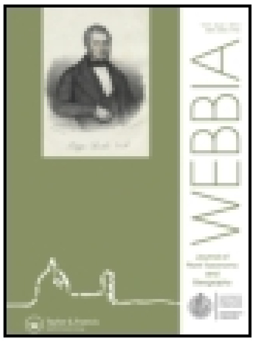

Webbia
Journal of Plant Taxonomy and Geography

ISSN: 0083-7792 (Print) 2169-4060 (Online) Journal homepage: https://www.tandfonline.com/loi/tweb20

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To cite this article: Riccardo Guarino, Corrado Marcenò, Vincenzo Ilardi, Anna Maria Mannino & Angelo Troia (2019): One *Chara* does not make *Charetea* in the Mediterranean aquatic vegetation, Webbia

To link to this article: https://doi.org/10.1080/00837792.2019.1607142

Published online: 23 May 2019.

WEBBIA
https://doi.org/10.1080/00837792.2019.1607142

ARTICLE

One *Chara* does not make *Charetea* in the Mediterranean aquatic vegetation

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ABSTRACT
The results of preliminary phytosociological investigations on freshwater communities of Sicily biotopes with a significant presence of Characeae are presented. In spite of the relatively frequent occurrence of Characeae, a typical *Charetea intermediae* vegetation is rather rare in the investigated biotopes. Indeed, the Characeae are mainly part of communities attributable to the classes *Potamogetonetea*, *Phragmito-Magnocaricetea*, *Juncetea maritimi* and *Isoeto-Nanojuncetea*. Some ecological and functional implications are discussed, along with some consequences on conservation measures and policies, caused by the lack of knowledge on the Characeae of Sicily.

ARTICLE HISTORY
Received 28 February 2019
Accepted 10 April 2019

KEYWORDS
Characeae; vegetation classification; phytosociology; freshwater hydrophytes; Mediterranean region; Sicily

Introduction

Taxonomy, distribution and role of Characeae species (also called stoneworts) living in freshwater aquatic habitats are poorly studied in Italy, especially in Sicily (Bazzichelli and Abdelahad 2009). Moreover, only a few investigations have been carried out on the associated algal community (e.g. Naselli-Flores and Barone 2002, 2012). This represents a large gap in research in the systematic, biogeographic and ecological fields, as well as for applied research addressed to environment monitoring and to habitat and biodiversity conservation, especially considering the increasing pressures on the freshwater ecosystems of the whole planet (Darwall et al. 2018).

The ecological role of the Characeae, e.g. maintaining high transparency of the water (Blindow et al. 2002), storing carbon and nutrients (Lucas 1975) or providing food and habitat for many animal species (Soulié-Märsche 2004; Schneider et al. 2015), is well known. For these reasons, Characeae have been recognised as important bioindicators for inland water ecosystems (Lambert-Servien et al. 2006; TäUscher 2012; Pukacz et al. 2013). Stoneworts are also related to habitats of community interest (EU Directive 92/43), threatened by several anthropogenic actions, and therefore in regression at the national and European level (Davidson 2014).

According to the European phytosociological classification system (Mucina et al. 2016, henceforth Eurovegchecklist), stonewort meadows of carbonate-rich lakes and gravel pits are included in the class *Charetea intermediae* F. Fukarek 1961. However, Characeae can occur in a large variety of chemically different water types, at different depths, from still to slow-flowing basins, including artificial ditches, forest sumps and shallow temporary ponds (Lambert 2007). Their physiognomic role in classes other than *Charetea intermediae* has been poorly investigated in the phytosociological literature, being limited to the recognition of the vegetation ascribed to *Ruppietea maritimae* J. Tx. ex Den Hartog et Segal 1964, as preferential habitat for *Chara horrida* and *C. intermedia* (Schaminée and Den Hartog 1995).

Here, we present some results of preliminary investigations on the vegetation of Sicilian habitats characterised by a significant presence of Characeae. Some general remarks on the classification of stonewort-rich vegetation in different Mediterranean habitats are also included.

Materials and methods

Data collection

Field surveys and 25 phytosociological relevés (Braun-Blanquet 1964; Guarino et al. 2018) in (lentic) freshwater communities were carried out in selected biotopes of Sicily, chosen to encompass the whole altitudinal range of the so far known stonewort vegetation in the island (Table 1).

