Syntaxonomic considerations of the Mediterranean vegetation dominated by perennial psammophilous graminaceous plants

E. Biondi, D. Galdenzi
Department of Agricultural, Food and Environmental Sciences, Polytechnic University of Marche, Via Brecce Bianche I-60131, Ancona, Italy.

Abstract
The vegetation dominated by perennial psammophilous grasses along the Mediterranean coasts is reviewed and updated according to the new concepts, with particular reference to the European grasses. First, the class of the dune psammophilous vegetation that is already indicated in the Vegetation Prodrome of Italy with the name of Ammophiloë australis is updated to Euphorbio paraliæ-Ammophilaë australis. Thus, the dune vegetation of the central and northern Atlantic is distinguished in syntaxonomic terms from that of the similar Mediterranean and south-Atlantic formations. This separation is carried out at the order level, by recognizing the order Ammophilalia arenaria for the north-European Atlantic coasts and the order Ammophilalia australis for the Mediterranean and thermo-Atlantic coasts. For the Mediterranean area is also recognized the order Elymaliæ gigantei, for the Pontic zone and specifically for the Black Sea coasts and the Marmara Sea areas.

The main aim of this revision is therefore recognition of the syntaxa that make up the hierarchical scheme proposed for the Mediterranean Basin, with the definition of the alliance Ammophilië australis for the vegetation of the white dunes, the alliance Agropyrië juncei for that of the embryonic dunes and the alliance Elymioni gigantei for that of the Pontic dunes. In terms of the alliance Ammophilië australis, the suballiance Ammomphiëlië australis is recognized for the European thermo-Atlantic and Mediterranean coastal areas except for the coasts of north Africa and the new suballiance Silene succulentae-Ammophilië australis is described for the Mediterranean part of north Africa. For the alliance Agropyrië farciti that defines the vegetation that shows the richest biodiversity of the whole system, four suballiances are recognized. Of these, two are ‘structural system’, even if they are well characterised in ecological and floristic terms, and two are biogeographic. The first two of the suballiances are Sporoboliënarenari, which includes the first perennial vegetation of the first parts of embryonic dunes directly reached by seawater, and Elymo farciti-Outletië maritimi suball. nova, which includes the vegetation of the inner parts of the embryonic dunes characterised by reduced mobility of the sandy substrate. Defined in chorological terms, the two suballiances within the Mediterranean Basin are: the suballiance Agropyrië farciti, which includes the European psammophilous communities from the Iberian Peninsula to the Balkan one up to the Pontic Region except for the Crete and Cyprus Islands; and the suballiance Sileno succulentae-Elymenië farciti suball. nova, which includes the communities of the north African Mediterranean coast. Finally, within the order Elymalië gigantei, the alliance Elymioni gigantei is recognized for the psammophilous vegetation of the Pontic dunes.

Keywords: Atlantic coasts, coastal vegetation, embryonic dunes, Mediterranean coasts, mobile dunes, syntaxonomy.

Introduction
The sandy coasts are characterised by particular vegetation formations that are in chain succession along a gradient defined by ecological factors, such as the salinity, the winds, and the particular quality of the substrate, especially in terms of its mobility and extreme dryness (Biondi, 2007). Stabilisation of the sandy substrate occurs through the annual and, in particular, perennial psammophytes. These are characterised by their hypogean structure, which together with their above-ground structure can retain the sand, thus promoting the progressive growth of the dunes.

In more detail, along the Mediterranean and thermo-Atlantic coasts, the Sporobolië pungens (Schreb.) Kunth and Elymus farcit (Viv.) Runemark ex Melderis formations promote the building of the first sand accumulations, or drifts (the embryonic dunes) that then grow to increased heights (as the mobile dunes). This is due to the presence of the geophyte Ammophila arenaria (L.) Link subsp. australis (Mabille) Lainz [= Ammophila arenaria (L.) Link subsp. arundinacea H. Lindb.] in the inner part of the dune system (Braun-Blanquet, 1933; Géhu, 1986, 1998; Géhu & Géhu-Franc, 1986, 1988; Géhu et al., 1990; Rivas-Martínez et al., 2002, 2011; Géhu & Biondi, 1994; Biondi, 1999; Biondi et al., 2001; Brullo et al., 2001; Biondi & Bagella, 2005). These communities are included in a single vegetation class and organised into the relevant subordinate syntaxonomic ranks according to the different criteria.

The aim of this article is to update the syntaxonomic scheme already published in the Vegetation Prodrome of Italy according to the concepts which are presented here.

