

Rocky coastal vegetation of the class *Crithmo-Staticetea* in the south-east of Italy

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Abstract – In the south-east of Italy, rocky coasts are almost entirely concentrated in the Apulia region. Several phytosociological papers have already dealt with the rocky coastal vegetation of the class *Crithmo-Staticetea* in some parts of the Apulian coast. However, there is still no overall revision carried out by using modern statistical treatments of phytosociological data. This paper aims to revise the syntaxonomy and nomenclature of the class *Crithmo-Staticetea* in the south-east of Italy. The revision is based on a data set of 225 relevés consisting of new and original phytosociological relevés (66) and others already published. The data matrix was classified with the use of flexible beta clustering. Indicator species analysis was employed to identify the indicator species of the main clusters of relevés. Results were interpreted from a syntaxonomic point of view. Non-metric multidimensional scaling ordination was performed in order to visualize the floristic relationships among associations. Rocky coastal vegetation of the *Crithmo-Staticetea* class in the south-east of Italy is represented by two orders, *Crithmo maritimi-Staticetalia* and *Helichrysetalia italici*. The first one includes two alliances, *Crithmo-Staticion* and *Limonion anfracti-cancellati*, with four associations and one, respectively. However, since they rely on very few character species, the floristic and syntaxonomic relationships between these two alliances need to be deepened by further investigations, involving a larger data set and investigation area. The second order, *Helichrysetalia italici*, includes two associations, well differentiated by their ecology, structure and floristic composition. For this reason, they were classified within two different alliances, *Anthyllidion barbae-jovis* and *Helichryson litorei*. The *Helichryson litorei* is here validated.

Keywords: Adriatic, coastal vegetation, *Helichryson litorei*, limestone coasts, Mediterranean Basin, syntaxonomy, *Crithmo-Staticetea*

Introduction

Coastal environments have an important ecological value, providing ecosystem services essential to people and the environment (e.g. food provision, erosion control, water control, and habitats for many threatened and endangered species) and are worthy of attention and conservation. Coastal areas are one of the most threatened environments, both in the Mediterranean region and worldwide. In fact, especially in the last decades, they are undergoing rapid anthropogenic development. Increasing human pressure (e.g. urbanization, exploitation of natural resources, plant invasion) is causing coastal areas to diminish, in concert with the degradation and isolation of their habitats (Médail and Quézel 1997, Biondi 1999, Gibbs 2000, van der Maarel 2003, Underwood et al. 2009). The need to preserve these habitats was recognized by European policies so that they were included

in Annex I of Directive 92/43/EEC, the ‘habitat directive’. Cliffs and rocky coasts, identified by the habitat type code 1240, ‘Vegetated sea cliffs of the Mediterranean coasts with endemic *Limonium* spp.’, are currently represented within many protected areas along the north Mediterranean Basin.

Vegetation of rocky coasts is composed of a typical flora, with halophilous chasmophytes and comophytes directly exposed to the action of marine aerosol, wind and waves, tolerating a high concentration of sodium chloride in the substrate and large temperature ranges. A large part of this vegetation belongs to the class *Crithmo-Staticetea*, which includes halophytic and halotolerant plant communities structurally formed by hemicryptophytes, chamaephytes and nanophanerophytes (Rivas-Martinez et al. 2002, Fanelli et al. 2004, Biondi et al. 2014). Among the character species, many

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Limonium species play a pivotal role, being represented by numerous endemics with a very restricted distribution area, and often including groups of vicariant species (Dolcher and Pignatti 1971, Diana 1992). Due to the presence of such endemics, most of the associations of the *Crithmo-Staticion* have endemic closely regional distribution. Along the coasts of the Mediterranean Basin, and up to the Black Sea, the class is traditionally represented by only one order (*Crithmo-Staticetalia*), whilst another two have been described for the European Atlantic coasts (*Crithmo-Armerietalia maritima*, habitat code 1230), the Canary Island, the Azores and Morocco (*Frankenio-Astydamietalia*, habitat code 1250). A fourth order, *Helichrysetalia italici*, was described to represent the sub-aerohaline coastal dwarf scrub vegetation on the inland edges of the Mediterranean coasts (Mucina et al. 2016).

The coastline of the Italian Peninsula extends over nearly 8000 km. The Apulia region is characterized by nearly 900 km of coast and represents the region of the Italian peninsula with the longest coastline (Giandonato 2003). Many phytosociological surveys have been carried out along the Apulian coast, on both sandy and rocky shores (e.g., Cristofolini et al. 1967, Curti and Lorenzoni 1968, Corbetta 1970, Caniglia et al. 1984, Géhu et al. 1984, Corbetta et al. 1989, Bartolo et al. 1992, Brullo and De Marco 1989, Mariotti et al. 1992, Beccarisi et al. 2003, Biondi et al. 2006, Corbetta et al. 2006, Biondi and Casavecchia 2010, Tomaselli et al. 2011, Pirone 2014, Sciandrello and Tomaselli 2014). The vegetation of the rocky coasts was classified in several associations of the orders *Crithmo-Staticetalia*, *Helichrysetalia italici* and *Senecionetalia cinerariae*. Since the rocky coasts of the south-east of Italy are almost entirely concentrated in the Apulian region (Biondi, 1999), these associations are representative of the class *Crithmo-Staticetea* in the south-east of Italy.

This paper aims to revise the syntaxonomy and nomenclature of the class *Crithmo-Staticetea* in the south-east of Italy and to establish the floristic, coenological, syntaxonomic and synchorological relationships among its associations. Several phytosociological papers have already dealt with this vegetation type in some parts of the Apulian coast (e.g. Cristofolini et al. 1967, Curti and Lorenzoni 1968, Bartolo et al. 1992, Biondi et al. 2006); however, there is still no overall revision carried out by using modern statistical treatments of phytosociological data. To this end, new original phytosociological data, sampled from the Gargano Promontory to the tip of the Salento Peninsula, and already published data were analysed together. Moreover, since different syntaxonomic schemes of the *Crithmo-Staticetea* have been proposed for this area, the results have been discussed in the light of these different interpretations.

