communities are referred to four classes: *Potametea*, *Isoeto-Nanojuncetea*, *Isoeto-Littorelletea*, and *Phragmito-Magnocaricetea*. The classes *Isoeto-Nanojuncetea*, *Isoeto-Littorelletea* include typical amphibious vegetation. The former had been reported in Sardinia by Biondi & Bagella (2005), Camarda *et al.* (1995), De Marco & Mossa (1980), and Mossa (1987); the latter is here reported for the first time in the island, but it was previously reported for Corsica (Paradis & Pozzo di Borgo, 2005).

In the study area, 11 associations were found, 4 of which are here described for the first time (*Isoeto tiguliana*-*Callitriche brutiae*, *Romuleo requienii-Isoetum histricis*, *Apio crassipedis-Elatinum macropoda*, and *Lythro hyssopifoliae-Crassuletum vaillantii*).

Within the *Isoeto-Nanojuncetea* class, communities of the 2 orders *Isoetalia* and *Nanocyperetalia* were found, the majority of communities (7 out of 8) being part of *Isoetalia*. The other order includes the summer vegetation which develops in July-August, here referred to the association *Mentha pulegii-Exaculetum pusilli* which develops in the deepest part of TPs where the water persists until June-July.

Seven communities have been referred to the order

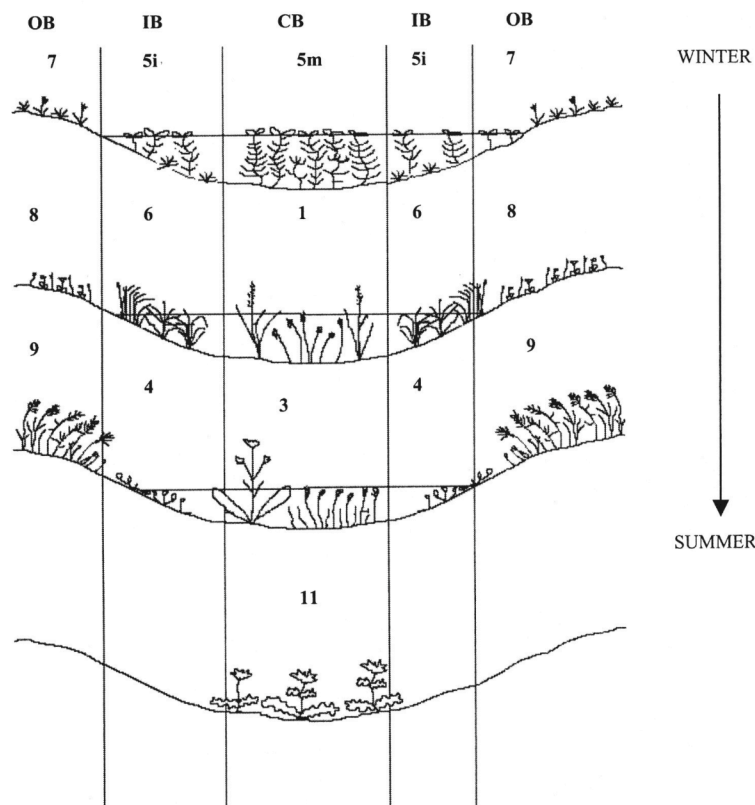


Fig. 7 – Spatial distribution and temporal succession of the plant communities in the temporary ponds (1 = *Eleocharo palustris*-*Juncetum heterophylli*; 3 = *Baldellio ranunculoidis*-*Eleocharitetum palustris*; 4 = *Apio crassipedis*-*Elatinetum macropodae*; 5m = *Isoeto tigulianae*-*Callitrichetum brutiae* subass. *myriophylletosum verticillati*; 5i = *Isoeto tigulianae*-*Callitrichetum brutiae* subass. *isoetetosum tigulianae*; 6 = *Apio crassipedis*-*Isoetetum tigulianae*; 7 = *Romuleo requienii*-*Isoetetum histricis*; 8 = *Bellido annuae*-*Cicendietum filiformis* subass. *solenopsidetosum laurentiae*; 9 = *Anthoxantho aristati*-*Agrostietum salmanticae*; 11 = *Mentho pulegii*-*Exaculetum pusilli* subass. *eryngetosum barrelieri*).

Isoetalia, including the late winter–spring aquatic vegetation of the *Preslion cervinae* alliance, and the amphibious vegetation of *Isoetion*, developing in late winter, *Cicendio-Solenopsis laurentiae*, developing in spring, and *Agrostion salmanticae*, developing in late spring.

The *Preslion cervinae* alliance, represented by 3 associations (*Apio crassipedis*-*Elatinetum macropodae*, *Isoeto tigulianae*-*Callitrichetum brutiae*, and *Apio crassipedis*-*Isoetetum tigulianae*), shows ecological traits intermediate between communities of the *Isoetion* alliance and the *Phragmito-Magnocaricetea* class (Brullo & Minissale, 1998). Otherwise, even if the *Preslion cervinae* alliance is well represented in Sardinia by some species

considered characteristic of this syntaxon following Brullo & Minissale (1998), e.g. *Callitriche brutia* (sub *Callitriche pedunculata* DC.), *Damasonium alisma* subsp. *bourgaei* (Cosson) Maire (sub *Damasonium bourgaei* Cosson), *Juncus foliosus* Desf., and *Veronica anagalloides* Guss. or in Rivas-Martinez *et al.* (2002), e.g. *Isoetes velata* A. Braun subsp. *velata*, or in both, e.g. *Eryngium corniculatum* Lam., several characteristic species of the alliance indicated by the same authors are not present in the island, e.g. *Callitriche platycarpa* Kutz, *Eryngium galioides* Lam., *Isoetes setacea* Lam., *Juncus tenageja* Eeh. subsp. *perpusillus* Fern.-Carv. & F. Navarro, *Marsilea batardae* Launert, *Mentha cervina* L., *Pulicaria paludosa* Link, *Ranunculus lateriflorus* DC., *R.*

nodiflorus L. and *Sysimbrella aspera* (L.) Spach. Some of these species are not present in Sardinia or in the Italian peninsular Tyrrhenian lands, Corsica, Sicily and Mediterranean parts of Tunisia and Algeria. In the same areas, communities of the *Preslion cervinae* alliance are instead characterized by the presence of some endemic and sub-endemic taxa such as *Antinoria insularis*, *Apium crassipes*, and *Isoetes tiguliana*. Therefore, within the *Preslion cervinae* alliance, the new Tyrrhenian endemic suballiance *Apienion crassipedis* suball. nova hoc loco, is established. As characteristic and differential species are proposed: *Antinoria insularis*, *Apium crassipes*, and *Isoetes tiguliana*. *Apium crassipedis*-*Isoetum tigulianae* is indicated as typical association. As a consequence, the continental northern suballiance *Preslienion cervinae* is established, whose characteristic and differential species could be considered to be *Callitriche platycarpa*, *Eryngium galioides*, *Isoetes setacea*, *Marsilea batardae*, *Mentha cervina*, *Pulicaria paludosa*, and *Sysimbrella aspera* and whose typical association is the *Preslietum cervinae* Br.-Bl. ex Moor 1937. Characteristic and differential species of the *Preslion cervinae* alliance as a whole are *Callitriche brutia*, *Damasonium alisma* subsp. *bourgaei*,

Eryngium corniculatum, *Juncus foliosus*, *J. tenageja* subsp. *perpusillus*, *Isoetes velata* subsp. *velata*, *Ranunculus lateriflorus*, *R. nodiflorus*, and *Veronica anagalloides*. The geographical distribution of the new suballiance *Apienion crassipedis* coincides with the Italo-Tyrrhenian biogeographic province established by Rivas-Martinez *et al.* (2001).

