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Halocnemum vegetation in the Mediterranean Basin

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Abstract

Subject of the article is the syntaxonomic interpretation of hyperhalophilous woody or semi-woody vegetation with *Halocnemum* Bieb. along the coasts of the Mediterranean Basin. For this area, the two species of *Halocnemum strobilaceum* (Pall.) Bieb. and *H. cruciatum* (Forssk.) Tod. are identified; their morphological characteristics, synonymy and distribution are here described. (; their morphological characteristics, synonymy and distribution are here described. The study of particular aspects of plant morphology and the study of the micromorphological characteristics of the seeds collected in different places in the Mediterranean allow to better differentiate the two species. Vegetation studies already done in many communities of the Mediterranean by several authors, threw into great confusion because only *H. strobilacem* has been recognized as a dominant species. As regards the syntaxonomic analyses of the vegetation, the authors refer to the proposals already made by various scientists for the vegetation of inland salt basins of Eurasia and the Irano-Anatolian area, who suggested the classes *Kalidietea foliate* and *Halocnemetea strobilacei irano-anatolica* respectively. Conversely, in the Mediterranean Basin the study vegetation is present only in coastal areas where it is considerably impoverished in the number of species. Therefore, the authors propose to include hyperhalophilous, woody and fruticose vegetation, in the class *Sarcocornietea fruticosae.* However, the phytosociological and ecological diversity is highlighted proposing the order *Halocnemetalia cruciati* in which both the alliance *Halocnemion strobilacei,* for middle Eastern Europe, and the alliance *Halocnemion cruciati,* for North Africa with penetrations in the Western and Eastern Europe up to the Middle East coast, are included. This new interpretation has required the correction of the names of the two associations (*Frankenio corymbosae-Halocemetum cruciati*; *Zygophyllo albi-Halocnemetum cruciati*) and the proposal of two new associations *Arthrocenemo macrostachyi-Halocnemetum cruciati* and *Halocnemo cruciati-Sarcocornietum fruticosae.* A further proposal concerns the addition of the alliance *Limoniastrion monopetali,* previously included in the order *Limonietalia*, in the order *Halocnemetalia cruciati*.

Key words: *Halocnemum cruciatum; H. strobilaceum*; *Halocnemetalia cruciati*; *Halocnemion cruciati; Halocnemion strobilacei;* Hyperhalophilous vegetation; Phytosociology; Mediterranean Basin; Syntaxonomy; Taxonomy; Seed coat microstructure.

Introduction

The study of halophytic vegetation in the world represents a relevant problem since it concerns wide areas that are no longer suitable for agriculture. The increase of soil

salinity due to the irrigation systems in the arid regions makes the knowledge of the role of saline vegetation an important challenge (Khan et al. 2006).

Nevertheless, these areas present a highly specialized flora with morphological, physiological and anatomical adaptations during their life cycle, which are of great interest for researchers who deal with plant ecology and the struggle against desertification. In this respect, the destruction of halophytic shrub vegetation can be considered as a first step towards desertification in arid areas.

Indeed, EU adopted a legislation for the protection of biodiversity in its territory, the 92/43/EEC Directive (European Commission 2007), which aims to create the Natura 2000 network, made up of interconnected protected areas (Evans 2012).

According to the Annex I of the Directive the study vegetation is included in the category of the "Mediterranean and thermo-Atlantic salt marshes and salt meadows" and in the habitat 1420 "Mediterranean and thermo-Atlantic halophilous scrubs (*Sarcocornietea fruticosi*)", according to CORINE Biotopes Code 15.6 - Mediterraneo-Nemoral saltmarsh scrubs (Biondi et al. 2012).

Salinity is a stress factor for many species and therefore results in relatively poor vegetation (García et al. 1993, El-Sheikh et al. 2003). In this regard, *Halocnemum* vegetation is usually very poor in species diversity, often monotypic (Akhani & Ghorbanli 1993). This vegetation with *Halocnemum* species is reported as one of the most salt tolerant, it even tolerates salinities above seawater levels (Al-Oudat et al. 2011), and its distribution depends on soil salinity and the competition relationships between halophytic species (Perez-Lahiguera et al. 2009, Pujol et al. 2000).

These kind of communities usually occupies very large zones of inland salt deserts and littoral marshes subject to temporary flooding, in land-water areas mainly related to geomorphological structures such as river deltas, coastal lagoons and inland salt lakes (Perez-Lahiguera et al. 2009). In many areas of the Mediterranean coastline of Africa and Arabia and in the inland sub-arid areas as well, *Halocnemum* species also behaves as a psammophyte species that favours the formation of sand accumulations.