On the basis of this vision the class of vegetation that characterises the plant communities of the Atlantic and Mediterranean dunes that is currently proposed according to different definitions is here recognized, and the syntaxonomic scheme of this class, for each hierarchical level and in relation to the Mediterranean Basin is completed. The following proposed syntaxonomic scheme follows the interpretation of Géhu (1986), which is adapted according to the views of the
The syntaxonomic schemes proposed by Rivas-Martínez et al. (2002, 2011) included the perennial dune vegetation initially in the class Ammophiletalia Br.-Bl. & Tüxen ex Westhoff, Dijk & Pusschier 1946. Later they were included in the newly proposed class Euphorbio paralicae-Ammophiletalia australis Géhu & Rivas-Martínez in Rivas-Martínez et al. 2011, on the basis that the class published by Géhu & Géhu-Franck (1988) was invalid according to Articles 5 and 8 of the ICPN. Within this class, Rivas-Martínez et al. (2011) defined the order Ammophiletalia australis Br.-Bl. 1933, with three alliances that include the psammophilous communities according to their ecological particularities. They recognized an alliance that includes the different communities of the embryonic dunes, Honkeny psychopepidis-Elytrigion boreoalpinae Tüxen in Br.-Bl. & Tüxen 1952 nom. inv. et nom. mut. in Rivas-Martínez et al. 2002. This alliance includes two suballiances, which are respectively characterised by the two geovariant species of the genus Elymus (= Elytrigia): one of the Temperate and Mediterranean macrobioclimate with an Atlantic distribution, Honkeny psychopepidis-Elytrigion boreoalpinae (Tüxen in Br.-Bl & Tüxen 1952) Rivas-Martínez 2011; and the other of the Mediterranean macrobioclimate with eastern Mediterranean distribution that reaches west to the north African coasts, Elytrigion junceae Rivas-Martínez, Costa, Castroviejo & Valdés 1980. The second alliance defined by Rivas-Martínez et al. (2011) includes the vegetation that colonizes the mobile dunes, the alliance Ammophilion australis Br.-Bl. 1921 corr. Rivas-Martínez, Costa & Izco in Rivas-Martínez, Lousá, Díaz, Fernández-González & Costa 1990. For this alliance, Rivas-Martínez et al. (2002, 2011) also defined two suballiances: Ammophilenion australis Rivas-Martínez & Géhu in Rivas-Martínez, Lousá, Díaz, Fernández-González & Costa 1990, for the communities dominated by Ammophila australis that develop along the Mediterranean coasts and reach up to the European Atlantic coasts as far as Galicia; and Ammophilenion arenariae (Tüxen ex Br.-Bl. & Tüxen 1952) Rivas-Martínez, Costa, Castroviejo & Valdés 1980, for the vegetation of the mobile dunes found along the Cantabrian coasts, up to the southern Baltic (Rivas-Martínez et al., 1980). Finally, there is the third alliance defined by Rivas-Martínez et al. (2011), Sporobolion arenarii (Géhu & Géhu-Franck ex Géhu & Biondi 1994) Rivas-Martínez & Cantó 2002, which includes the halo-nitrophilous communities of the Mediterranean salt-flat coastal dunes. On this basis, the ecological dimension, expressed as the alliance, has priority, while the biogeographical aspect is relegated to the subordinate level. The classification proposed in the Vegetation Prodrome of Italy (Biondi et al., 2014) is obviously defined only for the Mediterranean communities. Within the vegetation class Ammophiletalia Br.-Bl. & Tüxen ex Westhoff, Dijk & Pusschier 1946, the order Ammophilietalia australis Br.-Bl. 1933 is recognized with two alliances that differentiate the communities of the mobile dunes, Ammophilotalia australis Br.-Bl. 1921 corr. Rivas-Martínez, Costa & Izco in Rivas-Martínez, Lousá, Díaz, Fernández-González & Costa 1990, from those of the embryonic dunes, Agropyro-Minuartion
peploidis Tx. in Br.-Bl. & Tx. 1952. This latter alliance refers in effect to the formations of the embryonic dunes of the Atlantic coast, and in Biondi et al. (2014) it was used on a provisional basis.

Results

The classifications considered here highlight the different definitions in syntaxonomic terms, for which there is proposed a classification system of the plant communities that is consistent with what is stated in the presentation of the Vegetation Prodrome of Italy (Biondi et al., 2014). For some aspects, this follows the update of the concept of the plant associations (Biondi, 2011).

As far as the class is concerned, the proposal of Rivas-Martínez et al. (2011) is adopted, with the class Euphorbio paralae-Ammophiletalia australis Géhu & Rivas-Martínez in Rivas-Martínez et al. 2011 (including the Honckenyo-Elymtea arenarii Tüxen 1966) accepted here to include the vegetation of both the north Atlantic dune systems and those of the Mediterranean and thermo-Atlantic. On this basis, therefore, the subordinate syntaxa are recognized and defined according to specific assumptions.