The only criterion followed in the selection of the vegetation plots was the occurrence of Characeae, with cover values visually estimated to be higher than 5%. Vascular plants were recorded and included in the relevés only if they were well developed and directly in contact with the Characeae, i.e. occupying

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Published online 23 May 2019

Table 1. Unpublished relevés of stonewort vegetation from Sicily.

Plot number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Class	ISO	ISO	ISO	JUN	JUN	JUN	JUN	JUN	PHR	PHR	PHR	PHR	PHR	PHR	PHR	POT	POT	POT	POT	POT	POT	Y-A	Y-A	Y-A	Y-A
Altitude (m asl)	720	720	720	1	1	1	2	2		3	2	2	3	4	4				720	1460	1460		65	65	
Electric conductivity (April) (µS/cm)	–	200	200	–	–	–	–	–	–	–	–	–	–	–	2000	–	–	–	200	–	–	–	–	–	–
Plot size (m^2)	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Cover (%)	90	60	60	100	100	80	100	100	45	60	70	100	80	90	75	90	80	75	45	70	65	85	90	90	85
Algae																									
Chara vulgaris	4	2	.	.	1	+	2	.	3	+	1	.	1	.	2	2	.	5	.	.	.	5	.	.	5
Lamprothamnium papulosum	.	.	.	2	1	1	1	2	.	1	2	1	1	1	.	.	.	.	.	.	.	.	.	.	.
Enteromorpha sp.	.	.	.	.	.	1	1	.	.	1	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.
Nitella opaca	.	1	2	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	2	.	.	.	.	.	.
Nitella capillaris	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.
Chara contraria	.	.	.	.	.	.	.	.	.	.	2	4	.	1	.	.	.	.	.	.	.	.	.	.	.
Chara baltica	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	5	.
Chara conimbrigensis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	+	.	.	.	.
Chara globularis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	+	.	.	.	.	.	.
Chara aspera	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
Phanerophytes																									
Bolboschoenus maritimus	.	.	.	5	5	4	5	5	.	4	4	5	1	1	1	.	.	.	.	.	.	.	.	.	.
Phragmites australis	.	.	.	1	1	4	1	1	.	4	1	1	1	1	.	.	.	.	.	.	.	.	.	.	.
Juncus subulatus	.	.	.	1	2	2	1	.	.	1	1	.	1	.	.	.	.	.	.	.	.	.	.	.	.
Ruppia maritima	.	.	.	1	.	.	1	1	.	.	1	.	1	1	.	.	.	.	.	.	.	.	.	.	.
Juncus maritimus	.	.	.	1	1	1	2	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Schoenoplectus litoralis	.	.	.	.	.	.	.	.	.	2	5	5	4	5	.	.	.	.	.	.	.	.	.	.	.
Eleocharis palustris	.	1	1	.	.	.	.	.	.	.	.	.	.	.	4	.	.	.	2	.	.	.	.	.	.
Eryngium pusillum	.	2	2	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	+	.	.	.	.	.	.
Glyceria notata	.	2	1	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	2	1	1	.	.	.	.
Mentha pulegium	2	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
Potamogeton natans	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	.	2	.	2	1	.	.	.	.
Ranunculus trichophyllus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	5	4	.	.	.	.	.	.	1
Groenlandia densa	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	3	.	.	.	2
Limbarda crithmoides	.	.	.	1	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Lythrum junceum	1	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.
Molineriella minuta	.	2	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.
Alisma lanceolatum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	1	.	.	.	.	.	.	.	.
Callitriche sp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	+	.	.	.	.	.
Carex acutiformis	+	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Equisetum ramosissimum	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Glyceria sp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	2
Juncus articulatus	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	2
Juncus effusus	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Limonium narbonense	.	.	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pulicaria dysenterica	1	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ranunculus baudotii	.	1	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Rumex pulcher	1	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.
Sarcocornia fruticosa	.	.	.	.	1	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.
Schedonorus pratensis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	1
Suaeda spicata	.	.	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Trifolium resupinatum	2	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

(*Continued*)

Table 1. (Continued).