Materials and methods

This revision is based on a data set consisting of 225 relevés from the Apulia region (Fig. 1). Some of these relevés (123) were taken from phytosociological literature (Tab. 1), selecting those that have already been classified in the *Crith-*

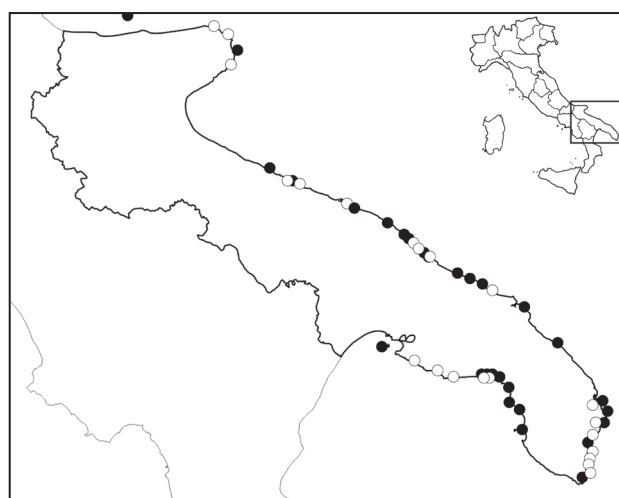


Fig. 1. Map of the study area (Apulia region, south-east of Italy) with indications of the relevés' locations. Empty circles indicate the new relevés; full circles indicate relevés taken from phytosociological literature (see Tab. 1).

mo-Staticetea class. Another 33 relevés published by Biondi et al. (2006) and describing two communities dominated by *Arthrocaulon macrostachyum* (= *Arthrocnemum macrostachyum*), namely '*Arthrocnemum macrostachyum* community' and '*Limonio virgati-Arthrocnemetum macrostachyi*', were added to the data set in order to define the syntaxonomic and floristic relationships with the *Crithmo-Staticetea* class, and clarify the typical zonation of the Apulian rocky coast vegetation. In fact, these communities were originally classified in the *Arthrocnemion glauci* alliance of the class *Salicornietea fruticosae* but show floristic and habitat similarities with vegetation of the *Crithmo-Staticetea* growing in a close catenal relationship. For analogous reasons, we also added to the data set another three relevés assigned to the *Salicornietea fruticosae* by Mariotti et al. (1992). The data set includes also 66 new relevés carried out in rocky coastal habitats, along the distribution area of four Apulian endemic *Limonium* species (Fig. 1, On-line Suppl. Tab. 1). Three of them, *L. apulum*, *L. diomedei* and *L. japygicum*, were frequently recorded in the relevés whereas the fourth, *L. peucetium*, was not found. This latter was originally identified by Pignatti (1982) from old plant material collected in the 19th century along the rocky coast near Bari where, however, it is no longer observed (Wagensommer et al. 2014, Bartolucci et al. 2018).

The new relevés were collected by using the Braun-Blanquet approach (Westhoff and van der Maarel 1980). For each sample, geographical coordinates, slope, exposure, distance from the shoreline, total vegetation cover and plot size, the latter ranging from 10 to 50 m², were detected. Species abundance–dominance values were estimated in the field by using the Braun-Blanquet scale.

Considering the entire set of relevés, the average plot size turned out to be 43.5 m², with a median of 20 m² and minimum and maximum values of 5 and 500 m², respectively.

Tab. 1. Data sources of relevés of the *Crithmo-Staticetea* class and *Limonio-Arthrocnemetum* (*Arthrocnemion glauci*) from Apulia region, south-east of Italy, taken from phytosociological literature and included in the data set. Bibliographic source, number of relevés (No.), and original classification (at association/alliance level) are reported.

Source	No.	Association and alliance as reported in the original paper
Bartolo et al. (1992: tab. 9, rel. 1–6)	6	' <i>Crithmo-Limonietum apuli</i> ', ' <i>Crithmo-Limonion</i> '
Bartolo et al. (1992: tab. 10, rel. 1–9)	9	<i>Limonietum japygici</i> , ' <i>Crithmo-Limonion</i> '
Bartolo et al. (1992: tab. 11, rel. 1–20)	20	<i>Crithmo-Limonietum diomedei</i> , ' <i>Crithmo-Limonion</i> '
Bartolo et al. (1992: tab. 12, rel. 1–8)	8	<i>Limonio virgati-Plantagnetum grovesii</i> , ' <i>Crithmo-Limonion</i> '
Bartolo et al. (1992: tab. 15, rel. 1–16)	16	<i>Agropyro-Helycrisetum italici</i> , ' <i>Plantagini-Thymelaeion hirsutae</i> '
Biondi et al. (2006: tab. 8, rel. 1–18)	18	' <i>Arthrocnemum macrostachyum comm.</i> ', ' <i>Arthrocnemion macrostachyi</i> '
Biondi et al. (2006: tab. 9, rel. 1–11)	11	<i>Limonio virgati-Arthrocnemetum macrostachyi</i> , ' <i>Arthrocnemion macrostachyi</i> '
Biondi et al. (2006: tab. 9, rel. 12–15)	4	<i>Limonio virgati-Arthrocnemetum macrostachyi</i> subass. <i>crithmetosum maritimi</i> , ' <i>Arthrocnemion macrostachyi</i> '
Biondi et al. (2006: tab. 10, rel. 1–7)	7	<i>Limonietum japygici</i> , ' <i>Crithmo-Limonion</i> '
Biondi et al. (2006: tab. 11, rel. 1–3)	3	<i>Limonietum japygici</i> subass. <i>capparidetosum spinosae</i> , ' <i>Crithmo-Limonion</i> '
Biondi et al. (2006: tab. 13, rel. 1–12)	12	<i>Crithmo maritimi-Inuletum crithmoidis</i> , ' <i>Crithmo-Limonion</i> '
Brullo and De Marco (1989: tab. 3, rel. 34–42)	9	<i>Anthyllido-Centaureetum diomedeeae</i> , ' <i>Anthyllidion barbae-jovis</i> '
Caniglia et al. (1984: tab. 16, rel. 1–9)	9	' <i>Limonietum japygici</i> subass. a <i>Salicornia</i> e <i>Inula</i> ', ' <i>Crithmo-Staticion</i> s.l.'
Cristofolini et al. (1967: tab. 1, rel. 1–6)	6	' <i>Crithmo-Staticetalia</i> '
Curti and Lorenzoni (1968: tab. 2, rel. 6–9)	4	<i>Limonietum japygici typicum</i> , ' <i>Crithmo-Staticion</i> '
Curti and Lorenzoni (1968: tab. 2, rel. 10–17)	8	' <i>Limonietum japygici</i> subass. a <i>Salicornia fruticosa</i> e <i>Inula crithmoides</i> ', ' <i>Crithmo-Staticion</i> '
Mariotti et al. (1992: tab. 5, rel. 29–31)	3	'Aggr. a <i>Limonium virgatum</i> e <i>Sarcocornia fruticosa</i> ', ' <i>Limonion galloprovincialis</i> '
Mariotti et al. (1992: tab. 10, rel. 53–54)	2	' <i>Frankenio laevis-Limonietum cancellati</i> ', ' <i>Crithmo-Limonion</i> '
Mariotti et al. (1992: tab. 10, rel. 55–58)	4	' <i>Frankenio laevis-Limonietum cancellati</i> ' subass. <i>sarcocornietosum fruticosae</i> ', ' <i>Crithmo-Limonion</i> '

Relevés sampled on extremely large (> 100 m²) and extremely small (<10 m²) plots were excluded from the data analysis, since they could have affected the results of statistical analyses (see Otýpková and Chytrý 2006). Taxa recorded only at the genus level as well as lichens and bryophytes were omitted from the data set. Taxon scores originally recorded according to the Braun-Blanquet scale, were replaced with the ordinal scale as proposed by van der Maarel (1979). The resulting data matrix consisted of 205 relevés sharing 115 taxa.