The genus *Halocnemum* occurs in saline habitats from northern Africa and Mediterranean Europe to Western Asia (Qu et al. 2008), and it has its centre of diversity on the inland dry areas of Asia, where it is much more widespread and it behaves as a dominant species in the salt deserts such as those of Northwest China. Several ecological and phytosociological studies were carried out in this area (Asri & Ghorbanli 1997, Alaie, 2001, El-Sheikh et al 2006, Hamzaodlu & Aksoy 2009) some of them proposing new syntaxa, even though the majority without a valid typification, this fact is also observed in some studies concerning to the Mediterranean area (Sarika 2012).

An important part of this previous ecological research has focused on the knowledge of the relationship between soil features and vegetation response all over the distribution area of the genus (Jafari et al 2003, Zahran et al 1989, Caballero et al, 2002, Aksoy & Hamzaoglu 2006).

Although this vegetation is present in many other parts of the northern hemisphere, it is mainly widespread in the steppe zones of Eurasia and in the Irano-Saharan area. This article mainly discusses the aspects that concern to the woody and semi-woody hyperhalophilous vegetation, widespread along Mediterranean coast, where species of *Halocnemum* are often associated with other succulent species of the same class. The study of halophilous and hyperhalophilous vegetation of Mediterranean coasts involves many problems which refer to taxonomical and syntaxonomical aspects that in turn concern chorological, synchorological and ecological aspects.

Material and methods

Vegetation study

The study of the phytocoenoses was carried out following the phytosociological methods of the Sigmatist School of Zurich-Montpellier, as successively integrated (Rivas-Martínez, 2005; Géhu, 2006 and 2011; Biondi, 2011; Blasi et al.2011; Pott, 2011). The syntaxa names comply with the ICPN (Weber et al. 2000).

Studied populations for seed characterization

In order to compare morphological seed coat aspects between the two species of the genus *Halocnemum*, seeds from six different populations from Spain, Italy and Egypt (Figure 4) were analyzed.

Seed morphological features

Seed descriptions were according to Werker (1997). The terminology of Stearn (1992) and Barthlott (1984) was adopted for the scanning electron microscopy (SEM) aspects of the seed coat. Images of the seeds were taken over millimetre paper in a binocular microscope (Nikon SMZU) and dimensions, width and length, were measured using the image analyses software Image J (Rasband 1997-2012). Seed weight was determined using an Orion Cahn C-33 microbalance. Seed surface was analyzed with a SEM Hitachi S-4100, file emission, from the SCSIE department, electronic microscopy section of the University of Valencia. Samples were mounted on aluminium stubs with a carbon double-sided tape, and were sputter-coated with a 100–200 Å thick layer of gold and palladium by an Ion Sputter (Bio-Rad SC-500), and were examined at an accelerating voltage of 5 KV. Seed micrographs at two different magnifications, x1500 and x6000, were used to determine the seed coat morphological features of the species.
Batches of 50 seeds from each population were used for all measures and means and standard deviations were calculated for each measured character. A logarithmic transformation of data and a Levene's test for homogeneity of variances was carried out in order to apply a one way Anova and Tukey test to determine homogeneous groups ($p<0.05$) using SPSS 15.0.

Results and discussion

Taxonomic aspects of the genus Halocnemum

For many years the populations of the genus *Halocnemum* Bieb., dominant on some types of the hyperhalophilous vegetation of the Mediterranean region, Eurasia, Mongolia and North Africa (Nilhan et al. 2008) were all attributed to *Halocnemum strobilaceum* species, as reported in phytosociological literature (Wolff 1968; Shaltout et al.1995; Zahran et al. 1990; Géhu et al. 1984 a and b; 1986, 1992 b and c; Géhu & Géhu-Franck 1991; Rivas-Martínez 1984; Biondi 1992, 1999; Oberdorfer 1952; Brullo & Furnari 1981, 1988; Barbagallo et al. 1990).
In fact, some time ago some researchers (Forskal 1775; Todaro 1873; Lojacono-Pojero 1904; Yaprak & Kadereit 2008; Perez-Lahiguera et al. 2009) recognized and described different species and subspecies on samples collected in the Mediterranean coasts, whose size is remarkably higher, more similar to a shrub.
Now, these entities are referred to *Halocnemum cruciatum* (Forssk.) Tod. species (syn.: *Halocnemum drepanensis* Lojacono, *Salicornia drepanensis* Tin., *Salicornia cruciata* Forssk., *Halocnemum strobilaceum* var. *cruciatum* Moq., *Halocnemum yurdakuloii* Yaprak & Kadereit) (Bacchetta et al. 2012).