Plot number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Zannichellia palustris	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.			.	.	.	.
Cirsium creticum subsp. *triumfetti*	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Coronopus squamatus	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Cyperus longus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.
Dittrichia viscosa	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Eleocharis sp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.
Galium palustre	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Helosciadium nodiflorum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.
Isoetes velata subsp. *longissima*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.
Montia sp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.
Myosotis sicula	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.
Nasturtium officinale	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.
Orchis laxiflora	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Paspalum distichum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.
Phalaris aquatica	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Polypogon maritimus	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Polypogon monspeliensis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	.	.	.	.	.	.	.	.	.	.
Polypogon viridis	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ranunculus aquatilis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	.	.	.	.	.	.
Ranunculus fontanus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.
Ranunculus peltatus subsp. *fucoides*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.
Rumex sanguineus	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Schoenoplectus lacustris	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.
Teucrium scordium	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Trifolium sp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Typha angustifolia	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Veronica anagallis-aquatica	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.

ISO = *Isoeto-Nanojuncetea*; JUN = *Juncetea maritimi*; PHR = *Phragmito-Magnocaricetea*; POT = *Potamogetonetea*; Y-A = *Charetea intermediae*. Location and date of the relevés: [1, 9, 22] Stagno Rocca dell'Aquila (north-west Sicily), 31 May 2018; [2, 3, 19] Rebuttone Pond (north-west Sicily), 16 May 2018; [4–8, 10–14] Hyblaean Marshes (south-east Sicily), 28 April 1973; [15] Anguillara Ponds (west Sicily), 23 May 2018; [16, 18, 25] Stagno portella Maganoce (north-west Sicily), 31 May 2018; [17] Lake Coda di Riccio (north-west Sicily), 23 May 2018; [20, 21] Lake Maulazzo (north Sicily), 11 June 2018; [23, 24] Lago Preola (south-west Sicily), 20 September 2018.

Table 2. Synoptic table of the 59 processed relevés classified by the expert system of the Eurovegchecklist.

Number of plots	3	5	17	29	5
Expert system classification	ISO	JUN	PHR	POT	Y-A
Mentha pulegium	100^{1-2}	–	–	3^{+}	–
Trifolium resupinatum	66^{1-2}	–	–	–	–
Ranunculus baudotii	66^{+-1}	–	–	–	–
Glyceria notata	66^{1-2}	–	6^{3}	3^{3}	–
Eleocharis palustris	66^{1}	–	6^{4}	3^{3}	–
Eryngium pusillum	66^{2}	–	6^{+}	3^{+}	–
Molineriella minuta	66^{2}	–	–	3^{+}	–
Rumex pulcher	33^{1}	–	6^{1}	–	–
Phalaris aquatica	33^{+}	–	–	–	–
Carex acutiformis	33^{+}	–	6^{1}	–	–
Coronopus squamatus	33^{1}	–	–	–	–
Polypogon viridis	33^{1}	–	–	–	–
Rumex sanguineus	33^{+}	–	–	–	–
Teucrium scordium	33^{1}	–	–	–	–
Dittrichia viscosa	33^{+}	–	–	–	–
Pulicaria dysenterica	33^{1}	–	6^{1}	–	–
Juncus maritimus	–	100^{+-3}	–	–	–
Juncus subulatus	–	80^{1-3}	18^{+-1}	–	–
Limbarda crithmoides	–	60^{+-2}	–	–	–
Ruppia maritima	–	60^{1}	18^{1}	–	–
Suaeda spicata	–	40^{1-2}	–	–	–
Enteromorpha	–	40^{1}	18^{1}	–	–
Limonium narbonense	–	40^{1}	–	–	–
Polypogon maritimus	–	20^{1}	–	–	–
Sarcocornia fruticosa	–	20^{1}	6^{2}	–	–
Schoenoplectus litoralis	–	–	29^{3-5}	–	–
Helosciadium nodiflorum	–	–	18^{+-3}	31^{+-2}	–
Groenlandia densa	–	–	6^{2}	21^{+-5}	–
Chara baltica	–	–	–	–	40^{5}
Ranunculus trichophyllus	–	–	–	10^{4-5}	20^{2}
Glyceria sp.	–	–	–	3^{3}	20^{3}
Ruppia cirrhosa	–	–	–	–	20^{4}
Chara aspera	–	–	–	–	20^{1}
Juncus effusus	–	–	6^{1}	–	20^{1}
Lythrum junceum	33^{1}	20^{1}	–	3^{+}	–
Juncus articulatus	33^{5}	–	–	–	20^{3}
Phragmites australis	–	100^{+-4}	53^{+-4}	3^{+}	–
Bolboschoenus maritimus	–	100^{4-5}	35^{+-5}	–	–
Lamprothamnium papulosum	–	100^{1-3}	29^{1-3}	–	–
Zannichellia palustris	–	–	47^{+-2}	79^{+-5}	–
Veronica anagallis-aquatica	–	–	29^{+}	24^{+}	–
Chara vulgaris	66^{2-4}	6^{1}	59^{+-4}	83^{1-5}	40^{5}
Alisma lanceolatum	–	–	6^{3}	4^{1}	–
Typha latifolia	–	–	18^{+-2}	–	–
Chara sp.	–	–	18^{1-4}	–	–
Nasturtium officinale	–	–	18^{+}	10^{+-2}	–
Scrophularia auriculata	–	–	12^{+-2}	10^{+}	–
Potamogeton natans	–	–	–	10^{3-5}	–
Nitella opaca	100^{1-3}	–	–	7^{1-3}	–
Nitella capillaris	100^{+-1}	–	–	–	–
Alisma plantago-aquatica	–	–	18^{+}	10^{+}	–
Schoenoplectus lacustris	–	–	18^{2}	14^{+-2}	–
Equisetum telmateia	–	–	18^{+-2}	17^{+}	–
Enteromorpha clathrata	–	–	–	17^{+}	–
Rhizoclonium riparium	–	–	–	10^{1}	–
Ranunculus aquatilis	–	–	–	10^{3-4}	–
Equisetum arvense	–	–	18^{+}	14^{+}	–
Veronica beccabunga	–	–	6^{+}	7^{+}	–
Glyceria fluitans	–	–	18^{+}	3^{+}	–
Chara contraria	–	–	–	7^{2-4}	–
Potamogeton polygonifolius	–	–	6^{+}	7^{+-2}	–
Chara globularis	–	–	–	7^{+-1}	