In more detail, the order is assigned the role of the fundamental rank that includes the phytoecotosenes according to the biogeographical macro-units of Region and Subregion (Rivas-Martínez, 2007). Indeed, this view allows the better definition and clustering of the plant communities into the lower hierarchical levels. In this way, the alliance can represent the hierarchical level on the basis of the ecological characteristics of the community, while the suballiance can represent the rank for which both the biogeographical and ecological features are more detailed.

On the basis of this, with reference to the Mediterranean dune vegetation, the order Ammophiletalia australis Br.-Bl. 1933, as it has been interpreted to date (Bardat et al. 2004; Rivas-Martínez et al., 2011), should be considered as nomen ambiguum because of the use of the subspecies epithet "australis", which must follow the interpretation of Braun-Blanquet (1933) that defines a Mediterranean order with thermo-Atlantic penetration. Instead, in the different classifications analysed, this order includes both Mediterranean and Atlantic communities, and also the north European ones.

Therefore, three distinct orders are proposed: the order Elymetalio arenarii Br.-Bl. & Tüxen 1943, for the perennial psammophilous vegetation of the Atlantic and north European dunes and two orders for the Mediterranea area, the order Ammophiletalia australis Br.-Bl. 1933, which includes the perennial dune communities of the Mediterranean and south Atlantic coasts and the order Elymetalio gigantei Vicherek 1971 for the Black Sea coasts and the Marmara Sea areas. Within the order Ammophiletalia australis, two alliances are recognized: Ammophilion australis, for the mobile dune and Agropyron juncei, for the embryonic dune. The classification here defined at the level of alliance has already been recognized for a long time in the literature and is therefore kept unchanged. However, it is considered more suitable to cluster mainly the vegetation of the alliance Agropyron juncei at the lower hierarchical level, as it is characterised by higher specific and phytoecotonic biodiversity. In contrast, these aspects are not found in the mobile dune communities, where in their more stable parts Ammophila arenaria gives origin to dense structures where the other psammophilous species of a smaller size cannot survive, which is also linked to the accumulation of the sand.

The vegetation of the Mediterranean mobile dunes has been included in the alliance Ammophilion australis Br.-Bl. 1933 em. Géhu & Géhu-Franck 1988, which was reported by Géhu & Géhu-Franck (1988), and not in the alliance Ammophilion australis Br.-B. 1921 corr. Rivas-Martínez, Costa & Izco in Rivas-Martínez et al. 1990, which is instead currently used in the recent classifications analysed. Indeed, as was defined in Rivas-Martínez et al. (1990), this latter syntaxon includes both the Mediterranean vegetation (Ammophilion arundinaceae) and the Atlantic vegetation (Ammophilion arenariae). The syntaxon reported by Géhu & Géhu-Franck (1988) included only the thermo-Atlantic and Mediterranean communities and for this reason it is the most suitable for the classification proposed here. Within this alliance two suballiances are recognized: the suballiance Ammophilon australis, for the European thermo-Atlantic and Mediterranean coastal areas, except for the north African coasts, and the new suballiance Sileno succulentae-Ammophilon australis, for the north African Mediterranean coast.

The vegetation that forms the embryonic dunes is included in the alliance Agropyron juncei (R.Tüxen 1945 in Br.-Bl. & R.Tüxen 1952) Géhu, Rivas-Martínez & R. Tüxen 1972 in Géhu, Costa, Scoppola, Biondi, Marchiori, Peris, Franck, Caniglia & Veri 1984, within which four suballiances are recognized that include and subdivide the communities in ecological and biogeographical terms. The suballiance tipicum is Sporobolenia arenariae Géhu ex Biondi & Galdenzi suball. nova hoc loco. This syntaxon was not published in a valid form (according to Articles 5 and 8) by Géhu (1986), although it is proposed again here, in accordance with the ICPN rules, through the definition of the holotypus: the association Sporoboleno arenarii-Agropyretum juncei (Br.-Bl. 1933, Géhu, Rivas-Martínez & R. Tüxen 1972) Géhu in Géhu, Costa, Scoppola, Biondi, Marchiori, Peris, Franck, Caniglia & Veri 1984, which was also the holotypus of the alliance
Agropyron juncei. The communities with Sporobolus arenarius included in this suballiance define the structure of the embryonic dunes, making up the vegetation of the first parts of the sand dune systems that are still influenced by the waves, for all of the sandy coasts of the Mediterranean.