Relevés were hierarchically clustered by using flexible beta linkage, with the Bray-Curtis coefficient. Beta was set at -0.25 so that flexible beta clustering became a space-conserving method (McCune and Grace 2002). The dendrogram was pruned at the level yielding the highest number of indicator species (IndSp). To this end, indicator species analysis (ISA, Dufrêne and Legendre 1997) was run for the first 20 partitioning levels of the resulting dendrogram, further divisions dealing with minor variations. A taxon was considered as the IndSp of a cluster for a given partition if its indicator value (IndVal, Dufrêne and Legendre 1997) turned out to be higher for that cluster than for the others of the same partition. The statistical significance ($p < 0.01$) of IndVal was assessed by means of a Monte Carlo test with 10000 permutations.

In order to enhance the interpretability of the results, each IndSp was assigned to only one cluster of relevés along the hierarchical descending typologies of the dendrogram, that is to the cluster for which the IndVal of that taxon first reached its maximum value (Dufrêne and Legendre 1997,

see also Terzi 2015). Two taxa yielded the highest value for the first trivial partition with all the relevés in one cluster (Fig. 2, cluster C1), and they were considered as diagnostic for the *Crithmo-Staticetea* class.

The clusters of relevés were interpreted from a syntaxonomical viewpoint, on the basis of the occurrence of nomenclatural type-relevés within each of them. Diagnostic species of syntaxa were selected from the IndSp of the relevant cluster or of its subdivisions.

The relevés were also ordinated by means of nonmetric multi-dimensional scaling (NMDS), using the Bray-Curtis coefficient as a dissimilarity measure. The whole of the statistical analysis described above was carried out by using PC-Ord software, version 6.22 (McCune and Mefford, 2011). For NMDS, the 'slow and thorough' option of the auto-pilot mode provided in PC-Ord was used.

Taxonomic nomenclature follows Bartolucci et al. (2018), except for *Plantago holosteum* Scop. subsp. *grovesii* (Beg.) Brullo. In fact, the taxonomic status of this taxon is controversial and requires further in-depth studies, being considered as a species by Conti et al. (2005, '*Plantago grovesii*'), as a subspecies of *Plantago holosteum* by Brullo (1988) and as a synonym of *Plantago subulata* by Hassemmer et al. (2017).

Syntaxonomic nomenclature follows Mucina et al. (2016), except where indicated. The nomenclatural decisions were taken according to the 3rd edition of the International Code of Phytosociological Nomenclature (ICPN, Weber et al. 2000), whose articles (art) are cited within brackets.

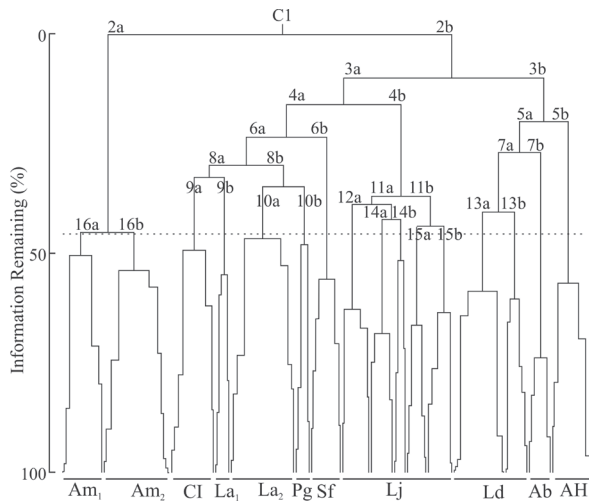


Fig. 2. Flexible beta clustering of relevés of the *Crithmo-Staticetea* class and *Limonio-Arthrocnemum* (*Arthrocnemum glauci*) from Apulia region, south-east of Italy. Each cluster of the first 16 partitions of the dendrogram, is identified by a two digit code: the number refers to the partitioning level, while the letters ('a' or 'b') identify the two clusters originating at that partition. The first trivial partition, with all the relevés in only one group, is indicated as 'C1'. Ab - *Anthyllido barbae-jovis-Centaureetum diomedea*; AH - *Agropyro pungentis-Helichrysetum italicum*; Am_{1/2} - *Limonio virgati-Arthrocnemum macrostachyum*; CI: *Crithmo maritimi-Inuletum crithmoides*; La_{1/2} - *Crithmo maritimi-Limonietum apuli*; Ld: *Crithmo maritimi-Limonietum diomedei*; Lj - *Limonietum japygicum*; Pg - *Limonio virgati-Plantaginetum grovesii*; Sf - relevés with *Salicornia fruticosa*.

Results

The dendrogram was pruned to give 16 clusters of relevés (Fig. 2). Few clusters turned out to be clearly differentiated from the others by having a high number of IndSp (e.g., clusters 5b, 7b); most have no or few IndSp (Fig. 3). Therefore, only 9 out of these 16 clusters can be considered as representative of associations, the others representing only minor variations without syntaxonomic relevance. Cluster 2a includes the relevés dominated by *Arthrocaulon macrostachyum*. Further subdivision of this cluster does not show a clear distinction between the '*Arthrocnemum macrostachyum* community' and '*Limonio virgate-Arthrocnemum macrostachyum*', the relevés of these two community types being mixed together in clusters 16a and 16b. The relevés of these clusters are characterized by very low species richness (1-6 taxa for relevés), with four IndSp: *Arthrocaulon macrostachyum*, *Halimione portulacoides*, *Limonium narbonense* and *Juncus maritimus* (Fig. 3).

The relevés with *Limonium apulum* are grouped in clusters 9b and 10a. Few IndSp characterize these clusters and, with the exception of *L. apulum*, all of them have a low IndVal and are usually considered diagnostic for other vegetation types (e.g., *Suaeda vera* for the salt-marsh shrub vegetation of the *Salicornietea fruticosae*, *Parapholis incurva* for the therophytic vegetation of the *Saginetea maritimae*). Cluster 9a has no IndSp and includes relevés dominated by *Limbarda crithmoides* subsp. *longifolia* and without *Limonium apulum*.