Species are ordered by their percentage frequencies, exponents represent minimum and maximum cover values for each species in the processed relevés. Species with frequency <10%, not in Characeae, are not shown. ISO = *Isoeto-Nanojuncetea*; JUN = *Juncetea maritimi*; PHR = *Phragmito-Magnocaricetea*; POT = *Potamogetonetea*; Y-A = *Charetea intermediae*.

the same vegetation layer. This choice was driven by the observation, unanimously shared in the phytosociological literature consulted, that stonewort vegetation usually develops below the water level occupied by the phanerogamic layer or, if this is not the case, there should be at least a temporal displacement, with the Characeae completing their life cycle before the phanerogamic layer is fully developed.

Characeae samples were collected by hand or by means of a hook. After washing the fresh material to remove sediment and organic matter, they were observed fresh with a stereomicroscope (Leica MZ9.5, maximum magnifications of 60×). Characeae were identified following Mouronval et al. (2015) and vascular plants were identified and named after Pignatti et al. (2017–2019).

In addition to the unpublished phytosociological relevés presented here, a comprehensive literature review on phytosociological data from Sicily was carried out in order to select all available vegetation plots (relevés) recording the occurrence of Characeae with cover values higher than 10%. In total, 59 relevés have been collected (Table 2), of which 25 are unpublished and 34 are taken from Sortino et al. (1974), Marcenò and Raimondo (1977), Brullo and Furnari (1976), Brullo et al. (1994), Brullo and Sciandrello (2006), Minissale et al. (2007), Sciandrello (2007) and Sciandrello et al. (2016).

The 59 relevés collected are unevenly distributed in Sicily, along an elevation gradient from sea level to 1460 m asl, circumscribed by a triangle with the vertices in the following coordinates: 36°70′N, 15°02′E; 37°94′N, 14°67′E; 37°87′N, 12°44′E.

Data analysis

The 59 relevés were stored in TURBOVEG (Hennekens & Schaminée 2001), imported in JUICE (Tichý 2002) and classified by means of the expert system of the Eurovegchecklist (Mucina et al. 2016), containing the formal definitions and indicator species of all the European phytosociological classes. In order to summarise the variation in species composition explained by the attribution to different classes and to measure the average dissimilarity of species composition among the classes, we performed an ordination analysis by means of the software CANOCO 5 (Smilauer and Leps 2014). We decided to run a constrained ordination, using the results of the expert system classification as nominal explanatory variables. In this way, the distance between species and phytosociological classes corresponds to the relative preference of a given species for a given class, measured by chi-square distances. With our data being compositional, with a gradient of 9.2 SD, we opted for a linear method, i.e. redundancy analysis (RDA), in which the response data were centred on species. We tested and explored the predictor effect of all constrained axes by running an unrestricted permutation test of 499 permutations.