The *holotypus* of this species is stored at the Swedish Museum of Natural History Department of Phanerogamic Botany (S), S04-1004. Collected by Forsskål, P., s.n. in the date 1761/10, in the Alexandria, Egypt (http://plants.jstor.org/specimen/s04-1004).
In the Mediterranean basin, *Halocnemum cruciatum* looks like as a proper shrub. It is high up to 1.5 m and it is clearly higher than *Halocnemum strobilaceum* (Pall.) M. Bieb. which, on the contrary, is a little shrub high up to 60 cm high with a more or less prostrate habit, see Flora of China and Flora of Pakistan (eFloras 2008). The species, mainly found in the Eurasiatic region, has been described on samples collected on the coasts of the Caspian Sea.
The main morphological and structural characteristics of the two species of *Halocnemum* suggest that they can be identified as "nano-phanerophytic morphotype" in the case of *H. cruciatum* and "chamaephytic morphotype" in the case of *H. strobilaceum* (Corbetta 1976; Géhu et al. 1984c; Andreucci et al. 1999; Biondi & Casavecchia 2010).
According to a recent taxonomic research carried out by Bacchetta et al. (2012), the Mediterranean populations of *Halocnemum* should be attributed to the species *Halocnemum cruciatum*. Actually, we do not agree with this attribution as we think that the populations of thyrrhenian coasts and North Adriatic coasts belong to *Halocnemum strobilaceum*. In fact, entities occurring in the Italian localities of northern Adriatic and Tuscany are small in size, so similar to *Halocnemum strobilaceum* while entities of Sardinia, Sicily and other Mediterranean localities and North Africa are large in size and therefore correspond to *Halocnemum cruciatum*.
Actually, in Italy the plant seems to have two different morpho-ecotypes, a nanophanerophytic morphotype up to 1-1,5 m (thermomediterranean morphotype) and a much shorter chamaephytic morphotype, 40 cm high at most (mesomediterranean and submediterranean morphotype). The chamaephytic morphotype was observed in Tuscany at the mouth of River Ombrone and the Palude della Trappola in Maremma (Arrigoni et al. 1985) and in the North Adriatic at the mouth of River Reno (in the State Nature Reserve of Bellocchio) and at Valli di Comacchio (Corbetta 1976; Piccoli et al. 1999a and b).
On the contrary, the "nanophanerophytic morphotype" occurs in some ponds near Cagliari and in south-western Sicily (Trapani).
The two localities in peninsular Italy are in the area of transition between the Temperate and the Mediterranean macrobioclimate, rather in the sub-Mediterranean variant of the Temperate macrobioclimate. Indeed, the phenotype of smaller size occurs in ecological and bioclimatic conditions more similar to those of continental Europe, and therefore we believe that it is *H. strobilaceum*. Even the *Halocnemum* populations of the Balkan Peninsula of the island of Corfu (Biondi 1992) and of continental Greece as it can be seen in the original photograph published by Oberdorfer (1952) belong to the species *H. strobilaceum*.
At least for the Italian populations of *Halocnemum*, the genetic studies support this interpretation. In fact, the genetic analyses carried out by Papini et al. (2004) on samples of *Halocnemum* from the north Adriatic and from the pools of Cagliari has allowed the recognition of as many as 17 transitions and 9 transversions, which supports the existence of two subspecies.

Seed characterization
Significant differences were found in seed morphological characterization between studied populations. Macroscopically, seeds of this species show an elliptic to obovate outline, a smooth and slightly translucent reddish brown surface.

As regards seed size comparison, we observed that the largest seeds are those collected in Egypt, while seeds from El Hondo are the smallest; the Italian populations show intermediate dimensions. Seed weight is correlated with size, so seeds from Sharm el Sheik are the heaviest, whilst seeds from El Hondo are the lightest. Mean values of seed proportions and weight are listed in Table 1.

We agree with Khan et al. (2012) who indicated that seed weight and dimensions are complex traits deriving from of the interaction between the genetic control and the environmental conditions. In the case of the genus *Halocnemum*, no significant correlations were found between seed size or seed weight and the taxonomic differences separating the species in the studied area. By contrast, these seed features seem to be directly related with some ecological factors, as the soil texture and the duration of the dry period in the different sites of growth.