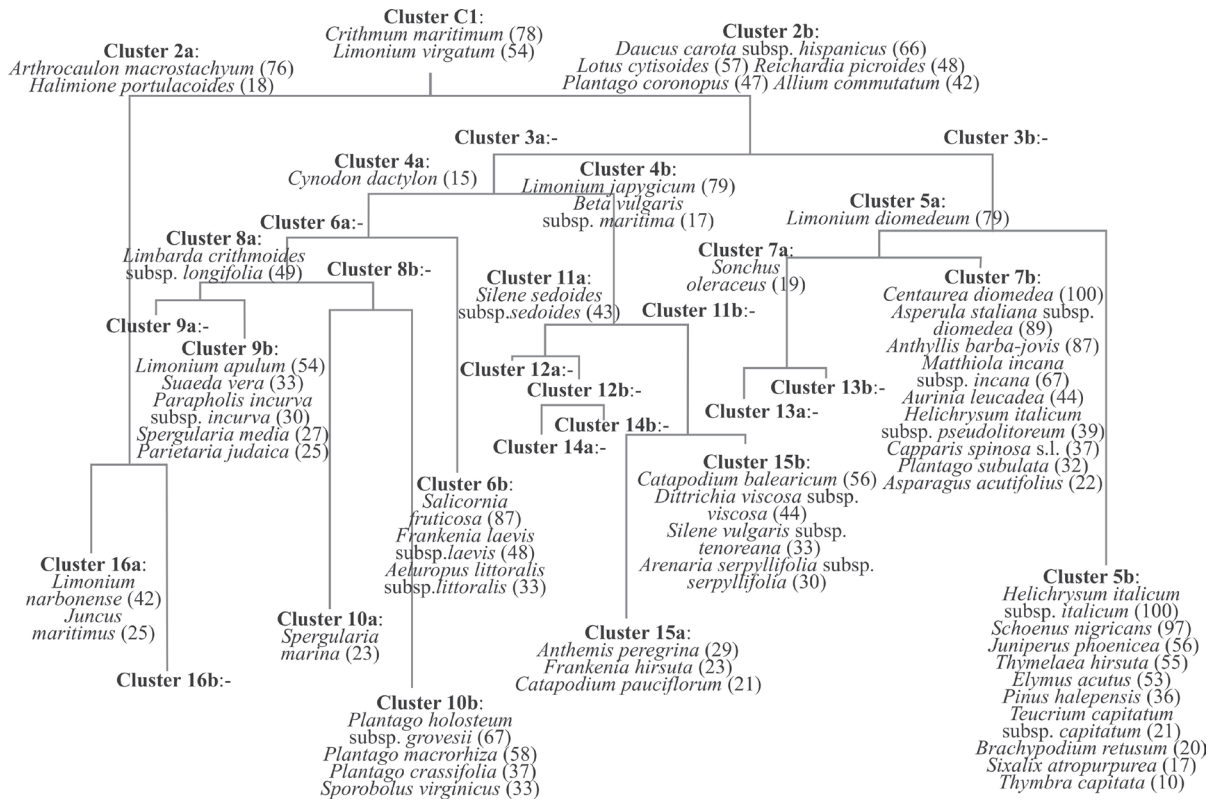


Fig. 3. Results of the indicator species analysis, according to Dufrêne and Legendre (1997), for the first 16 partitioning levels of the dendrogram (see Fig. 2). Indicator species associated to each cluster are reported together with the corresponding indicator values (within brackets). Each cluster of the dendrogram is identified by a two digit code: the number refers to the partitioning level, while the letters ('a' or 'b') identify the two clusters originating at that partition. The first trivial partition, with all the relevés in only one group, is indicated as 'C1'.

This cluster represents the *Crithmo-Inuletum*. Cluster 10b includes the relevés of the *Limonio-Plantaginetum grovesii* that is a typical aspect of coastal vegetation, developing in a restricted area on marls near Otranto. This cluster is characterized by several IndSp, such as *Plantago holosteum* subsp. *grovesii*, *Pl. macrorhiza* and *Pl. crassifolia*.

Cluster 4b and its subdivisions represent the *Limonietum japygici*. Few IndSp are associated with these clusters and they do not support the identification of more than one sub-association, the typical one. A second subassociation is represented by cluster 6b, which includes relevés already classified in the subassociation 'a *Salicornia e Inula*' by Curti and Lorenzoni (1968) and Caniglia et al. (1984) together with others previously assigned to the '*Frankenio laevis-Limonietum cancellati* subass. *sarcocornietosum fruticosae*' by Mariotti et al. (1992).

The relevés from the Gargano and Tremiti coasts are grouped in cluster 3b. The three main subdivisions of this cluster represent the *Agropyro-Helichrysetum italicum* (cluster 5b), *Anthyllido-Centaureetum diomedea* (7b) and *Crithmo-Limonietum diomedei* (7a), respectively. The first two associations turned out to be differentiated by many IndSp, some of them having a high IndVal (Fig. 3). The *Crithmo-Limonietum diomedei* (7a) is recognizable for the occurrence of the sole *Limonium diomedei*, and its two sub clusters (13a and 13b) are not associated to any IndSp.

The NMDS ordination resulted in a three-axis solution, with a final stress of 14.7. The three axes accounted for 71.3% of the variance in the Bray–Curtis dissimilarity matrix (first axis 47.8%, second axis 11.7% and third axis 11.9%). In the NMDS diagram (Fig. 4), axis 1 clearly separates the commu-

nities dominated by *Arthrocaulon macrostachyum* (Am) on one side, and *Agropyro-Helichrysetum italicum* (AH), *Anthyllido-Centaureetum diomedea* (Ab) and *Crithmo-Limonietum diomedei* (Ld) on the other. In the middle, there are the other vegetation types without clear separation among them (a similar situation is observed on the diagram for axis 1 and 2 – data not shown). Axis 3 roughly separates the relevés of the *Limonietum japygici* (filled circular marks in Fig. 4: Lj), concentrated in the lower part of the diagram, from those of the *Crithmo-Limonietum apuli* (La), *Limonio-Plantaginetum grovesii* (Pg) and *Crithmo-Inuletum* (CI), which are in the upper part. Results of the NMDS ordination approximately confirm the general syntaxonomic pattern highlighted by the cluster analysis.

A synoptic table (Tab. 2) summarizes the nine groups identified, with the percentage frequency for each species in each plant community.