All the communities of the *Isoeto-Nanojuncetea* and of the *Isoeto-Littorelletea* classes have to be considered habitat of community interest (European Commission 1992). Following the scheme proposed by Bagella *et al.* (2007), they can be assigned to the following habitats: 3170* (*Romuleo requienii*-*Isoetum histricis* and *Lythro hyssopifoliae*-*Crassuletum vaillantii*); 3120 (*Bellido annuae*-*Cicendietum filiformis* subass. *solenopsidetosum laurentiae*, *Apium crassipedis*-*Elatinum macropodae*, *Isoeto tigulianae*-*Callitricetum brutiae* subass. *isoetetosum tigulianae*, *Isoeto tigulianae*-*Callitricetum brutiae* subass. *myriophylletosum verticillati*, *Apium crassipedis*-*Isoetum tigulianae*, and *Anthoxantho aristati*-*Agrostietum salmanticae*); 3130 (*Mentho pulegii*-*Exaculetum pusilli* subass. *eryngetosum barrelieri*, *Baldellio ranunculoidis*-*Eleocharitetum palustris*, and *Eleocharo palustris*-*Juncetum heterophylli*).

Syntaxonomical list

- POTAMETEA Klika in Klika & Novák 1941
 Potametalia Koch 1926
Ranunculion aquatilis Passarge 1964
Callitricetum stagnalis Segal 1965
- ISOETO-NANOJUNCETEA Br.-Bl. & Tüxen ex Westhoff, Dijk & Passchier 1946
 Isoetetalia Br.-Bl. 1936
 Isoetion Br.-Bl. 1936
Romuleo requienii-*Isoetum histricis* ass. nova
Lythro hyssopifoliae-*Crassuletum vaillantii* ass. nova
Cicendio-Solenopsion laurentiae Brullo & Minissale 1998
Bellido annuae-*Cicendietum filiformis* de Foucault 1988
solenopsidetosum laurentiae Paradis & Pozzo di Borgo 2005
- Preslion cervinae* Br.-Bl. ex Moor 1937
 APIENION CRASSIPEDIS suball. nova
Apium crassipedis-*Elatinum macropodae* ass. nova
Isoeto tigulianae-*Callitricetum brutiae* ass. nova
isoetetosum tigulianae subass. nova
myriophylletosum verticillati subass. nova
Apium crassipedis-*Isoetum tigulianae* Biondi & Bagella 2005 corr. hoc loco
- Agrostion salmanticae* Rivas Goday 1958
Anthoxantho aristati-*Agrostietum salmanticae* Biondi & Bagella 2005

- Nanocyperetalia Klika 1935
Verbenion supinae Slavnic 1951
Mentho pulegii-Exaculetum pusilli Paradis & Pozzo di Borgo 2005
exaculetosum pusilli subass. nova
eryngetosum barrelieri subass. nova
- ISOETO-LITTORALLETEA Br.-Bl. & Vlieger in Vlieger 1937
Littorelletalia Koch 1926
Hyperico elodis-Sparganion Br.-Br. & Tüxen ex Oberdorfer 1957
Eleocharo palustris-Juncetum heterophylli Paradis & Pozzo di Borgo 2005
- PHRAGMITO-MAGNOCARICETEA Klika in Klika & Novák 1941
Nasturtio-Glycerietalia Pignatti 1954
Glycerio-Sparganion Br.-Bl. & Sissingh in Boer 1942
Glycerienion fluitantis (Géhu & Géhu-Franck 1987) J. A. Molina 1996
Baldellio ramunculoidis-Eleocharitetum palustris Biondi & Bagella 2005

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Accidental taxa

- Tab. 2: rel. 1: *Lotus subbiflorus* Lag. +; rel. 3: *Poa infirma* H. B. K. +; rel. 5: *Glyceria spicata* Guss. +, *Apium crassipes* (Koch) Rchb. fil. 1.1.
- Tab. 3: rel. 1: *Eryngium barrelieri* Boiss. +; rel. 2: *Ranunculus baudotii* Godron r; rel. 4 *Myriophyllum verticillatum* L. 3.3, *Cuscuta planiflora* Ten.+2.
- Tab. 6: rel. 13 *Anagallis foemina* Miller +2; rel. 15: *Medicago minima* (L.) Bartal r; rel. 17: *Oenanthe fistulosa* L.+.
- Tab. 7: rel. 2: *Lolium multiflorum* Lam. +, *Plantago lanceolata* L. +; rel. 3: *Alopecurus bulbosus* Gouan +; rel. 4: *Montia fontana* L. subsp. *amporitana* Sennen r; rel. 5: *Ranunculus cordiger* Viv. subsp. *diffusus* (Moris) Arrigoni 2.3; rel. 8: *Trifolium resupinatum* L. 1.2; rel. 9: *Galactites tomentosa* Moench r; rel. 21: *Plantago lagopus* L. r.
- Tab. 8: rel. 2: *Ranunculus cordiger* Viv. subsp. *diffusus* (Moris) Arrigoni r; rel. 3: *Anthemis arvensis* L. +; rel. 5: *Serapias lingua* L. r; rel. 8: *Tuberaria guttata* (L.) Fourr. r.
- Tab. 9: rel. 4: *Anagallis foemina* Miller r, *Vulpia myuros* (L.) Gmelin subsp. *sciuroides* (Roth) Rouy r; rel. 12: *Oenanthe silaifolia* Bieb. r, *Rumex pulcher* L. r; rel. 14: *Plantago lagopus* L. r.
- Tab. 10: rel. 3: *Limum bienne* Miller +; rel. 6: *Lotus uliginosus* Schkuhr +; rel. 8: *Trifolium resupinatum* L. +; rel. 9: *Oglifa gallica* (L.) Chrtk & Holub r; rel. 10: *Trifolium subterraneum* L.+2, *Romulea requienii* Parl. r.
- Tab. 11: rel. 1: *Carex divisa* Hudson +2, *Plantago lanceolata* L. 1.2.