Seed coat under SEM examination, in the case of the genus *Halocnemum*, presents a micro-ornamentation with relevant differences between the studied species. All studied seeds show a characteristic papillate primary sculpture in their surface, with papillose cells aligned along the dorsal side in a more or less wide area over the seed outer edge, above the radicle of the embryo. In this ornamented zone of the seed coat, the outline of cells is irregularly polygonal with straight anticlinal walls, delimiting more or less isodiametric cells. The outer periclinal wall of the cell is convex, showing a patent papilla.

Differences between species were observed mainly in relation with the presence/absence of secondary sculpture, as well as in the size of the papillae (Figures 1 and 2).

Seeds from *Halocnemum strobilaceum* (populations from Ravenna and Tuscany) show a smaller size of the papillae, which present a double-structured ornamentation with an irregular granular-rugulose surface, while the papillae of the species *Halocnemum cruciatum* (populations from El Hondo, Cagliari, Trapani and Sharm el Sheik) are larger and have a smooth surface, without a patent secondary sculpture.

The seed coat features have been traditionally recognized as an important tool in taxonomic surveys for distinguishing different taxa at the species level and also to establish phylogenetic patterns (Bittrich 1993; Prasad & Singh 1978). According to this, Barthlott (1981) appointed the scanning electron microscopy examination as a valuable technique to identify seed micromorphological differences. This method was also applied successfully in other taxonomic studies within the *Chenopodicaceae* family (Alonso & Crespo 2008; Beer & Demina 2005; Gul et al. 1999; Sukhorukov & Zhang 2013).

In this sense, the observed differences in the secondary sculpture seem to be relevant to discern the two species of *Halocnemum*, in addition to the other macroscopic morphological characteristics.

Distribution of the genus Halocnemum

Halocnemum strobilaceum (Pall.) M. Bieb. (the "chamaephytic morphotype") occurs in eastern Europe, from Italy and Greece to Ukraine and more eastern in Anatolia, Caucasus, Iran, Iraq, Afghanistan, Pakistan, Arabia, China, Mongolia, Siberia and Kazakhstan.

Halocnemum cruciatum (Forssk.) Tod. occurs along the coasts of the Mediterranean Basin: Southern Spain, Southern Italy (Sicily and Sardinia), Algeria, Tunisia, Egypt and Libya (Cyrenaica). It also occurs in the Sinai Peninsula and in Morocco in the inner salt basin of Sahara and in the inner basins of the Saharo-Iranian area.

The different distribution of the two species has to be mostly related to the macrobioclimatic characteristics of the different coastal areas of the Mediterranean Basin. The northernmost European populations of *H. strobilaceum* in the Mediterranean Basin are in the Tyrrhenian part of the Italian peninsula, in the transitional zone between the Mediterranean and the Temperate macrobioclimate. The populations of the North Adriatic are found in the same conditions. The easternmost European populations are present in the Ionian and Aegean part of Greece; they are linked to the populations of northern Turkey (Sea of Marmara, Géhu & Uslu 1989).
Throughout the whole distribution area, and according to the bioclimatic classification of Rivas-Martínez (2008), most of the populations of the *Halocnemum* species are spread over areas with Mediterranean macrobioclimate, with a very low level of precipitation, from Inframediterranean to Mesomediterranean thermotypes, and from dry to arid ombrotypes. (Figure 3). The only exception is the population of Ravenna (Italy), the northernmost among the studied populations, characterized by a Temperate macrobioclimate (Fig. 2). H. cruciatum has its maximum distribution in the Central-Eastern sector of African coast; it spreads from Tunisia to Sinai coasts and in those of the South of Turkey and Cyprus. In areas with thermo-mediterranean thermotype, arid to hyperarid ombrotype (Mediterranean macrobioclimate)

Distribution of morphotypes in the Mediterranean Basin
H. cruciatum is found along Mediterranean coasts of Europe and rarely also in more inland areas such as in the southern coasts of the Iberian Peninsula. Conversely, both morphotypes are present in Italy and Greece. The nanophanerophytic one is found in South Sardinia (Santa Gilla and Molentargius, near Cagliari) and in West Sicily (Saline di Trapani). In Greece, the majority of the populations belong to this morphotype occurring along the coasts. In the Aegean islands all the populations belongs to this morphotype, because of their bioclimate. The same occurs in Cyprus and in most of the coastal populations of Turkey.
Populations from Middle-East and from North African coasts belong to the nanophanerophytic morphotype.
The "chamaephytic morphotype" was observed in the North Adriatic coast at the mouth of River Reno (in the State Nature Reserve of Bellocchio) and at Valli di Comacchio (Corbetta 1976; Merloni 2007) and in the Tyrrhenian coast of Tuscany at the mouth of River Ombrone in the Palude della Trappola (Arrigoni et al. 1985). In the Eastern part of the Ionian coasts it is present in Corfù (Biondi 1992) and along Aegean coasts (Oberdorfer 1952; Géhu et al. 1986).