Discussion

The syntaxonomic classification of the rocky coastal vegetation of the Italian peninsula has been subjected to numerous changes and revisions in the last decades. In a thorough survey on the *Crithmo-Staticetea* class, Bartolo et al. (1992) reported two alliances of the order *Crithmo-Staticetalia* for the Italian peninsula, *Crithmo-Staticion* and *Plantagini-Thymelaeion hirsutae*, with the first one including the halophilous pioneer communities next to the coastline, and the second one including halotolerant shrub vegetation, located towards the hinterland and in catenal contact with the *Crithmo-Staticion*. The *Plantagini-Thymelaeion hirsutae* was, however, originally invalidly published (art. 5, 8 and 3g ICPN). Subsequently Mayer (1995: 101) explicitly listed the diagnostic taxa of the alliance – as required by article 8 of the ICPN. However, the alliance remained invalid because it is unclear from what *Plantago* species the alliance name is formed (art 3g) and because it still lacks the nomenclatural type (art. 5). Brullo and De Marco (1989) described another alliance, *Anthyllidion barbae-jovis*, for the halotolerant nanophanerophytic vegetation of vertical high cliffs next to the coast, including this syntaxon in the order *Crithmo-Staticetalia*. Subsequently, the *Anthyllidion barbae-jovis* and *Plantagini-Thymelaeion hirsutae* were moved to the *Helichrysetalia italicum*, of the class *Helichryso-Crucianelletea maritimae* (Biondi et al. 1997, Biondi 1999). In a subsequent contribution, Biondi (2007) separated the chasmophytic halophilous pioneer vegetation of the *Crithmo-Staticetalia* from the chomophytic and halotolerant vegetation dominated by chamaephytes as well as nanophanerophytes, clearly distinct from both an ecological and a physiognomic-structural point of view (see Fanelli et al. 2004), and described a new order, *Senecionetalia cinerariae*, for these last communities. The alliance *Anthyllidion barbae-jovis* was thus attributed to this new order, whilst halotolerant dwarf shrub communities were included in the *Helichryson litorei*, of the *Helichrysetalia italicum* (Biondi 2007; Biondi et al. 2014). As pointed out by Biondi et al. (2013), the *Helichryson litorei* was originally

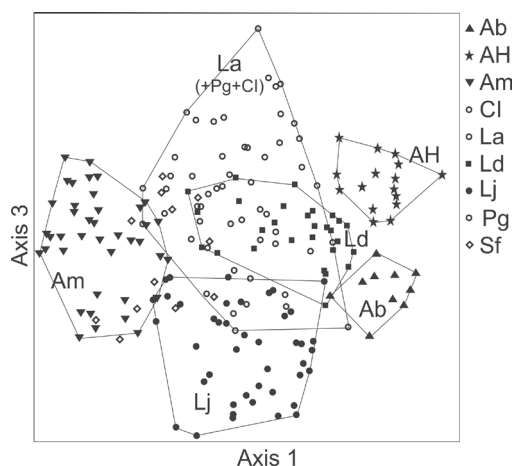


Fig. 4. Nonmetric multi-dimensional scaling ordination of relevés of the *Crithmo-Staticetea* class and *Limonio-Arthrocnemetum* (*Arthrocnemion glauci*) from the Apulia region, south-east of Italy. Ab - *Anthyllido barbae-jovis-Centaureetum diomedea*; AH - *Agropyro pungentis-Helichrysetum italicum*; Am - *Limonio virgati-Arthrocnemetum macrostachyi*; CI - *Crithmo maritimi-Inuletum crithmoidis*; La - *Crithmo maritimi-Limonietum apuli*; Ld - *Crithmo maritimi-Limonietum diomedei*; Lj - *Limonietum japygici typicum*; Pg - *Limonio virgati-Plantaginetum grovesii*; Sf - relevés with *Salicornia fruticosa*.

Tab. 2. Abridged synoptic table of the *Crithmo maritimi-Staticetea* class in the south-east of Italy (taxon scores represent the taxa percentage frequencies). Columns: I – *Arthrocaulon macrostachyum* group (*Limonio virgati-Arthrocnemum macrostachyi*); II – *Limbaria crithmoides* group (*Crithmo maritimi-Inuletum crithmoidis*); III – *Limonium apulum* group (*Crithmo-Limonietum apuli*); IV – *Plantago holosteum* subsp. *grovesii* group (*Limonio virgati-Plantaginetum grovesii*); V – *Salicornia fruticosa* group (*Limonietum japygici salicornietosum fruticosae*); VI – *Limonium japygicum* group (*Limonietum japygici*); VII – *Limonium diomedea* group (*Crithmo-Limonietum diomedei*); VIII – *Anthyllis barba-jovis* group (*Anthyllido-Centauretum diomedea*); IX – *Helichrysum italicum* group (*Agropyro-Helichrysetum italicum*).

Group	I	II	III	IV	V	VI	VII	VIII	IX
No. of relevès	42	23	25	6	12	43	29	9	16
Char. and diff. species of associations									
<i>Limonium apulum</i>	0	0	90	0	25	0	0	0	0
<i>Plantago holosteum</i> subsp. <i>grovesii</i>	0	0	0	67	0	0	0	0	0
<i>Limonium japygicum</i>	21	12	0	0	50	98	0	0	0
<i>Centaurea diomedea</i>	0	0	0	0	0	0	0	100	0
<i>Asperula staliana</i> subsp. <i>diomedea</i>	0	0	0	0	0	0	0	89	0
<i>Aurinia leucadea</i>	0	0	0	0	0	0	0	44	0
All. <i>Limonium anfracti-cancellati</i>									
<i>Limonium diomedea</i>	2	0	0	0	0	0	100	44	13
Cl. <i>Crithmo-Staticetea</i>, ord. <i>Crithmo-Staticetalia</i>, all. <i>Crithmo-Staticion</i>									
<i>Crithmum maritimum</i>	31	100	97	100	33	86	100	100	94
<i>Limonium virgatum</i>	43	65	84	100	100	51	41	0	19
<i>Plantago macrorrhiza</i>	0	0	0	67	0	12	0	0	0
<i>Lotus cytisoides</i>	0	29	58	50	17	56	86	78	94
<i>Frankenia hirsuta</i>	12	24	32	0	8	33	7	0	0
<i>Allium commutatum</i>	0	6	32	33	0	5	45	56	69
<i>Daucus carota</i> subsp. <i>hispanicus</i>	0	6	3	50	0	7	62	89	94
<i>Frankenia laevis</i> subsp. <i>laevis</i>	14	6	6	0	67	2	0	0	0
<i>Plantago holosteum</i> subsp. <i>scopulorum</i>	0	0	0	0	0	0	17	56	19
<i>Senecio leucanthemifolius</i> subsp. <i>leucanthemifolius</i>	0	0	0	0	0	0	3	0	0
<i>Reichardia picroides</i>	0	29	29	67	0	37	62	78	75
Ord. <i>Helichrysetalia italicum</i>, all. <i>Anthyllidion barbae-jovis</i> and all. <i>Helichryson litorei</i>									
<i>Anthyllis barba-jovis</i>	0	0	3	0	0	0	0	89	0
<i>Matthiola incana</i> subsp. <i>incana</i>	0	0	0	0	0	0	0	67	0
<i>Helichrysum italicum</i> subsp. <i>pseudolitoreum</i>	0	0	0	0	0	0	17	56	0
<i>Helichrysum italicum</i> subsp. <i>italicum</i> (d)	0	0	0	0	0	0	0	0	100
<i>Thymelaea hirsuta</i>	0	0	0	0	0	0	0	0	62
Cl. <i>Salicornietea fruticosae</i>, ord. <i>Salicornietalia fruticosae</i>, all. <i>Arthrocnemion glauci</i>									
<i>Arthrocaulon macrostachyum</i>	100	54	58	0	8	37	48	0	0
<i>Limbaria crithmoides</i> subsp. <i>longifolia</i>	19	100	19	33	67	19	10	0	0
<i>Suaeda vera</i>	7	54	13	0	0	2	28	0	13
<i>Halimione portulacoides</i>	24	24	0	0	17	7	0	0	0
<i>Salicornia fruticosa</i>	7	0	0	0	92	0	0	0	0
<i>Limonium narbonense</i>	21	0	0	0	8	0	0	0	0
<i>Puccinellia festuciformis</i> subsp. <i>festuciformis</i>	2	0	0	0	0	0	0	0	0