Dates of surveys

- Tab. 1: rel. 1, 2, 3, 4: 21/04/2004. Tab. 2: rel. 1, 2, 3, 4: 12/02/2004; rel. 5, 6, 7: 15/03/2004. Tab. 3: rel. 2: 21/04/2004; rel. 1, 3, 4, 5, 6: 09/06/2004. Tab. 4: rel. 1, 2, 3, 4: 09/06/2004. Tab. 5: rel. 2, 3: 15/03/2004; rel. 1, 4, 5, 6, 7: 21/04/2004. Tab. 6: rel. 2, 3, 7, 8, 9: 15/03/2004; rel. 1, 4, 5, 6, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21: 21/04/2004. Tab. 7: rel. 4, 5, 7, 8, 9, 10, 11, 12: 15/03/2004; rel. 6, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23: 07/04/2004; rel. 1, 2, 3: 21/04/2004. Tab. 8: rel. 1, 2, 3, 4, 5, 6, 7, 8: 27/05/2004. Tab. 9: rel. 14: 27/05/2004; rel. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15: 09/06/2004. Tab. 10: rel. 1, 2, 4, 5, 6, 7, 8, 9, 10, 11: 15/03/2004; rel. 3: 07/04/2004. Tab. 11: rel. 1, 2, 3, 4, 5: 05/08/2004.

Chapter 2

Small scale plant distribution in Mediterranean temporary ponds: implication for conservation

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Chapter 3

Issues related to the classification of Mediterranean temporary wet habitats according with the European Union Habitats Directive

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Abstract

From a biological and biogeographic point of view, Mediterranean temporary wet habitats are recognised to be amongst the most interesting habitats in the Mediterranean bioclimatic region. They are considered to be habitats of Community Interest and are included in the "standing water group". Due to an overlap in the plant species and syntaxa indicated as characteristic, the assignment of the plant communities to the habitats 3120, 3130 and 3170* is far from straightforward. We propose that the *Isoetion* communities be assigned to habitat 3170*, the *Preslion cervinae*, *Cicendio-Solenopsis* and *Agrostion pourretii* communities to habitat 3120, and the *Cyperetalia fuscii* and *Littorelletea uniflorae* communities to habitat 3130.

Key words: Habitats of Community Interest, *Isoetion*, Natura 2000, temporary ponds.

Riassunto

Problematiche connesse con la classificazione degli habitat umidi temporanei mediterranei in attuazione alla Direttiva Habitat. Gli habitat umidi temporanei sono considerati tra quelli di maggiore interesse biologico e biogeografico della regione mediterranea. La Direttiva Habitat li include tra quelli di interesse comunitario nel gruppo "acque dolci stagnanti". L'attribuzione delle comunità vegetali a tre di questi habitat, il 3120, il 3130 e il 3170* è resa difficile dalla sovrapposizione di alcune delle specie vegetali e dei sintaxa indicati come caratteristici. Si propone pertanto uno schema di riferimento che dovrebbe consentire un'interpretazione univoca della Direttiva Habitat. Viene pertanto proposto di riferire all'habitat 3170* le comunità dell'*Isoetion*, al 3120 quelle del *Preslion cervinae*, *Cicendio-Solenopsis* e *Agrostion pourretii* e al 3130 le comunità dei *Cyperetalia fuscii* e della *Littorelletea uniflorae*.

Parole chiave: Habitat di interesse comunitario, *Isoetion*, Natura 2000, stagni temporanei.

Introduction

From a biological and biogeographic point of view, Mediterranean temporary wet habitats are recognised to be amongst the most interesting habitats in the Mediterranean bioclimatic region (Quezel, 1998; Médail *et al.*, 1998; Médail, 2004). They shelter extremely rare and isolated taxa: in New Zealand, for example, 18% of all protected species occur in these habitats (Johnson & Rogers, 2003) and a considerable part of the Red-List-species in France is dedicated to temporary wet habitats (Oliver *et al.*, 1995).

Temporary wet habitats are characterized by considerable spatial and temporal variability, which is influenced by a number of factors, such as flooding period, water depth variation and habitat size (Barbour *et al.*, 2003; Battaglia & Collins, 2006; Biondi & Bagella, 2005; Gopal, 1986; Fernández-Aláez *et al.*, 1999; Oertli *et al.*, 2002; Rhazi *et al.*, 2006; Rita & Bibiloni, 1991).

From a syntaxonomic point of view the vegetation which characterizes these habitats is mainly referable to the class *Isoeto-Nanojuncetea* Br.-Bl. & Tüxen ex Westhoff, Dijk & Passchier 1946, including pioneer annual and dwarf perennial ephemeral isoetid communities on periodically flooded bare soils, but also

to the classes *Isoeto-Littorelletea* Br.-Bl. & Vliieger in Vliieger 1937, including dwarf helophyte amphibious oligotrophic communities on shore dystrophic lakes, nutrient-poor standing or slow flooding water and *Charetea fragilis* Fukarek ex Krausch 1964, including charophyte pioneer communities growing on sub-aquatic barren soils of pools, lakes and shallow water courses (Rivas Martínez *et al.*, 2002). Furthermore, communities belonging to other classes, such as *Potametea* Klika in Klika & Novák 1941, *Phragmito-Magnocaricetea* Klika in Klika & Novák 1941, *Molinio-Arrhenatheretea* Tüxen 1937 and *Helianthemetea guttati* (Br.-Bl. in Br.-Bl., Roussine & Nègre 1952) Rivas Goday & Rivas-Martínez 1963 em. Rivas-Martínez 1978, could be present in the temporal succession in the same sites.

Mediterranean temporary wet habitats are considered to be habitats of Community Interest (European Commission, 1992) and are included in the "standing water group". Reference habitats in Annex I of the Habitats Directive are the following: 3120 - Oligotrophic waters containing very few minerals, generally on sandy soils of the West Mediterranean, with *Isoetes* spp.; 3130 - Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoeto-Nanojuncetea*; 3140 -

Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp.; 3160 - natural dystrophic lakes and ponds; 3170* - Mediterranean temporary ponds. The other temporary wet habitats of the "standing water group" denominated 3110 - Oligotrophic waters containing very few minerals of sandy plains (*Littorelletalia uniflorae*) and 3180* - Turloughs, are not present in the Mediterranean region.

Aims

The aims of this paper are: 1) to outline the issues related to the classification of Mediterranean temporary wet habitats in relationship to the application of the Habitats Directive (European Commission, 1992) and the Nature 2000 network institution; 2) to propose criteria for adoption to facilitate univocal identification of the habitats of Community Interest referable to this typology.

Issues

Mediterranean temporary wet habitats are highly vulnerable due to their shallow water and their frequently small surface area. Despite an improvement in the public's perception of wetlands over recent years, temporary pools are often poorly identified and their importance largely unappreciated, leaving them vulnerable to unintentional destruction (Grillas, 2004).