Halocnemum vegetation in the Mediterranean Basin
The hyperhalophilous woody or semi-woody vegetation, mainly occupies extended areas in the northern hemisphere in the inland salt basins, both in the Eurasian and in Saharo-Arabic area.
For the inland Irano-Anatolian vegetation, the *Halocnemetea strobilacei irano-anatolica* class has been proposed by Zohary (1973), whereas the class *Kalidietea foliatae* Rukhlenko 2013 has recently been proposed for Eurasia, elevating the *Kalidienea foliatae* Golub et al. 2001 subclass (Rukhlenko & Sorokin 2013).
In the Mediterranean Basin, this vegetation is mainly restricted to the coast areas and it shows a remarkably reduced flora which is linked only with a few species. The main typologies of hyperhalophilous vegetation along the Mediterranean coasts occur in the area between Tunisia, Libya, Egypt and Sinai; while it is scarce along the European

coasts, because of the strong impoverishment due to anthropic actions. Reviewing the phytosociological literature it is possible to find different syntaxonomic interpretations.
Halocnemum strobilaceum makes up thick communities poor in species. The most widespread community is the association *Arthrocnemo glauci-Halocnemetum strobilacei* that was described by Oberdorfer (1952) for North-Aegean coasts. As the author wrote, this community found at the Delta of River Vardar and along the Thracian coasts, has a huge distribution in all the north-Aegean coasts and in the Black See coasts. Other phytosociologists found the same association along the north-African coasts such as in Tunisia (Barbagallo et al. 1990; Géhu & Géhu-Franck 1991), in Cyrenaica (Brullo & Furnari 1988), in the Island of Cyprus (Géhu et al. 1984a) in continental Greece (Géhu et al.1986), in Turkey along the Mediterranean coast (Géhu et al.1992c) in Sicily (Brullo & Di Martino 1974; Brullo & Furnari 1976), in Sardinia (De Marco 1980; Mossa & Biondi 1992), in the Island of Corfù (Biondi 1992), in North-Adriatic coasts (Corbetta 1976; Géhu et al. 1982; Andreucci et al. 1999; Biondi & Casavecchia 2010) and in Tuscany, (sub. *Halocnemetum strobilacei* (Keller) E. Topa 1938 (Arrigoni et al. 1985)).
According to the taxonomic revision of *Halocnemum strobilaceum* discussed above, it is necessary to better define the distribution range of this association and to describe a new community, grouping together the phytocoenoses dominated by *H. cruciatum* but previously attributed to the *Arthrocnemo glauci-Halocnemetum strobilacei*.
Thus, the association *Arthocnemo glauci-Halocnemetum strobilacei* Oberdorfer 1952 has an eastern-Mediterranean distribution occurring in peninsular Italy, in Greece (in the Island of Corfù and along the Peloponnesian coast and the Aegean coasts) and in Northern Turkey coast. Probably, it is also represented in Albania, in Bulgaria and Romania along the Black Sea coasts, where the species is present.
The new association whose name is *Arthrocnemo macrostachyi-Halocnemetum cruciati* (*holotypus*: rel. 5 of Tab. 8 in Géhu, Costa, Biondi, Peris & Arnold 1984) has a central-southern Mediterranean distribution occurring in Cyprus, Sicily, Sardinia, Tunisia, Libya and probably in Algeria where the species occurs.
The *Halocnemum strobilaceum* vegetation of Tuscany (Palude della Trappola), as indicated above, has been attributed by Arrigoni et al. (1985) to the association *Halocnemetum strobilacei* (Keller) E. Topa 1938, defined by Keller (1928) in Turkistan for the first time. Later, Topa (1939) found the same association in Romania and Wendelberger (1950), around the Neusiedler Lake. This association, occurring in Central Anatolia, was attributed to the *Halostachyetalia* order by Topa (1939). The association is characterized by different species not present in the phytosociological table published by Arrigoni et al. (1985). And thus, the vegetation of Tuscany should be attributed to the association *Arthrocnemo glauci-Halocnemetum strobilacei*.
For the Southern Spanish Mediterranean coast, the association *Frankenio corymbosae-Halocnemetum strobilacei* has been described (Rivas-Martínez et al. 1984). The association is endemic of Southeast of the Iberian Peninsula. Also in this case, it is necessary to correct the name of the association and, according to Art. 43 of the ICPN (Weber et al. 2000), the new name of the association is *Frankenio corymbosae-Halocnemetum cruciat*i Rivas-Martínez, Alcaraz, Belmonte, Cantó & Sánchez-Mata 1984 *corr. hoc. loco.*
For the more humid or flooded conditions a new association is proposed, *Halocnemo cruciati-Sarcocornietum fruticosae Holotypus*: Rel. 5, Tab. 6 in Mossa & Biondi (1992). This new association is distributed in areas where *Sarcocornia fruticosa* is the dominant species, sometimes coinciding with the association *Arthrocnemo glauci-Halocnemetum strobilacei*, which stands always the drier areas.