Finally, in order to draw some conclusions on the conservation status of the stonewort vegetation in

Sicily, the management plans for the 'Natura2000 sites' (protected areas designated according to the European Directive 92/43/CE, sometimes overlapping with other kinds of natural parks and reserves), available on the website of the Sicilia Region (http://www.artasicilia.eu/old_site/web/natura2000/index.html, accessed February 2019), were consulted to assess in how many sites '*Chara* meadows' (habitat code 3140) or, at least, generic records of stonewort occurrences, are reported.

Results

The average floristic richness in the processed relevés was 5.7 species per 25 m^2, with clear gaps related to the submersion gradient (Figure 1), whereas the altitude did not prove to be significantly influential on the average species richness (Figure 2).

The expert system of the Eurovegchecklist (Mucina et al. 2016) classified 49.2% of the relevés in *Potamogetonetea* Klika in Klika et Novák 1941, 28.8% in *Phragmito-Magnocaricetea* Klika in Klika et Novák 1941, 8.5% in *Juncetea maritimi* Br.-Bl. in Br.-Bl. et al. 1952 and 5.1% in *Isoeto-Nanojuncetea* Br.-Bl. et Tx. in Br.-Bl. et al. 1952. An additional 8.5% of the relevés, corresponding to five relevés in which only Characeae were recorded, have been classified as generically 'aquatic' (Y-Aqu) because the formal definition of the class *Charetea intermediae* F. Fukarek 1961 is missing in the expert system.

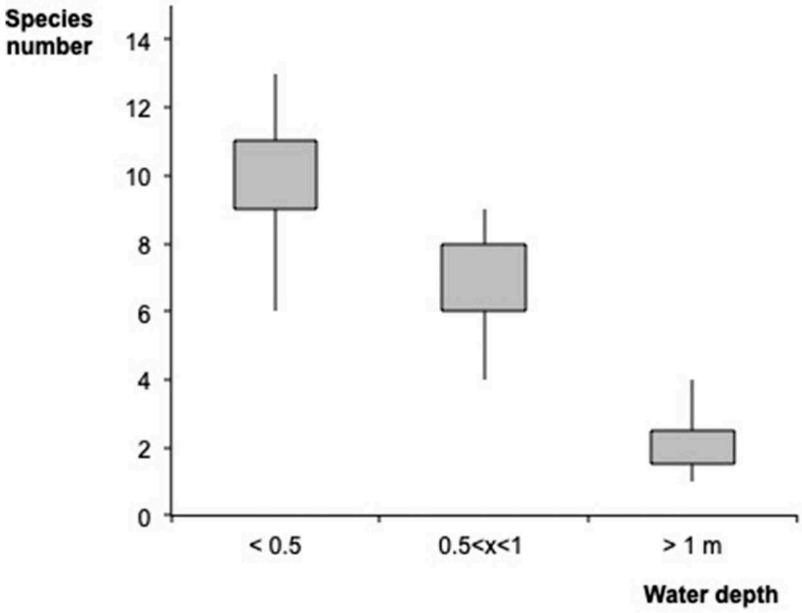

Figure 1. Boxplots of the relationship between water depth and number of species in the processed relevés.

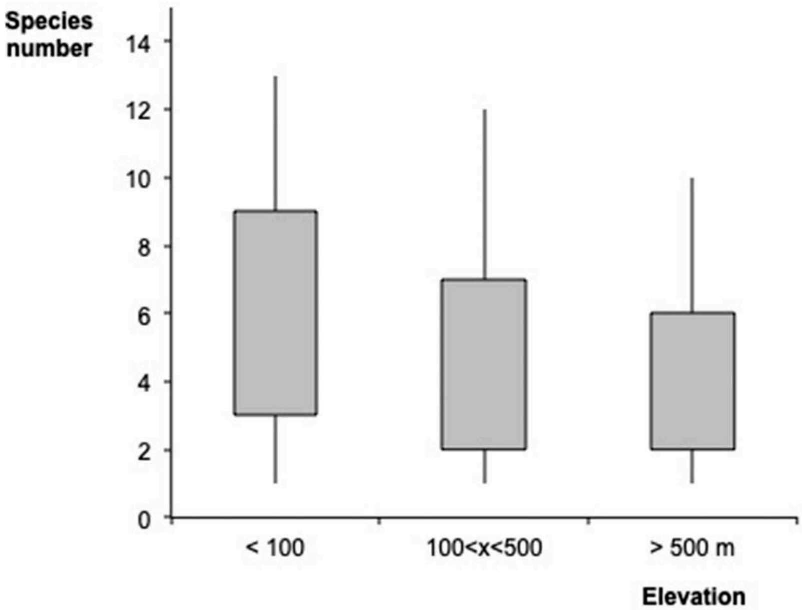

Figure 2. Boxplots of the relationship between altitude and number of species in the processed relevés.