Issues related to the individuation and the classification of Mediterranean temporary wet habitats are due at least partly to their intrinsic characteristics and to the traits of the plants that they host. In fact they cover very limited surface areas, are ephemeral and

present high variability in the duration of the flooding period. Furthermore, the species which colonise them are often inconspicuous (e.g. dwarf annuals or dwarf geophytes), exhibit a very short life cycle and are often not well-known.

Although the Interpretation Manual (European Commission, 2003) gives more details than the list of habitat names in Annex I itself, there are still many problems concerning the identification of habitat types in the field, and in both selecting sites and assessing the national lists of proposed sites. Some of these problems arise from poorly defined, sometimes overlapping, habitat types (Evans, 2006).

The "standing water" group of habitat types is particularly complex, with both priority subtypes of wider habitats and similar vegetation in several habitat types in some cases separated by substrate and/or water quality (Evans, 2006). Furthermore, these habitat types rarely, if ever, occur as isolated stands: more frequently they are found in a dynamic mosaic of several types.

Habitat type 3130 includes two phytosociological classes: *Littorelletea uniflorae* and *Isoeto-Nanojuncetea*. However, some communities within the class *Littorelletea uniflorae* can also be assigned to habitat type 3110 which includes communities of the unique order of the class *Littorelletea uniflorae*: *Littorelletalia uniflorae*. The communities of the class *Isoeto-Nanojuncetea* are also included in habitats 3120 and 3170* (*Isoetion*, *Nanocyperion flavescens*, *Preslion cervinae*, *Agrostion salmanticae*, *Heleochoion* and *Lythron tribracteati*). The 3170* habitat, the only priority habitat of the group, is considered to be a subtype of habitat 3120. These overlaps concern syntaxonomic units, as well as some characteristic plant species (Fig. 1).

As a result, it is hard to assign the plant communities

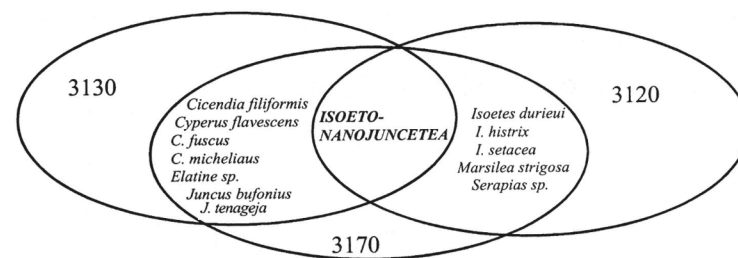


Fig. 1 - Overlapping of taxa and syntaxa amongst habitats 3120, 3130 and 3170*

to the different typology of habitats. Another explanatory problem derives from the fact that the priority habitat 3170* has an exact biogeographical reference in its name “Mediterranean temporary ponds” which would imply a restriction of the range of distribution to the Mediterranean biogeographical region.

The lack of knowledge concerning flora and vegetation and the issues relating to the understanding of the Interpretation Manual of the Habitats Directive (European Commission, 2003) have had several consequences on the process of filling in Nature 2000 forms in Italy (www.minambiente.it): i) difficulty in the assignment of plant communities to the relative habitats; ii) lack of indications concerning the presence of these habitats in several pSCIs; iii) shortage of proposals for pSCI establishment in sites where these habitats are so well represented that they may be considered to be “typical”. Furthermore, habitat 3170* has also been recognised outside the Mediterranean area. In this case the solution is not so clear, but interpretations have tended to be flexible rather than strict (Evans, 2006). As a consequence, an inflation of habitat 3170* has been brought about, leading to a decrease in its rarity index. In Italy the habitat is reported in 89 sites (Petrella *et al.*, 2005), of which 23, about 26%, fall within the continental biogeographic region.

Syntaxonomic aspects

The class *Isoeto-Nanojuncetea* is to be considered a very complex syntaxon in terms of its wide distribution area and its floristic diversity due to both phytogeographic and ecological factors. Several syntaxonomical classifications have been proposed for this class (e.g. Kock, 1926; Braun-Blanquet, 1935; Rivas Goday, 1955), as well as the following, that was recently proposed by Deil (2005) based to a large extent on the syntaxonomic scheme proposed by Brullo & Minissale (1998), with some modification according to Mucina (1997); Täuber & Petersen (2000) and Rivas- Martínez *et al.* (2001, 2002).

ISOETO-NANOJUNCETEA Br.-Bl. & R. Tüxen ex Westhoff *et al.* 1946
ISOETETALIA Br.-Bl. 1935 em. Rivas Goday 1970
Isoetion Br.-Bl. 1935

Cicendio-Solenopsion Brullo & Minissale 1998 (= *Cicendion* auct. mediterran.)

Agrostion pourretii Rivas Goday 1958 em. Rivas-Martínez *et al.* 1986

Preslion cervinae Br.-Bl. ex Moor 1936 (= *Menthion cervinae*)

CYPERETALIA FUSCI Pietsch 1963 (= *Nanocyperetalia*)
Nanocyperion flavescens Koch ex Lippert 1936

Radiolion linoidis (Rivas Goday 1961) Pietsch 1973
Elatino triandrae-Eleocharition ovatae (Pietsch & Müller-Stoll 1968) Pietsch 1973

Verbenion supinae Slavnic 1951

The *Isoetetalia* are of circum-Mediterranean distribution, with a higher density of the habitats and richer flora in the Western parts of the Mediterranean area. The *Cyperetalia fusci* are distributed in the temperate zone of Europe and include summer communities.

Among the *Isoetetalia* only two alliances present a closely Mediterranean distribution: *Isoetion* and *Preslion cervinae*. The *Isoetion* alliance has a circum-Mediterranean distribution and occurs in thermomediterranean and mesomediterranean bioclimates. Geophytic quillorts are a major component of the biomass (Deil, 2005). Amongst them, the terrestrial *Isoetes durieui* and *I. hixtrix* are considered characteristic of the alliance (Rivas Martínez *et al.*, 2002). The *Preslion cervinae* alliance also presents a Mediterranean distribution, but occurs in long submerged depressions. Amongst the others some aquatic quillorts, such as *I. velata* subsp. *velata*, are considered characteristic taxa (Rivas Martínez *et al.*, 2002).

Discussion and proposals

The issues encountered in the surveying and classification of Mediterranean temporary wet habitats underline the advantage of having more detailed data regarding characteristic flora and vegetation in order to facilitate their assignment to the different typologies of Annex I of the Habitats Directive. The more problematic matters are due to overlaps among habitats 3130, 3120 and 3170*.

Taking as a reference point the *Isoeto-Nanojuncetea* class, which builds up the connection among the 3 habitat types, the syntaxa belonging to this class were clustered in order to clearly define the reference habitats (Fig. 2).