invalidly described because the sole association of its original diagnosis, the *Senecioni-Helichrysetum litorei* Barbagallo, Brullo et Signorello 1983, had been in turn invalidly published, it being unclear from what *Senecio* species the association name was formed (art. 3g). Biondi (in: Biondi et al. 2013) described the new association ‘*Senecioni bicoloris-Helichrysetum litorei*’ (cf art. 6) but failed to validate the alliance *Helichryson litorei*. In fact, Biondi (in: Biondi et al. 2013) designated as nomenclatural type of the alliance the invalid ‘*Senecioni-Helichrysetum litorei* Barbagallo, Brullo et Signorello 1983’ instead of the new and valid *Senecioni bicoloris-Helichrysetum litorei* Biondi in Biondi et al. 2013.

More recently, Mucina et al. (2016) proposed a new classification scheme. According to this contribution, two orders of the *Crithmo-Staticetea* can be recognized for the Italian peninsula: the *Crithmo-Staticetalia* for the rupicolous vegetation of salt-sprayed cliffs, and the *Helichrysetalia italicum* for the sub-aerohaline coastal dwarf scrub on the inland edges of salt-sprayed cliffs of the seaboard. Within the *Crithmo-Staticetalia*, two alliances are recognized: *Crithmo-Staticion* for the rupicolous dwarf-herb vegetation of salt-sprayed limestone cliffs of the Tyrrhenian and Ligurian coasts, and *Limonium anfracti-cancellati* for the rupicolous herb-rich vegetation of salt-sprayed rocky cliffs of the Adriatic coasts. The

Plantagini-Thymelaion hirsutae and *Helichryson litorei* are dealt with as syntaxonomic synonyms of the *Anthyllidion barbae-jovis*, within the *Helichrysetalia italici*. According to the syntaxonomic proposal of Mucina et al. (2016), the associations *Limonio virgati-Plantaginetum grovesii*, *Crithmo-Limonietum apuli*, *Crithmo maritimi-Inuletum crithmoidis* and *Limonietum japygici* should be classified in the *Crithmo-Staticion*, whilst the *Crithmo-Limonietum diomedei* has to be ascribed to the Adriatic alliance *Limonion anfracti-cancellati*. On the other hand, the *Anthyllido-Centauretum diomedea* and *Agropyro-Helichrysetum italici* should be classified in the *Anthyllidion barbae-jovis* which encompasses both the nanophanerophytic vegetation of the high cliffs (*Anthyllido-Centauretum diomedea*) and the coastal dwarf scrub communities (*Agropyro-Helichrysetum italici*). However, these two vegetation types are characterized by different structures and ecological requirements, and in the end by a different floristic composition. The clusters representing these two associations turned out to be clearly distinguished, being separated both in the ordination diagram (Fig. 4) and in the dendrogram (Fig. 2). Moreover, each of them was characterized by many IndSp, indicating their floristic autonomy (Fig. 3). Therefore, in our opinion, these two associations should be kept at least in separate alliances, as already proposed by other authors (Biondi 2007; Pirone 2014; Biondi et al. 2014). As a consequence, the *Helichryson litorei* is here validated (see below) and the *Agropyro-Helichrysetum italici* is classified in this alliance.

As regards the spatial distribution and vegetation zonation of the rocky coasts, several belts can be described (Fig. 5 and 6). In a thorough analysis of the coastal vegetation of the Salento peninsula (South Apulia), Biondi et al. (2006) described a first belt, subject to continuous salt-water spraying and characterized by plant communities formed by succulent chamaephytes or nanophanerophytes such as *Arthrocaulon macrostachyum* (*Arthrocaulon macrostachyum* communities and *Limonio virgati-Arthrocnemetum macrostachyi*) or by *Limbarda crithmoides* (*Crithmo maritimi-Inuletum crithmoidis*), depending on the geological nature of the substrate (cluster 16a-16b and 8a in Fig. 2). Although these communities with *Arthrocaulon macrostachyum* develop on rocky substrates and in close catenal contact with communities of the *Crithmo-Staticetea* class, they were originally classified in the *Arthrocnemion glauci*, of the *Salicornietea fruticosae*

class (Biondi et al. 2006). In our analyses, this vegetation type turned out to be well differentiated from all the other types (Fig. 2) and characterized by few IndSp, most of them of the *Salicornietea fruticosae* class. In two previous contributions about the vegetation of some coastal sites of Southern Apulia, Curti and Lorenzoni (1968) described a subassociation of the *Limonietum japygici* with '*Salicornia fruticosa e Inula crithmoides*' whereas Mariotti et al. (1992) described the subassociation *sarcocornietosum fruticosae* of the *Frankenio laevis-Limonietum cancellati* (here considered as a synonym of the *Crithmo-Limonietum apuli*). In our numerical analyses, these relevés segregate into a group (6b) characterized by *Salicornia fruticosa* and including both subassociations. The first subassociation could be considered as a halophilous aspect of the *Limonietum japygici*, subject to periodic submersion with stagnation of sea water, due to the low elevation above sea level (see below). However, as regards the subassociation '*sarcocornietosum fruticosae*' of the *Frankenio laevis-Limonietum cancellati*, described by Mariotti et al (1992) in the site of Torre Guaceto, it is necessary to point out that, during our surveys in Torre Guaceto and other coastal sites of the same area, in the same habitat types we have found *Arthrocaulon macrostachyum* instead of *Salicornia fruticosa*. Therefore, we suppose that the *Frankenio laevis-Limonietum cancellati salicocornietosum fruticosae* could actually refer to a transition between the *Crithmo-Limonietum apuli* and *Limonio virgati-Arthrocnemetum macrostachyi*.