In the whole data-set, only these five vegetation plots displayed the typical structure of *Charetea intermediae* vegetation, i.e. a dense benthonic layer of stoneworts separated by a water column varying from 0.4 to a few metres of depth from the fanerogamic layer. The remaining part of the analysed data reveals the occurrence of stoneworts as structural elements of: (1) rooted floating or submerged phanerogamic vegetation of stagnant or lentic mesotrophic to eutrophic/brackish water (*Potamogetonetea*), with a strong affinity for the crosswort rooted macrophytes in shallow stagnant freshwaters (*Ranunculion aquatilis* Passarge 1964 ex Theurillat in Theurillat et al. 2015); (2) early season stages of the swamp vegetation of mesotrophic to eutrophic water dominated by rhizomatous helophytes (*Phragmito-Magnocaricetea*); (3) vegetation of coastal brackish swamps dominated by *Juncus maritimus*, under a prolonged flooding regime (*Juncetea maritimi*); and (4) ephemeral vegetation of temporary pools and seasonally wet depressions (*Isoeto-Nanojuncetea*).

In comparison with the other vegetation classes, the *Juncetea maritimi* is the one displaying the most remarkable floristic individuality (Figure 3), which is likely to be driven by the salinity. The remaining part of the observed floristic variability is probably influenced by the water chemistry and, above all, by the length of the submersion period.

Of the Characeae recorded, *Chara vulgaris* showed the widest ecological amplitude. Indeed it was recorded in plots assigned to all five vegetation classes, even if the highest cover values were reached in the plots classified as *Potamogetonetea*. However, it cannot be excluded that such amplitude could be partially due to misidentification or to the application of a *sensu lato* species concept, at least in the 34 relevés taken from literature.

Chara contraria, *C. conimbrigensis* and *C. globularis*, often growing together with *C. vulgaris*, have been exclusively found in the vegetation ascribed to *Potamogetonetea*, with average cover values ranging between 40 and 5%.

Chara baltica and *C. aspera*, instead, were exclusively found in the permanent lake named Lago Preola (south-west Sicily), participating in a typical *Charetea intermediae* vegetation.

Nitella opaca and *N. capillaris* were found in *Potamogetonetea*, *Phragmito-Magnocaricetea* and *Isoeto-Nanojuncetea* vegetation, in all cases not very common and seldom exceeding the 5% of cover altogether.

Lamprothamnium papulosum has been found both in *Phragmito-Magnocaricetea* and in *Juncetea maritimi* vegetation, with a clear preference for the latter, in terms of frequency and cover values.

Discussion

Synecology

Our results highlighted a close relationship between the classes *Charetea intermediae* and *Potamogetonetea* in some biotopes of Sicily. Both classes include aquatic communities with rooted hydrophytes (rhizophytes), but *Charetea intermediae* vegetation is dominated by species of the family Characeae (Felzines and Lambert 2012, 2016), whereas *Potametea* is dominated by vascular plants but it can include one or more species of Characeae as well (Schaminée and Den Hartog 1995). In some Sicilian biotopes, the *Charetea intermediae* vegetation is ecologically and spatially distinct, although close, from that referable to the class *Potamogetonetea*.