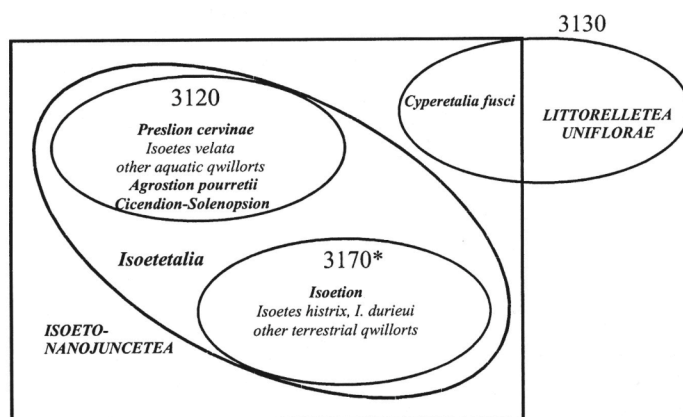


Fig. 2 – Schematic interpretation of habitats 3120, 3130 and 3170*

Our proposal is: i) to assign to the habitat 3170* only the communities which develop in “very shallow temporary ponds (a few centimetres deep) which exist only in winter or late spring, with a flora mainly composed of Mediterranean therophytic and geophytic species” as suggested in the Interpretation Manual of the European Union Habitats (European Commission, 2003). Nevertheless, these communities do not all belong to the alliances indicated in the manual [e.g. *Isoetion*, *Nanocyperion flavescens*, *Preslion cervinae*, *Agrostion salmanticae* (= *Agrostion pourretii*), *Heleochoilon* and *Lythron tribracteati*], but among them only to that of *Isoetion* which is the only one including communities occurring in shallow water in early spring; ii) to assign to habitat 3120 the communities belonging to the other 3 alliances of *Isoetetalia*: *Preslion cervinae* (Mediterranean communities dominated by aquatic qwillorts such as *Isoetes velata* subsp. *velata* which include long flooded communities), *Cicendio-Solenopsis* (Mediterranean-Atlantic communities demanding water until the end of spring) and *Agrostion pourretii* (late communities generally in temporal succession with other *Isoeto-Nanojuncetea* communities); iii) to assign to habitat 3130 the *Cyperetalia fusci* communities which, in spite of those of *Isoetetalia*, are characterised by late summer and autumn bloom communities occurring on eutrophic or subeutrophic soils (Brullo & Minissale, 1998) and the *Littorelletea uniflorae* communities.

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Chapter 4

Spatial-time variability and conservation relevance of plant communities in Mediterranean temporary wet habitats: a case study in Sardinia (Italy)

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Spatial-time variability and conservation relevance of plant communities in Mediterranean temporary wet habitats: a case study in Sardinia (Italy)

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Abstract

This research was undertaken with the aims to improve the knowledge of floristic composition and spatial-temporal dynamic of plant communities in Mediterranean temporary wet habitats and to evaluate the diversity and conservation relevance of their plant assemblages. Three different types of temporary wet habitats were monitored throughout the growing season: large temporary ponds, small temporary ponds and rock pools. Large temporary ponds presented a small-scale zonation arranged in an inner, an intermediate and a peripheral belt. A total of 98 species were recorded, of which 40 were classified as temporary wet habitat specialists and 24 as rare. Eight different groups of plant assemblages were identified presenting a space-time dynamic related to water-depth variations and flooding period. In terms of diversity, the most relevant assemblages were located in the outer belt of the large temporary ponds and in the small temporary ponds. The mosaic of different assemblages and their time-variability determined the presence of several types of habitats of community interest according to the Habitat Directive. The wide heterogeneity should be taken into account to ensure that all types of temporary wet habitats are considered in conservation programs.

Keywords: flooding period, plant assemblages, rock pools, small-scale zonation, temporary ponds, water depth.

List of abbreviations: ITP = large temporary pond; RP = rock pool; sTP = small temporary ponds; TWH = temporary wet habitat.

Chapter 5

Identifying key environmental factors related to plant and crustacean assemblages in Mediterranean temporary ponds

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Biodiversity and Conservation (*submitted*)

Running head: Key factors for plant and crustacean assemblages in ponds

Identifying key environmental factors related to plant and crustacean assemblages in Mediterranean temporary ponds

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Abstract: The current interest in Mediterranean temporary wet habitats, considered to be habitats of European Community Interest, mainly due to their characteristic flora and fauna. Several contributions characterize each of these two components separately, but considering them simultaneously could reveal possible interactions and a more complete view of the habitat that would be useful to improve conservation measures. This paper investigates crustacean and plant assemblages in six Mediterranean temporary ponds and their relationship with several environmental variables. Significant positive relationships were found between species richness and Shannon diversity index of plant and crustacean assemblages. Crustaceans had a higher similarity among ponds than plants and, consequently, each pond had a more characteristic assemblage of plants than of crustaceans. The two groups showed a

different sensitivity to environmental factors and only two factors affected both: altitude and surface area of the wet system. Disturbances (e.g. grazing by cattle) and pond size were very important for plants, whereas they were irrelevant for crustaceans. On the other hand, distance to the nearest pond, hydroperiod length, and water nitrogen were only important for crustaceans. Although similar trends on richness and diversity were observed for both biotic groups, the use of only one of them for conservation programs would not be sufficient. Our results suggest that simultaneously taking into account several community fractions would result in a better understanding of ecosystem functionality.

Key words: altitude, conservation programs, hydroperiod, landscape, land use, pond size, Sardinia, wet system

Chapter 6

Patterns of emblematic habitat types in Mediterranean temporary wetlands

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Comptés Rendus Biologies (*submitted*)

PATTERNS OF EMBLEMATIC HABITAT TYPES IN MEDITERRANEAN
TEMPORARY WETLANDS

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Abstract

This paper presents the floristic, structural, and syntaxonomical features of plant assemblages in temporary wetlands and the pattern of the corresponding habitat types according to the Habitat Directive. Nine pristine temporary wetlands covering a wide range of shapes, elevations and substrates were monitored. The “within temporary wetlands” hydrological gradient was strong enough to drive the vegetation and habitat type patterns. Plant assemblages presented a physical arrangement in three concentric belts repeatedly present in each site in the same relative position.

The presence of the H3120 habitat type was recognized in the central and in the intermediate belt.

The outer belt was the more suitable for the presence of the H3170* priority habitat. Therefore it should represent the main conservation target within temporary wetlands. On the other hand, it was the smallest in size (only 13% of the total surface) and in some cases absent, inconspicuous, or severely fragmented.

Chapter 7

Eryngium corniculatum Lam.

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**Informatore Botanico Italiano Flora da conservare:
Implementazione delle categorie e dei criteri della IUCN(2001)
per la redazione di nuove Liste Rosse (*submitted*)**

Eryngium corniculatum Lam.