The suballiance Elymo farcti-Otanthenion maritimis suball. nova hoc loco also covers a structural role, as it is found in the Mediterranean sand dune systems where it develops on the highest parts of the embryonic dunes, which for the larger systems tend to be more stable. This is due to the high levels of Onanthus maritimus, which characterises this new syntaxon. The other two suballiances included in the alliance Agropyriun juncei define instead the synchorology of the embryonic dunes and are among their geosynvicariants: the suballiance Agropyreniun juncei Rivas-Martínez, Costa, Castroviejo & Valdés 1980, which includes the European psammophilous communities from the Iberian Peninsula to the Balkan one up to the Pontic Region except for the Crete and Cyprus Islands; and the suballiance Sileno succulenta-Elymenion farcti suball. nova hoc loco, of the embryonic dune vegetation along the north African coast. The former suballiance includes the association Echinophoro spinosae-Elymum farcti, wich was described and reported by Géhu (1986) in an invalid way (Article 3f; Géhu, 1986). According to the ICPN rules, this syntaxon is here validated through the indication of the holotypus (holotypus: Ammophiletalia arenariae Tüxen 1966) in the Mediterranean coastal distribution, which is important in the dune construction and stabilisation processes.

Syntaxonomical scheme

For the syntaxonomic scheme, for each syntaxon and succession, the information and the rules are followed as already applied in the Vegetation Prodrome of Italy (Biondi et al., 2014).

Cl.: EUPHORBIO PARALIAE-AMMophileTEA AUSTRALIS Géhu & Rivas-Martínez in Rivas-Martínez, Asensi, Díaz-Garretas, Molero, Valle, Cano, Costa & Díaz 2011

[Ammophiletea arenariae sensu auct. non Br.-Bl. & Tüxen ex Westhoff, Dijk, Passchier & Sissingh 1946, quod est: Honckenyro-Elymetra arenariae Tüxen 1966].

Holotypus: Ammophiletea australis Br.-Bl. 1933

Diagnostic species: Ammophila arenaria (L.) Link subsp. australis (Mabille) Lainz (= A. arenaria (L.) Link subsp. arundinacea H. Lindb., A. littoralis (Beauv.) Rothm., Arundo arenaria L.), Anthemis maritimae L., Cyperus capitatus Vand. (= C. kalli (Forssk.) Murb., C. kalli (Forssk.) Murb., C. mucronatus (Mabille, non Steud. 1854, nom. illeg.), Euphorbia paraliae L., Lotus creticus L., Medicago marina L., Pan-cratum maritimum L. and Polygonum maritimum L.

Short description: Psammophilous perennial vegetation from the coastal sandy and fine-pebbly dunes, with a Mediterranean, thermo-Atlantic and Macaronesian coastal distribution, which is important in the dune construction and stabilisation processes.

Ord.: AMMOPHiLetaLIA AUSTRalIIS Br.-Bl. 1933


Diagnostic species: Ammophila arenaria subsp. australis, Echinophora spinosa L. and Sporobolus arenarius (Gouan) Duval-Jouve (= S. pungens (Schreber) Kunth, no S. virginicus Kunth).

Short description: Perennial herbaceous vegetation typical of the forward beach areas and the embryonic and mobile dunes, distributed in the Mediterranean coastal areas, with extensions into the European thermo-Atlantic areas.

All.: Ammophilion australis Braun-Blanquet 1933 em. Géhu & Géhu-Franck 1988


Holotypus: Medicago marinae-Ammophiletemum australis Br.-Bl. 1933

Diagnostic species: Ammophila arenaria subsp. australis, Echinophora spinosa, Euphorbia paraliae,
Psammophilous perennial herbsaceous communities that colonise the dunes in the Mediterranean and European thermo-Atlantic coastal areas.

Suball.: **Ammophilenion australis** (Br.-Bl. 1921) Rivas-Martínez & Géhu in Rivas-Martínez, Lousã, Díaz, Fernández-González & Costa 1990

[**Ammophilenion arundinaceae** Rivas-Martínez, Costa, Castroviejo & E. Valdés 1980 (art. 27a, 28), **Medicaginini-Ammophilenion arundinaceae** (Braun-Blanq. 1921) Géhu & Biondi 1994 nom. illeg.(art. 29, 43)]

**Holotypus:** The same as the alliance.

**Diagnostic species:** The same as the alliance.

**Short description:** Psammophilous perennial herbsaceous communities that colonise the mobile dunes in the European thermo-Atlantic and Mediterranean coastal areas except for the north African coast.