Along the Mediterranean coasts of Egypt and in the Sinai Peninsula, the association *Zygophyllo albi-Halocnemetum strobilacei* Géhu, Arnold, Géhu-Franck et Apostolides 1992 was described (Géhu et al. 1992a). According to the ICPN rules, the association is invalid (Art. 3f.). Furthermore, it deals with *Halocnemum cruciatum* and not *H. strobilaceum*. Indeed, we here describe the new association *Zygophyllo albi-Halocnemetum cruciati* Géhu et al. ex Biondi et al. ass. nova *hoc. loco* [= *Zygophyllo albi-Halocnemetum strobilacei* Géhu, Arnold, Géhu-Franck et Apostolides 1992 nom.inv. art. 3f] whose *holotypus* is rel. 10 of Tab. 15 in Géhu et al. 1992. We also observed the same community in the "Ras Mohamed National Park" near Sharm El Sheikh (Egypt), along the coast of the Red Sea.
The distribution area of this vegetation with the two species of *Halocnemum* in the Mediterranean basin is showed in Figure 4.

Syntaxonomical scheme of hyperhalophilous woody and semi-woody vegetation in the Mediterranean Basin

SARCOCORNIETEA FRUTICOSAE Br.-Bl. & Tüxen ex A. & O. Bolòs 1950 *em. hoc loco*
[*Salicornietea fruticosae* Br.-Bl. & Tüxen 1943 (art. 8), *Salicornietea fruticosae* Br.-Bl. & Tüxen ex A. & O. Bolòs 1950 (art. 45), *Arthrocnemetea* Br.-Bl. & Tüxen 1943 *corr.* Bolos 1957, *Salicornietea fruticosae* Br.-Bl. ex Tüxen & Oberdorfer 1958 (art. 8), *Sarcocornietea fruticosae* Braun-Blanq. & Tüxen ex A.Bolòs & O.Bolòs in A.Bolòs 1950 *nom. mut. propos*. Rivas-Martínez, T.E. Díaz, Fernandez-González, Izco, Loidi, Lousã & Penas 2002]
Pioneer, perennial, hyperhalophilous, succulent, woody and semi-woody vegetation mainly spread in the salt basins of the Mediterranean and thermo-Atlantic coasts also represented into the Sinai Peninsula.

SARCOCORNIETALIA FRUTICOSAE Braun-Blanq. 1933 *nom. mut. propos*. Rivas-Martínez, T.E. Díaz, Fernandez-González, Izco, Loidi, Lousã & Penas 2002
[*Salicornietalia* Braun-Blanq. 1931 *nom. nud.* (art. 2b, 8), *Salicornietalia* Braun-Blanq. 1933, *Salicornietalia fruticosae* (Braun-Blanq. 1933) Tüxen & Oberd. 1958 *nom. illeg.* (art. 22, 29), *Arthrocnemetalia fruticosi* (Braun-Blanq. 1933) O.Bolòs 1967 *nom. illeg.* (art. 22, 29, 30)]
Perennial, succulent, halophilous to hyperhalophilous order mainly spread in the Mediterranean basin.

HALOCNEMETALIA CRUCIATI ord. novo *hoc loco*
[*Halocnemetalia strobilacei nom. nud.* (art. 2b, 8; in Asri & Ghorbanli 1997)]
Woody and semi-woody, succulent, hyperhalophilous order spread along the Mediterranean coasts, reaching also the Middle East and, marginally, the Eurasian inlands.
Holotypus: *Halocnemion cruciati* all. nova
Characteristic species: *Halocnemum cruciatum*, *Halocnemum strobilaceum.*

Halocnemion cruciati all. nova *hoc loco*
[*Halocnemenion strobilacei* Géhu & Costa in Géhu, Costa, Biondi, Peris & Arnold 1984 p.p. (syn. syntax), *Zygophyllo-Arthrocnemion macrostrachyae* Géhu, Arnold, Géhu-Franck & Apostolides 1992 *nom. nud*. (art. 2b, 8)]

Halocnemum cruciatum communities of European and African Mediterranean littoral distribution, including the Middle East with penetrations in the Sinai Peninsula and growing on Mediterranean, arid to hyperarid.
Holotypus: *Zygophyllo albi-Halocnemetum cruciati* Géhu et al. ex Biondi et al. ass. nova
Characteristic species: *Zygophyllum album*, *Halocnemum cruciatum*, *Suaeda pruinosa*, *Frankenia corymbosa*.