M.C. CARIA e S. BAGELLA

Nomenclatura:

Nome scientifico : *Eryngium corniculatum* Lam.

Sinonimi : nessuno

Famiglia : Apiaceae

Nome comune : Calcatreppola cornuta

Descrizione. Pianta erbacea a portamento eretto, alta da 10 a 60 cm. Fusto fistoloso, ramificato a partire dalla base, glaucescente e violetto in alto. Foglie basali poco persistenti, spugnose, ovato-oblunghe intere, oscuramente dentate con lamina lunga 2-5 cm e molte volte più piccolo lungo della lamina, settato, inerme. Foglie caulinari inferiori simili alle basali, le altre sessili, lunghe 5-35 mm semiamplessicauli, da tripartite a tricuspide e spinose. Infiorescenze numerose, violette, da ovoidi a subglobose, di diametro 0.5-1 cm, prolungantesi in 1-3 brattee apicali pungenti lunghe 10-60 mm. Brattee lineari-lanceolate, intere acutamente spinose. Bratteole intere. Sepali 1-1.5 mm, ovati, brevemente aristati, con margine membranaceo. Mericarpi 1.5-2.5 mm densamente ricoperti di squame (CASTROVIEJO ET AL., 2003; PIGNATTI, 1982; TUTIN ET AL., 1993).

Biologia. Emicriptofita bienne, talvolta annuale. Fiorisce da maggio a settembre. Non si hanno conoscenze sul tipo di riproduzione, sull'impollinazione, sul tipo di dispersione degli acheni, sulla vitalità dei semi e sulla capacità germinativa. $2n=16$ (CASTROVIEJO ET AL., 2003).

Ecologia. Vive negli stagni temporanei, preferibilmente su substrati silicei, a quote comprese tra 0 e 1400 m s.l.m. È considerata caratteristica dell'alleanza *Menthion aëvinæ*. Per la penisola Iberica è nota l'associazione *Eryngio corniculati*-*Preslietum aëvinæ* Rivas Goday 1957.

Distribuzione in Italia.

Regione biogeografica: Mediterranea; *Subregione*: Mediterranea Occidentale; *Provincia*: Italo-Tirrenica; *Subprovincia*: Sarda (RIVAS-MARTÍNEZ, 2004). *Regione amministrativa*: Sardegna.

Numero di stazioni: la specie è segnalata per due stazioni: Monte Minerva, comune di Villanova Monteleone (SS) (dati non pubblicati) e Giarra di Gesturi (CA) (MOSSA E FOGU, 1988). Esistono indicazioni anche per altre due stazioni nelle quali però la specie non è più stata rinvenuta, dagli anni '80 nel caso di Tempio Pausania (OT) (Diana, comunicazione personale) e da 4-5 anni nel caso dello stagno di Bara (NU) (dati non pubblicati). In entrambi i casi la scomparsa delle subpopolazioni è stata determinata dal drenaggio artificiale dell'acqua con conseguente modificazione dell'habitat.

Tipo corologico e areale globale.

È una specie a distribuzione Mediterraneo-Occidentale, presente oltre che in Sardegna, nella Penisola Iberica e in Marocco. In Spagna e Portogallo è abbastanza diffusa. In Marocco è invece molto rara, essendo presente in due soli siti (dati non pubblicati).

Minacce.

Minaccia 1.1.8. *Other*. Nell'ambito delle minacce dovute alla degradazione/perdita di habitat indotta dall'uomo il drenaggio dell'acqua è attualmente la più grave, essendo stata la causa della scomparsa di due subpopolazioni, pari alla metà del totale delle subpopolazioni presenti in Sardegna.

Minaccia 1.2.1. *Abandonment*. L'abbandono delle attività agro-pastorali e, in generale del territorio, può favorire lo sviluppo di specie arbustive che modificano le condizioni dell'habitat (ad esempio con l'ombreggiamento) limitando lo sviluppo di questa specie.

Minaccia 10.1: *Recreation/tourism*. Le attività ricreative che prevedono il passaggio di veicoli (macchine e moto) e di animali domestici (cavalli) all'interno dell'habitat rappresentano una minaccia per la specie.

Criteri IUCN applicati. In base ai dati disponibili sono stati applicati i criteri d'indicizzazione B e D.

Criterio B:

Sottocriterio

B2-Superficie occupata (AOO): 8 Km².

Opzioni

- a) *severely fragmented or # locations* : la popolazione ha una distribuzione fortemente frammentata.
- b) (i) *continuing decline in extent of occurrence* : essendo scomparse due subpopolazioni tra quelle note l'EOO si è fortemente ridotto.
- b) (ii) *continuing decline in area of occupancy* : essendo scomparse due subpopolazioni l'AOO si è dimezzata.
- b) (iii) *continuing decline in area, extent and/or quality of habitat*: il drenaggio e l'utilizzazione delle aree umide per scopi ricreativi (equitazione, campi da golf, motocross etc.) hanno determinato il costante peggioramento della qualità dell'habitat della specie.
- b) (iv) *continuing decline in number of locations or subpopulations* : il numero di subpopolazioni note si è dimezzato.

Criterio D:

Sottocriteri

D2-Restricted area of occupancy: AOO <20 Km² e numero di locations < 5.

Categoria di rischio:

Criterio B. AOO inferiore a 10 Km²; la popolazione ha una distribuzione fortemente frammentata e ha subito negli ultimi decenni una forte riduzione dell'EOO e un dimezzamento dell'AOO. La situazione è resa più critica da un generale peggioramento della qualità dell'habitat. Anche il numero di subpopolazioni si è dimezzato.

Categoria di rischio: *Critically Endangered* CR, B2ab(i, ii, iii, iv).

Criterio D. La specie, presente attualmente in due *location* e con AOO < 20 Km², potrebbe ricadere,

nell'arco di un breve periodo di tempo, in una delle categorie di minaccia superiori.

Categoria di rischio: essendo soddisfatte le opzioni del sottocriterio D2, la specie ricade nella categoria *Vulnerable* (VU, D2).

Interazioni con la popolazione globale: si ritiene che le subpopolazioni regionali, a causa delle elevate distanze non possano interagire con le subpopolazioni iberiche e marocchine.

Status alla scala "regionale": CR B2ab(i,ii,iii,iv)

- status a scala globale: *Vulnerable*, VU (IUCN - Mediterranean aquatic plants evaluation, in progress).
- precedente attribuzione a livello nazionale *Lower risk* LR (CONTI ET AL., 1997).

Strategie/Azioni di conservazione e normativa.

Nessuna.