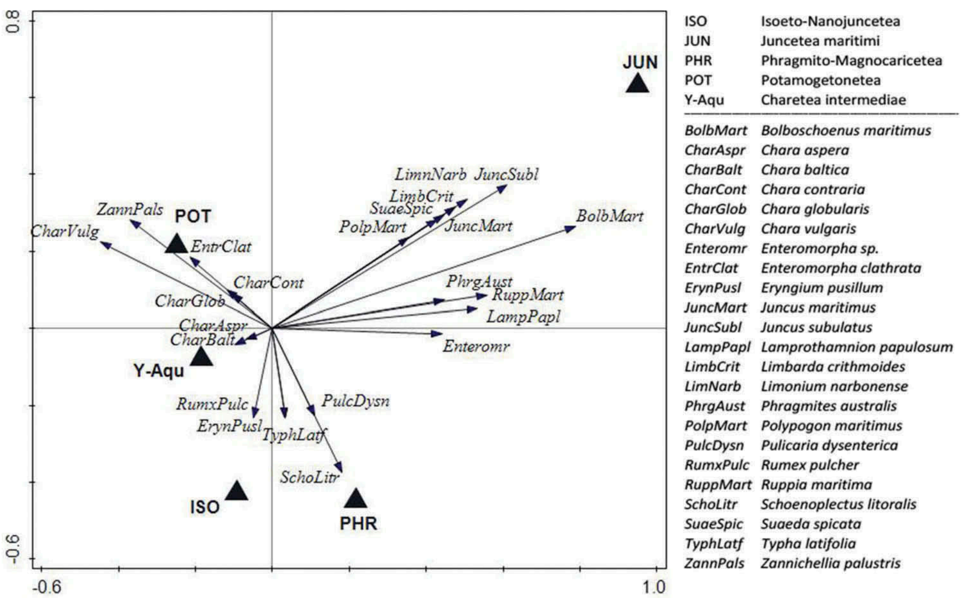

Figure 3. RDA of the processed relevés. Only diagnostic species are displayed. Each arrow points in the direction of the steepest increase of the correlation values for corresponding species. The length of the species arrows is the multiple correlation of that species with the ordination axes (Smilauer and Leps 2014).

In many other cases, instead, one or more species of Characeae are structurally intrinsic to the vegetation of *Potamogetonetea*. A meaningful example of this second case is offered by some pools next to the Maulazzo dam (Nebrodi Mountains, north Sicily, 1460 m asl), where *Chara conimbrigensis* A.G. Cunha (for details, see Troia et al. 2018; Romanov et al. 2019) enters the *Groenlandietum densae* Segal ex Schipper et al. in Schaminée et al. 1995, mixing together with *Groenlandia densa* (L.) Fourr., *Potamogeton natans* L. and other hydrophytes (Figure 4).

Another interesting result is the relationship of some *Nitella* species, namely *N. capillaris* (Krock.) J. Groves and Bull.-Webst. and *N. opaca* (C. Agardh ex Bruzelius) C. Agardh, with shallow-water vegetation ascribed to the phytosociological alliance *Ranunculion aquatilis* (*Potamogetonetea*). In particular, we observed that the occurrence of these two different dioecious *Nitella* species goes along with two different species of *Ranunculus* subgen. *Batrachium*, i.e. *Ranunculus saniculifolius* Viv. and *R. aquatilis* L., respectively, in two different temporary ponds: Anguillara, near Calatafimi (Troia and Lansdown 2016) and Rebuttone near Piana degli Albanesi (Naselli-Flores and Barone 2012).

The preference of *Nitella opaca* for low-conductivity waters agrees with data from the literature (Auderset Joye and Boissezon 2017), and conductivity could be the main driver in the floristic differentiation of the two communities at issue. In both cases, phenology could be an important additional trait, with the Characeae developing earlier (between the end of winter and the beginning of spring) to avoid the competition of the angiosperms that progressively develop during the spring months. This phenological displacement is a bit different from the successional role of typical *Nitella* communities (framed into: *Charetea intermediae* F. Fukarek 1961 >*Nitelletalia flexilis* W. Krause 1969 >*Nitellion flexilis* W Krause 1969), which are considered to be pioneer vegetation in the early stages of plant colonisation of mineral sandy-loamy substrata in oligo- to mesotrophic freshwater habitats of temperate ecosystems (Lambert-Servien et al. 2006; Felzines and Lambert 2012).

Figure 4. *Groenlandietum densae* with *Chara conimbrigensis* in the Maulazzo Ponds (Nebrodi Mountains, north Sicily, 1460 m asl). For details, see Table 1, relevés 20 and 21.

Vegetation classification

Aquatic vegetation is often poor in vascular species in comparison to terrestrial plant communities and usually only one or very few species are dominant. Whereas such dominance allows easy definition and identification of associations, it poses some problems in the recognition of higher *syntaxa*, which are very similar to the associations in species composition, being likewise characterised by only one or two species (Wiegleb 1980; Feoli and Gerdol 1982; Landucci et al. 2015).