Zygophyllo albi-Halocnemetum cruciati Géhu et al. ex Biondi et al. ass. nova *hoc loco*
[*Zygophyllo albi-Halocnemetum strobilacei* Géhu, Arnold, Géhu-Franck & Apostolides 1992 *nom. inval.* (art 3f)]
Association proposed for the Mediterranean coast of Egypt and the Sinai Peninsula.
Holotypus: Rel. 10, Tab. 15 in Géhu, Arnold, Géhu-Franck & Apostolides (1992).
Characteristic species: *Halocnemum cruciatum*, *Zygophyllum album*, *Arthrocnemum macrostachyum.*

Other associations belonging to the alliance:

Frankenio corymbosae-Halocnemetum cruciati Rivas-Martínez, Alcaraz, Belmonte, Cantó & Sánchez-Mata 1984 *corr*. *hoc loco*
This association was described for the Mediterranean Spanish coast.

Arthrocnemo macrostachyi-Halocnemetum cruciati ass. nova *hoc loco*
[*Halocnemetum* Pignatti 1952 non Topa 1939, *Halocnemetum* Tadros 1953 non Topa 1939, *Halocnemo-Parapholidetum incurvae* Brullo & Di Martino 1974, *Halocnemo-Parapholidetum filiformis* De Marco, Dinelli & Mossa 1980 (syntax. syn.)]
European (Sardinia, Sicily, Cyprus and Turkey) and North-African (from Tunisia to Cyrenaic) Central-Eastern Mediterranean coasts association.
Holotypus: Rel. 5, Tab. 8 in Géhu, Costa, Biondi, Peris & Arnold (1984). Relevé from the coasts of Cyprus.
Characteristic species: *Halocnemum cruciatum*, *Arthrocnemum macrostachyum*.

Zygophyllo albi-Arthrocnemetum macrostachyi ass. nova *hoc loco*
[*Zygophyllo albi-Arthrocnemetum macrostachyi* Géhu & Géhu-Franck 1991 *nom. nud.* (art. 2b, 8)]
Most elevated dune slack plant communities where salinity is lower than areas characterized by the presence of the *Zygophyllo albi-Halocnemetum strobilacei* association.
Holotypus: Rel. 6, Tab. 14 in Géhu, Arnold, Géhu-Franck & Apostolides (1992).
Characteristic species: *Zygophyllum album*, *Arthrocnemum macrostachyum*.

Halocnemo cruciati-Sarcocornietum fruticosae ass. nova *hoc loco*
More wet or inundated system plant communities, occurring in the ecological succession leading to the spread of the *Sarcocornietalia fruticosae* communities.
Holotypus: Rel. 5, Tab. 6 in Mossa & Biondi (1992).
Characteristic species: *Sarcocornia fruticosa*, Halocnemenion *cruciatum*.

Halocnemenion strobilacei all. nova *hoc loco*
[*Halocnemenion strobilacei* Géhu & Costa in Géhu, Costa, Biondi, Peris & Arnold 1984 p.p. (syntax. syn.)]

Halocnemum strobilaceum communities occurring along European coasts of the Mediterranean basin and growing on Temperate sub-mediterranean macrobioclimate or Mesomediterranean thermotype of Mediterranean macrobioclimate.
Holotypus: *Arthrocnemo glauci-Halocnemetum strobilacei* Oberdorfer 1952
This association describes the communities occurring along the Aegean coasts, the Adriatic (Sacca di Bellocchio and Valli di Comacchio) and the Tyrrhenian coasts (Focce Ombrone) of the Italian Peninsula. The association grows also on the Corfù island (Greece) and along the Peloponnesian, Aegean and Northern Turkey coasts.
Characteristic species: *Halocnemum strobilaceum*, *Arthrocnemum macrostachyum*, *Limonium narbonense*.