Following the zonation, the belt immediately towards the inland is occupied by plant communities characterized by the presence of *Limonium* sp.pl. (Figs. 5 and 6). In the Apulian region, four vicariant and endemic associations have been described. The *Limonietum japygici* is distributed along the south-western part of the Apulian coast and is characterized by *Limonium japygicum*, endemic to the Salento peninsula, from Taranto to Otranto (LE) (Pignatti 1971, Pignatti et al. 2014). This association was invalidly published by Curti and Lorenzoni (1968) because its name-giving taxon, *Limonium japygicum*, had not been validly published. This taxon has recently been validated (Pignatti et al. 2014), and consequently the *Limonietum japygici* and its two subassociations (*typicum* and *sarcocornietosum fruticosae*) are here validated. Based on the results of our revision, these two subassociations are sufficient to describe the floristic variability of this association. The *Crithmo-Limonietum apuli*, extend-

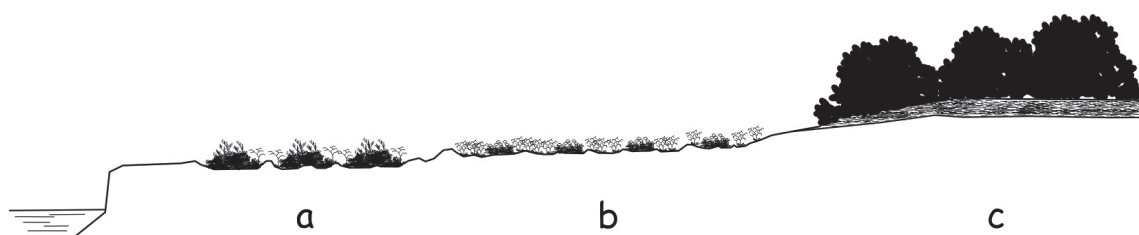


Fig. 5. Schematic outline of the distribution of plant communities on rocky coasts of central-southern Apulia: a) *Arthrocnemion glauci* (*Limonio virgati-Arthrocnemetum macrostachyi*) / *Crithmo maritimi-Staticion* (*Crithmo-Inuletum crithmoidis*); b) *Crithmo maritimi-Staticion* (*Limonietum japygici* in southern Apulia / *Crithmo-Limonietum apuli* in central Apulia); c) *Juniperion turbinatae* or *Oleo-Ceratonion*.

ing along the Adriatic coast of Apulia from Otranto to the Gargano peninsula, is characterized by *Limonium apulum*, a taxon belonging to the *L. cancellatum* group and endemic to the Adriatic coast of the Apulia region (Brullo et al. 1990, Bogdanović et al. 2012). This association was effectively published in 1992, although the year 1989 is reported on the first page of the article by Bartolo et al. (1992). In the same year, another association, *Frankenio laevis-Limonietum cancellati*, was described for Torre Guaceto for a similar habitat type (Mariotti et al. 1992). According to the results of our analysis, these two associations should be united. In fact, the nomenclatural types of the *Crithmo-Limonietum apuli* and *Frankenio laevis-Limonietum cancellati* were grouped in the same cluster (Fig. 2: cluster La₂). Having no information about the month of publication of the two volumes where these associations were validly published (vol. 47 of *Candollea* and vol. 19 of *Colloques Phytosociologiques*, both published in 1992), we choose to retain the name *Crithmo-Limonietum apuli*. In fact, *Limonium cancellatum*, one of the name-giving taxa of the other association, was excluded from the flora of Italy (Wagensommer et al. 2012) so that *Frankenio laevis-Limonietum cancellati* turns out to be incorrect.

The *Limonio virgati-Plantaginetum grovesii* is a restricted endemic association that develops on marl substrates near the Alimini Lakes (Otranto), within the distribution range of the *Crithmo-Limonietum apuli*. It is characterized by *Plantago holosteum* subsp. *grovesii* and differentiated by the higher frequency and cover of *Plantago macrorhiza* and *Pl. crassifolia*. The *Limonio virgati-Plantaginetum grovesii* could be considered a geographic vicariant of the *Plantagini holostei-Staticetum cancellatae* (i.e. the lectotype of the *Limo-*

nion anfracti-cancellati, cf. Mucina et al. 2016) that has been recorded in numerous localities along the Croatian coasts (Horvatić 1934, 1939, Pandža et al. 2007, Stančić et al. 2008).

The *Crithmo-Limonietum diomedei* is characterized by *Limonium diomedium* which is endemic to the Tremiti islands and Gargano Peninsula (Perrino and Wagensommer 2011) and is considered as a vicariant of *L. vestitum* which is endemic to the Kamik islet of the Vis archipelago in central Dalmatia (Brullo 1988, Bogdanović and Brullo 2015). Following the syntaxonomic scheme proposed by Mucina et al. (2016), this association has been here classified in the *Limonium anfracti-cancellati*. Nevertheless, this last attribution relies on the presence of one only diagnostic species of the alliance, that is, *Limonium diomedium*. More generally, the floristic differences between this alliance and the *Crithmo-Staticion* rely on few character/differential stenoendemic taxa. For this reason, in our opinion, further investigations are required in order to confirm the autonomy of the *Limonium anfracti-cancellati* as a distinct alliance.

A third zone, sheltered from the direct action of marine waters, is characterized by halotolerant shrub communities, with different ecologies and structures (Fig. 6). The *Agropyro-Helichrysetum italici* garrigues are discontinuously distributed along the Adriatic coasts of Apulia, in some localities near Brindisi and along the Gargano and Tremiti coasts. This association makes catenal contact with the *Crithmo-Limonietum apuli*, and with the *Crithmo-Limonietum diomedei*, depending on the geographic zone. The *Anthyllido-Centaureetum diomedea* Brullo et De Marco 1990, on the high cliffs of the Gargano Peninsula and Tremiti islands, makes catenal contact with the *Crithmo-Limonietum diomedei* communities.