Depending on the species, in their optimal milieus, stoneworts can form monospecific or paucispecific vegetation composed of scattered plants or dense carpets reaching 10 cm to 1 m in height, sometimes mixed with other hydrophytes (Felzines and Lambert 2012). Only a few water basins of Sicily are deep enough to allow stratified phytocenoses of hydrophytes, in which the *Charetea intermediae* vegetation occupies the lower stratum. As we have seen, stoneworts of Sicily are more frequently found integrated in *Potamogetonetea* and *Phragmito-Magnocaricetea* communities, in a monostratified occupancy of the biotopes. In these cases, the choice of recording Characeae and phanerophytes separately in a given plot is debatable. We should admit that hydrophytes can easily form homogeneous structures, yet are floristically heterogeneous from a phytosociological point of view.

The opportunity to sample and classify the algal vegetation together with the phanerogamic vegetation has been debated since the dawn of phytosociology (Allorge 1922; Margalef 1947). In this regard, Braun-Blanquet (1964) wrote: 'Are algae structural components of the macrophytic vegetation or are they independent communities of small volume subordinated to larger volumes? … The *Potametum* and the *Scirpo-Phragmitetum* share space with algae and well-determined planktonic series. In any case, it is doubtful to what extent they are dependent or merely subordinate communities' (p. 347).

Even if the ecological and/or phenological separation of Characeae from the phanerogamic vegetation is a well-established issue of coenological research in temperate ecosystems (but see some 'mixed' *syntaxa*, such as *Lemno-Nitelletum capillaris* Schaminée et al. 1995 and *Eleocharito-Nitelletum flexilis* W. Krause 1969), the same might not be true for the Mediterranean ecosystems, where Characeae are relatively frequent but the typical *Charetea intermediae* vegetation is rather rare. Certainly, the sampling of the whole algal community would be desirable to understand vegetation dynamics better.

Implication for conservation

In all kinds of biodiversity assessments, the more life forms considered, the better the accuracy and robustness of results. This is true for all kinds of sessile organisms, in all kinds of ecosystems. Non-vascular macrophytes are very often neglected in phytosociological literature (Poponessi et al. 2015) even if, according to our preliminary observations, Characeae may represent an important component, in terms of abundance and frequency, in some Mediterranean phanerogamic aquatic communities.

The unsatisfactory knowledge of Characeae's distribution and ecology in the Mediterranean region makes it difficult to apply the Habitats Directive, according to which Characeae characterise the habitat 'Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp.' (code 3140).

In fact, we verified that, considering the 238 sites of the Natura2000 network established in Sicily according to the Directive, the habitat 3140 is reported in 14 sites only, i.e. in 6% of them, a percentage that – according to our field surveys – seems far from the real situation.

This lack of data, basically deriving from the lack of people working on Characeae, makes it difficult to identify the stonewort habitats in the Mediterranean region and, consequently, to protect them, as requested by the Directive EC 92/43. This has serious implications (in Sicily as well as in most of Italy) for the aims of biodiversity conservation.

The kind of stonewort vegetation usually known as '*Chara* meadows' is commonly referred to the phytosociological class *Charetea intermediae* F. Fukarek 1961; however, as we have seen, the Characeae are not exclusively found in vegetation stands ascribed to this class but also in other habitat types. So we agree with Nicolas (2013) in saying that the presence of Characeae is not sufficient to declare the presence of the habitat 3140. The same author cites, for example, communities with Characeae ascribed to the class *Littorelletea uniflorae* Br.-Bl. et Tüxen ex Westhoff, Dijk and Passchier 1946 (Nicolas 2013). We verified ourselves the occurrence of Characeae in the classes *Potamogetonetea*, *Phragmito-Magnocaricetea*, *Juncetea maritimi* and *Isoeto-Nanojuncetea*.

Conclusions

To understand better the rich and fragile inland freshwater ecosystems of Sicily, and probably of the whole Mediterranean area, it is urgent to fill the current gaps in the knowledge regarding Characeae, starting from the taxonomy of the species and going through their biology, autoecology and synecology. Our preliminary observations are just a first step in this direction.

Acknowledgements

We gratefully thank Federico Marrone for providing the conductivity records reported in Table 1 and Salvatore Brullo for providing the so far unpublished relevés 4–8 and 10–14 reported in Table 1.

Disclosure statement

No potential conflict of interest was reported by the authors.

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