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Chapter 8

An investigation on soil and vegetation patterns in Mediterranean temporary wetlands (Sardinia, Italy)

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Manuscript

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Abstract (200 words)

Keywords: HSU, (4-6)

Introduction

Temporary wetlands (TWs) are very shallow water bodies, characterized by alternating phases of drought and flooding and by a very self-contained hydrology. They occur in endoreic depressions that are submerged for sufficiently long periods of time to allow the development of hydromorphic soils, aquatic or semi-aquatic vegetation. However, they dry out for a sufficiently long duration to exclude more widespread plant communities, characteristic of permanent wetlands (Grillas et al. 2004). TWs maintain specific communities of both aquatic and amphibious species (Rhazi et al. 2006). Then TWs occur in the Mediterranean climatic region of the world such as the Mediterranean basin, California (where they are well known as vernal pools), West Africa and Australia (Grillas et al. 2004, Barbour et al. 2005, Deil 2005, Pignatti and Pignatti 2005).

Hydromorphic soils are normally characterized by a period of wetness or saturation during the growing season of the plants, and anaerobic conditions in the root zone (Richardson and

Vepraskas 2001). Nevertheless the soil physico-chemical variables in TWs strongly differ from those of permanent ones, especially in terms of pH, oxygen and nitrogen contents (Della Bella et al. 2008). Several investigations of California vernal pool soil morphology, soil chemistry, and geomorphology (e.g Holland and Dains 1990, Crowe et al. 1994, Weitkamp et al. 1996, Hobson and Dahlgren 1998) are available while there remains a lack of detailed research within these wetland ecosystems in the Mediterranean basin. Soil type and topography have been indicated as primary factors in determining the vegetation patterns in Californian vernal pools and the availability of suitable soils and hydrological regimes for the development of vernal pools plants is necessary (Hobson and Dahlgren 1998). Differences in soil physical and chemical properties in relationship with the within pond position were also detected (Weitkamp et al. 1996).

To describe and classify the vegetation types of communities living in such habitats, it is useful to sample at a scale that is of higher definition than that of the entire TW (Barbour et al. 2003). In some areas of the Mediterranean basin an arrangement in three concentric belts (central, intermediate and outer) depending on water depth and flooding period, within TWs has been recognized (Rhazi et al. 2006, Bagella et al. 2009a, 2009b) corresponding to homogeneous spatial units (HSUs), as also already confirmed by the vegetation patterns. Nevertheless the arrangement in belts should be rough and in some cases the belts should be incomplete because the morphology of the basin. This irregularity in shape affects mostly the outer belt which could be absent or strongly reduced or phragmented (Bagella et al *submitted b*).

The aims of this study were: i) to evaluate soil physico-chemical parameters relevant to define soil pattern in Mediterranean TWs; ii) to assess soil and vegetation patterns and iii) to point out the relationships between soil and vegetation patterns.

Material and methods

Data analysis

An average of variables relative to the three soil samples of each HSU was calculated. The data, except pH, were log-transformed using natural logarithms. A similarities matrix between each pair of samples was calculated using the Euclidean distance coefficient. Non-metric multidimensional scaling (nMDS) was used to produce a two-dimensional ordination (Anderson and Underwood 1997) of the samples. The HSU corresponding to the MIN_CB was not included in this analysis because texture data were not available. Formal significance tests for differences in soil samples between TWs and HSUs were conducted by one-way analysis of similarities (ANOSIM) permutation/randomization test (Clarke and Warwick 2001).

Starting from the vegetation matrix a similarities matrix between each pair of samples was calculated using the Bray–Curtis similarity coefficient on untransformed data (Bray and Curtis 1957). Formal significance tests for differences in soil samples between TWs and HSUs were conducted by one-way analysis of similarities (ANOSIM) permutation/randomization test (Clarke and Warwick 2001). If no significant differences between samples were shown by the ANOSIM procedure, the assessment of characterising taxa which bring the main contribution to average similarity was performed using the SIMPER routine (Clarke 1993).

A Canonical Correspondence Analysis (CCA) was carried out, considering vegetation matrix as response variables and physico-chemical soil characteristic matrix as explanatory ones. Species composition data matrix were square-root-transformed. The physico-chemical variables, except pH were log-transformed using natural logarithms.

nMDS, ANOSIM and SIMPER were performed with the package PRIMER v6 (Clarle and Gorley 2006) while CCA was performed with the package XLSTAT version 2009 4.06.

Results

Relationships between soil and vegetation patterns

In the CCA triplot (Figure 4) F1 and F2 axes represent the 25.45 % and the 21.93% of the variability, respectively. The “site effect” was very clear because the HSUs relative to each TWs were close each other. Soil characteristics which most affected the vegetation were some macro-nutrients (e.g. total P, extractable P and assimilable P, and N), pH, silt and sand content. *Trifolium michelianum*, *Ranunculus aquatilis*, *Damasonium alisma* and *Pulicaria vulgaris* were particularly favoured by weakly-acid pH and richness in nutrients (SUN_CB, SCA_CB, MON_CB and SCA_IB). *Illecebrum verticillatum*, *Isoetes velata*, *Ranunculus revelieri* and *Bellis annua* were favoured by sand and low content in nutrients (LOE_CB, LOE_IB and LOE_OB). *Lythrum hyssopifolia*, *Isoetes histrix*, *Trifolium subterraneum*, *Juncus pygmaeus*, *Juncus bufonius*, *Plantago weldenii*, *Lotus subbiflorus* and *Lythrum borysthenicum* were favoured by acid pH and medium-low content in nutrients (MIN_OB, MON_OB, SCA_OB and MIN_IB). *Ranunculus ophioglossifolius*, *Oenanthe fistulosa*, *Ranunculus sardous* and *Lotus uliginosus* were favoured by weakly-acid pH not associated to high content in nutrients (SUN_IB, PUD_CB and PUD_IB).

Aquatic species (e.g. *Ranunculus aquatilis*, *Callitriche stagnalis* and *Glyceria spicata*) were more related to soils rich in silt, while amphibious and terrestrial species (e.g. *Isoetes velata*, *Illecebrum verticillatum* and *Lythrum hyssopifolia*) were more linked to sandy soils.