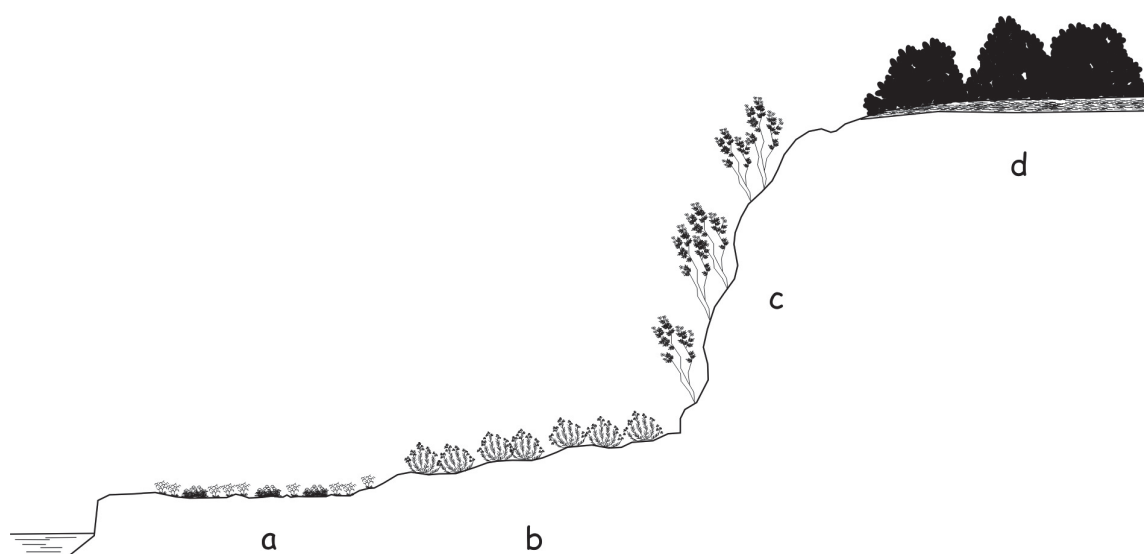


Fig. 6. Schematic outline of the distribution of plant communities on rocky coasts of northern Apulia (Gargano and Tremiti Islands): a) *Limonium anfracti-cancellati* (*Crithmo maritimi-Limonietum diomedei*); b) *Helichryson litorei* (*Agropyro pungentis-Helichrysetum italici*); c) *Anthyllidion barbae-jovis* (*Anthyllido barbae-jovis-Centaureetum diomedea*); d) *Juniperion turbinatae* or *Oleo-Ceratonion*.

Syntaxonomic scheme

CL. *Crithmo maritimi-Staticetea* Br.-Bl. in Br.-Bl. et al. 1952*

ORD. *Crithmo maritimi-Staticetalia* Molinier 1934*

ALL. *Crithmo maritimi-Staticion* Molinier 1934*

Limonietum japygici Curti et Lorenzoni ex Tomaselli et Terzi ass. nov. hoc loco [holotypus: see below the *Limonietum japygici typicum*; synonym: *Limonietum japygici* Curti et Lorenzoni 1968 (art. 3)]

Limonietum japygici typicum subass. nov. hoc loco [holotypus rel. 49 of the on-line Supplement Tab. S1, 15 May 2014, locality Ponte Ciolo (LE), Italy: *Allium commutatum* +, *Capparis spinosa* s.l. +, *Catapodium balearicum* +, *Crithmum maritimum* 3, *Dittrichia viscosa* subsp. *viscosa* +, *Elymus acutus* 1, *Limonium japygicum* 1, *Lotus cytisoides* 1, *Silene sedoides* subsp. *sedoides* +, *Silene vulgaris* subsp. *tenoreana* 1]; *Limonietum japygici salicornietosum fruticosae* subass. nov. hoc loco [holotypus rel. 14, tab. 2, in Curti and Lorenzoni 1968: 887];

Crithmo maritimi-Limonietum apuli Bartolo, Brullo et Signorello 1992 [syn. *Frankenio laevis-Limonietum cancellati* Mariotti et al. 1992]

Crithmo maritimi-Inuletum crithmoidis Biondi, Casavecchia et Guerra 2006

Limonio virgati-Plantaginetum grovesii Bartolo, Brullo et Signorello 1992

ALL. *Limonion anfracti-cancellati* (Horvatić 1934) Mucina in Mucina et al. 2016

Crithmo maritimi-Limonietum diomedei Bartolo, Brullo et Signorello 1992

ORD. *Helichrysetalia italici* Biondi et Géhu in Géhu et Biondi 1994

ALL. *Anthyllidion barbae-jovis* Brullo et De Marco 1989

Anthyllido barbae-jovis-Centaureetum diomedea Brullo et De Marco 1989

ALL. *Helichryson litorei* Biondi ex Tomaselli et Terzi all. nov. hoc loco [holotypus: *Senecioni bicoloris-Helichrysetum litorei* Biondi in Biondi, Allegrezza, Casavecchia, Galdenzi, Gigante et Pesaresi 2013 (p. 189); diagnostic taxa (cf. Biondi 2007): *Helichrysum litoreum*, *Helichrysum italicum* subsp. *pseudolitoreum*, *Helichrysum italicum* subsp. *italicum* (diff.), *Jacobaea maritima* subsp. *bicolor*, *Thymelaea hirsuta*; Synonyms: *Plantagini-Thymelaeion hirsutae* Bartolo et Brullo in Bartolo, Brullo et Signorello 1992 nom. inval. (art. 3g, 5, 8); *Plantagini-Thymelaeion hirsutae* Bartolo et Brullo ex Mayer 1995 (art. 3g, 5); *Helichryson litorei* Biondi 2007 nom. inval. (art. 5); *Helichryson litorei* Biondi in Biondi, Allegrezza, Casavecchia, Galdenzi, Gigante et Pesaresi 2013 nom. inval. (art. 5)]

Agropyro pungentis-Helichrysetum italicum Bartolo, Brullo et Signorello 1992

CL. *Salicornietea fruticosae* Br.-Bl. et Tx. ex A. de Bolos y Vayreda et O. de Bolos in A. de Bolos y Vayreda 1950

ORD. *Salicornietalia fruticosae* Br.-Bl. 1933

ALL. *Arthrocnemion glauci* Rivas-Mart. et Costa M. 1984

Limonio virgati-Arthrocnemetum macrostachyi Biondi, Casavecchia et Guerra 2006

*As already pointed out by Mucina et al. 2016, the presence of more than one species of the genus *Limonium* in the original diagnoses of the *Crithmo-Staticetea*, *Crithmo-Staticetalia* and *Crithmo-Staticion*, do not allow the addition of any epithet to the original forms of the names. However, since only one species of the genus *Crithmum* occurs (i.e. *Cr. maritimum*), the epithet has been added.

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