Limoniastrion monopetali Pignatti 1953
Shrubby communities dominated by *Limoniastrum monopetalum* occurring in the driest areas of the coastal salt marshes of the Mediterranean area: North Africa, Iberian Peninsula, southern Italy, western Sicily, Lampedusa, Sardinia and Crete. This alliance was previously integrated in the order *Limonetalia* Br.-Bl. & O. Bolòs 1958

Conclusions

On the basis of what here reported, the presence of *Halocenemum strobilaceum* and *H. cruciatum* in the Mediterranean Basin is demonstrated, since the two species differ for evident morphological features, also including seed coat structure, and for as much evident genomic characters.
SEM is proving to be an especially suitable tool for studying seed surfaces. It helps to detect the minute differences in seed coat patterns. The observed differences in the secondary sculpture seem to be significant to discern the two species of *Halocnemum*, in addition to the other macroscopic morphological characteristics.
The two species result in different types of vegetation, *Frankenio corymbosae-Halocemetum cruciati*; *Zygophyllo albi-Halocnemetum cruciati, Arthrocenemo macrostachyi-Halocnemetum cruciati, Halocnemo cruciati-Sarcocornietum fruticosae* and *Arthrocnemo glauci-Halocnemetum strobilacei.*
The distribution area of these communities is reported in the presented distribution map. This kind of maps results very useful for the identification of the areas in which this vegetation must be conveniently protected. In this regard, it is necessary to notice that this vegetation is extremely rare and threatened. In the European Community its conservation is very important and urgent because of the fast alteration of the EU coastal areas. Thus, we suggest including habitat 1420 in the list of priority habitats.
Undoubtedly, the conservation of the biodiversity of the arid and salt areas of the North Africa is also very important as Kawada *et al*. (2012) showed in the studies on several semi-arid areas of Tunisia. In these areas, biodiversity varies enormously but is generally lower compared to other semi-arid environments such as those of Eurasian region. This behavior is due to a minor adaptation capability to environmental change of this kind of vegetation. The cause of biodiversity loss in African semi-arid environments is the wrong management which favors desertification.

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Localities	Weight (mg)	Length (mm)	Width (mm)	L/W ratio
El Hondo (Spain)	0,09±0,02d	0,81±0,06d	0,58±0,05d	1,43±0,17d
Cagliari (Italy)	0,13±0,04c	0,89±0,06c	0,66±0,08c	1,36±0,13bcd
Tuscany (Italy)	0,15±0,02bc	0,95±0,07a	0,72±0,05b	1,33±0,12abc
Ravenna (Italy)	0,11±0,02d	0,90±0,05bc	0,65±0,05c	1,40±0,14cd
Trapani (Italy)	0,17±0,04b	0,92±0,08abc	0,71±0,08b	1,30±0,16ab
Sharm el Sheik (Egypt)	0,24±0,06a	0,95±0,10ab	0,76±0,09a	1,26±0,17a

Table 1. Mean values of seed proportions and weight of *Halocnemum* studied populations. The same letters indicate statistically homogeneous groups ($P<0.05$).

Figure 1. Cell surfaces SEM micrographs of *Halocnemum strobilaceum* in the studied populations: 1. Ravenna, Riserva Naturale Sacca di Bellocchio, 2. Tuscany, Principina a Mare, Parco Naturale della Maremma. (a) x1500 (b) x6000.

Figure 2. Cell surfaces SEM micrographs of *Halocnemum cruciatum* in the studied populations: 1. Crevillente, Parque Natural El Hondo, Spain, 2. Santa Gilla, Cagliari, Sardinia, Italy, 3. Sicily, Saline di Trapani, Italy and 4. Ras Mohammad National Park, Southern extreme of the Sinai Peninsula, Sharm el Sheikh, Egypt. (a) x1500 (b) x6000.

Figure 3. Climate diagrams of some populations of *Halocnemum* species showing different climatic conditions within their distribution area.

Figure 4. Plant communities with *Halocnemum strobilaceum* and *H. cruciatum*. Distribution in the coast of Mediterranean basin. ▲ *Frankenio corymbosae-Halocnemetum cruciati*; ■ *Arthrocnemo macrostachyi-Halocnemetum cruciati*; ● *Arthrocnemo glauci-Halocnemetum strobilacei*; ∇ *Halocnemo cruciati-Sarcocornietum fruticosae* ◆ *Zygophyllo albi-Halocnemetum cruciati*. Studied populations for seed characterization. 1. Crevillente, Parque Natural El Hondo, Spain, 2. Ravenna, Riserva Naturale Sacca di Bellocchio, 3. Tuscany, Principina a Mare, Parco Naturale della Maremma, 4. Sardinia, Cagliari, Santa Gilla, 5. Sicily, Saline di Trapani, in Italy and 6. Sharm el Sheikh, Ras Mohammad National Park, Southern extreme of the Sinai Peninsula, Egypt.