Suball.: **Sileno succulentae-Ammophilenion australis** suball. nova hoc loco

**Holotypus:** Sileno succulentae-Ammophiletum arundinaceae (Burrollet 1927) Géhu & Géhu-Franck 1986


**Diagnostic species:** Ammophila arenaria subsp. australis, *Silene succulenta* and *Zygophyllum album* L..

**Short description:** Psammophilous perennial herbsaceous communities that colonise the mobile dunes in the north African coast.


[**Sporobolion arenarii** (Géhu & Géhu-Franck ex Géhu & Biondi 1994) Rivas-Martínez & Cantó in Rivas-Martínez et al. 2002 (syntax. syn.)].

**Holotypus:** Sporobolo arenarii-Agropyretum juncei (Br.-Bl. 1933, Géhu, Rivas-Martínez & R. Tüxen 1972) Géhu in Géhu, Costa, Scoppola, Biondi, Marchiori, Peris, Franck, Caniglia & Veri 1984


**Short description:** Psammophilous perennial herbsaceous communities that colonise the embryonic dunes in the Mediterranean and European thermo-Atlantic coastal areas.

Suball.: **Sporobolion arenarii** Géhu ex Biondi & Galdenzi suball. nova hoc loco

[**Sporobolion arenarii** Géhu 1986 nom. inval. (art. 5, 8), Sporobolion arenarii Géhu & Géhu-Franck ex Géhu & Biondi 1994 non Rothmaler 1943 (art. 27a), Incl.: Sporobolion arenarii (Géhu & Géhu-Franck ex Géhu & Biondi 1994) Rivas-Martínez & Cantó 2002].

**Holotypus:** The same as the alliance.

**Diagnostic species:** Sporobolus arenarius, Polygonum maritimum, Ipomoea stolonifera.

**Short description:** Halo-nitrophilous perennial herbsaceous communities that occur in the first parts of the meso- and thermo-Mediterranean sand dune systems that are characterised by *Sporobolus arenarius*, which colonises the lower parts of the embryonic dunes that are regularly reached by the sea.

Suball.: **Elymo farcti-Otanthenion maritimi** suball. nova hoc loco.

**Holotypus:** Elymo farcti-Otanthenum maritimi Géhu ex Biondi & Galdenzi ass. nova

**Diagnostic species:** *Otanthus maritimus*, *Pancratium maritimum*, *Medicago marina*, *Euphorbia paralias*, *Launaea resedifolia*, *Diotis candidissima*, *D. maritima*, *Calystegia soldanella*, *Cyperus capitatus* and *Silene succulenta* subsp. *corsica*.

**Short description:** Psammophilous plant communities that are physiognomically dominated by *Otanthus maritimus*, which occur on the inner parts of the embryonic dunes that are characterised by reduced mobility of the sandy substrate.

Ass.: **Elymo farcti-Otanthenum maritimi** Géhu ex Biondi & Galdenzi ass. nova hoc loco

[**Echinophoro spinosae-Elymietum farcti** Géhu ex Biondi & Galdenzi 2014 subass. *otanthetosum* Géhu e Biondi 1994 (corresp. name)].

**Holotypus:** Relevé 44 in Table 4 of Géhu & Biondi 1994.

**Diagnostic species:** *Otanthus maritimus*.

**Short description:** Communities that occur on the inner parts of the embryonic dunes where the plants have reduced the mobility of the dunes. Under these conditions, *Otanthus maritimus* dominates over other psammophilous species, which are consequently less numerous.
Suball.: Agropyrenion farcetii, Rivas-Martínez, Costa, Castroviejo & Valdés 1980

Order: Elymion gigantei, Morariu 1957

Diagnostic species: Leymus racemosus subsp. sabulosus (M. Bieb.) Tzvelev., Convolvulus persiculus L., Argusia sibirica (L.) Dandy Show, Leymus arenaria subsp. australis and Eryngium maritimum.

Short description: Psammophyllum communities of the Pontic dunes.

Order: ELYMETALIA ARENARI I, Br.-Bl. & Tüxen 1943

Diagnostic species: Elymus farctus, Lotus creticus, L. cytisoides, Cyperus mucronatus, Echinophora spinosa, Calystegia soldanella.

Short description: Aridophyllum communities that occur in European Mediterranean area from the Iberian Peninsula to the Balkan Peninsula up to the Pontic Region except for the Crete and Cyprus Islands.

Ass.: Elymion gigantei, Morariu 1957

Diagnostic species: Leymus farctus, Lotus creticus, L. cytisoides, Cyperus mucronatus, Echinophora spinosa, Calystegia soldanella.

Short description: Aridophyllum communities that occur in European Mediterranean area from the Iberian Peninsula to the Balkan Peninsula up to the Pontic Region.

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