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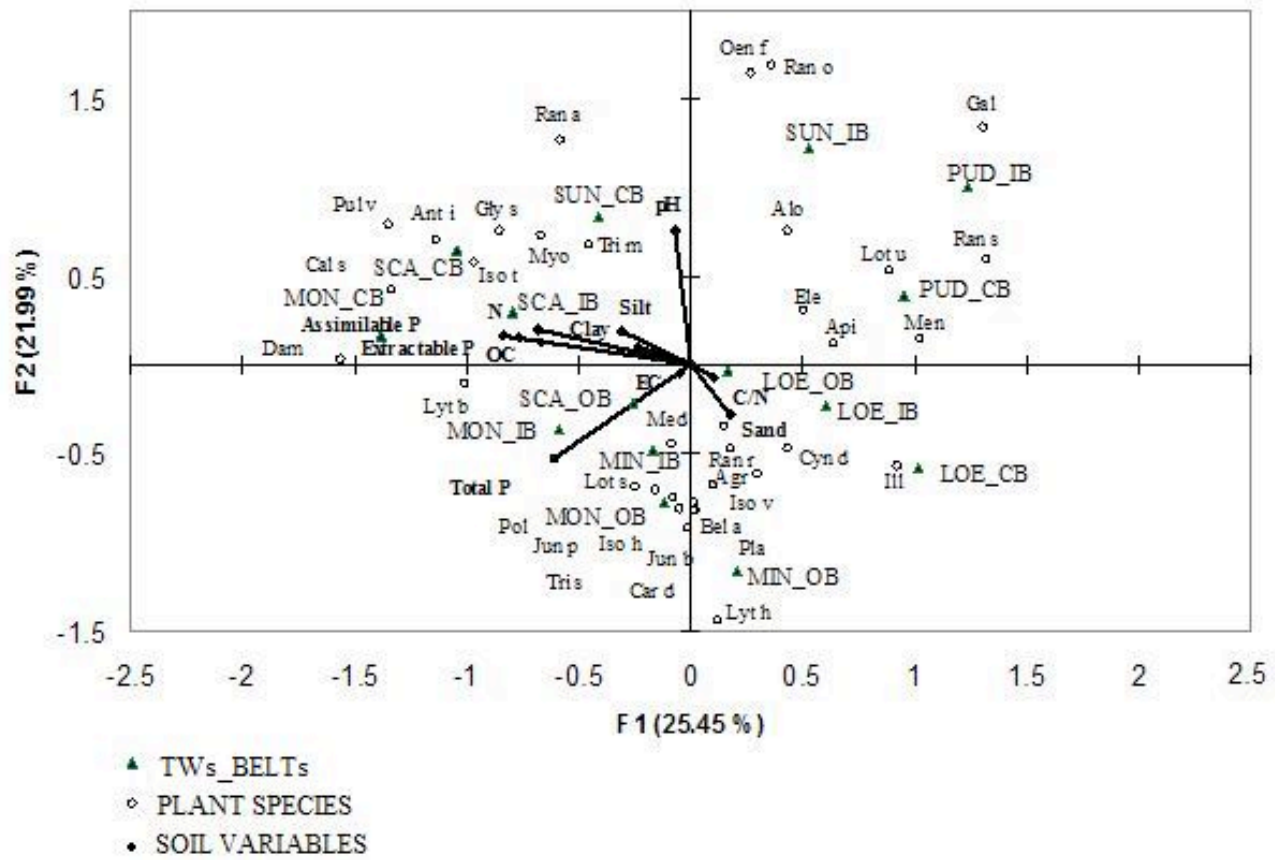
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Figure-captions

Figure x. Triplot showing the position of samples for the studied TWs_HSUs (see TW and HSU abbreviations in the text), plant species with a total cover $\geq 5\%$, and soil variables. The correspondence between codes and taxa names appears in the Appendix.

CCA



Chapter 9

Insight into *Isoetes histrix* Bory complex variability: a new view for a critical rendering

S. Bagella, M.C. Caria & J.A. Rossellò

Manuscript

Insight into *Isoetes hystrix* Bory complex variability: a new view for a critical rendering

S. Bagella, M.C. Caria & J.A. Rossellò

Introduction

Isoetes hystrix Bory is a terrestrial quillwort characterized by dark, shiny and persistent phyllopodia, tuberculatae macrospores, and sporangia completely covered by a *velum* (Valentine and Moore, 1992). It has a circummediterranean distribution, with some irradiations in the Atlantic-France (Quézel, 1998). Like other species of the *genus* this specie shows a conspicuous morphological variability, involving lateral and central phyllopodia prickles, leaf length and orientation, and spore ornamentation (Kott, 1980; Prada, 1983). This has prompted the description of several taxonomic segregates, mainly at the intraspecific level (e.g. Durieu, 1861; Braun 1864). Moreover, Gennari (1862) indicated an allied species, mainly characterized by the absence of the *velum*, first named *Cephaloceraton gymnocarpum* and later combined as *I. gymnocarpa* by Braun (1864). *Isoetes gymnocarpa* has been doubtfully considered a synonym of *I. hystrix* var. *subinermis* Durieu (Fiori, 1969; Cesca and Peruzzi, 2001; Arrigoni, 2005). Traditionally, macrospores have supplied the most relevant characters for the infrageneric classification of *Isoetes*, and since Pfeiffer (1922) recognized four basics macrospore surface patterns her systematic scheme was almost universally accepted for a long time. Later, Hickey (1985, 1986) observations on macrospore ornamentation suggested that surface morphology was extremely prone to convergence, despite earlier claims of Kott and Britton (1982) suggesting the opposite view. Microspore features have been largely neglected in taxonomic schemes and the patterns of surface ornamentation has not been standardized until recently (Musselman, 2003).

Although other morphological features of the sporophyte, such as microphyll intercellular pectic protuberances, have been proposed as reliable taxonomic

markers in some *Isoetes* complexes (e.g., Prada and Rolleri, 2005) their broad application through the whole genus seems premature. Hence, macrospores show the most relevant features to be used in the taxonomy of the genus.

Materials and methods

Statistical analyses

A four-way analysis of variance (ANOVA) was used to test for differences in macrospore size. Macrospore type (Ma) and site (Si) were considered as fixed and specimens (Spe) and sporangia (Spo) as random factors. The same experimental design was used to test for differences in microspore size considering microspores from specimens F and NF.

A three-way ANOVA was used to test for differences in lateral and central prickle length and in length of the 3 inner leaves among samples with the same macrospore type. A two-way ANOVA was used to test for differences in number of leaves, whole plant length and bulb diameter.

Prior to the analysis, the homogeneity of variance was tested by Cochran's test (Winer, 1971). Data were transformed whenever necessary.

When analysis of variance identified a significant difference for any factor, the *post hoc* test SNK (Student–Newman–Keuls) was applied to determine specific differences (Underwood, 1997).

ANOVA was performed using the GMAV 5 software (University of Sydney, Australia).

Results

Karyology

The observation of mitotic metaphase cells taken from apical meristems of primordial leaves was the most effective for chromosome counting, allowing a fast and reliable karyotyping for a large number of samples All the analyzed

specimens, independently of the macrospore and microspore ornamentation type, presented the same somatic chromosome number of $2n=20$ (Fig. 4).

Morphometrics

Overall, 1800 macrospores and 1800 microspores were measured. Results concerning size variation are given in Tables 1-5. Individuals showing macrospore type NF and F significantly differed in size (D and d parameters) (Table 1). However, variation in macrospore type was independent of that found in microspore length and the other measured characters involving the lateral and central prickles, leaf length and number, total length and bulb diameter (Tables 1-4). Differences between populations concerning the dimensions of the lateral and central prickles, leaf number, bulb diameter were detected (Tables 2-3); however these patterns were not related to any geographical or ecological trends.