

 RESEARCH PAPER

Numerical classification of Mediterranean riverine vegetation associated with *Carex panormitana* (Cyperaceae)

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Academic editor: Alireza Naqinezhad ♦ **Linguistic editor:** Megan J. McNellie

Received 24 April 2026 ♦ **Accepted** 17 August 2026 ♦ **Published** 20 September 2026

Abstract

Aims: Mediterranean watercourses are rather heterogeneous in their flow, particularly from a vegetation point of view. Streams with lotic waters are often characterised by a mixture of herbaceous to shrubby vegetation, while more lentic waters and less rocky parts of a river are mostly dominated by gallery forests or tall reed vegetation. Here, we studied vegetation dominated and co-dominated by *Carex panormitana*, a rare sedge endemic to the central Mediterranean (Sardinia, Sicily, and Tunisia). **Study area:** The island of Sardinia (Italy). **Methods:** Based on an extensive bibliographic review, long-term fieldwork, and a numerical classification approach, we analysed 218 original vegetation plots collected across the islands of Sardinia and Sicily, and investigated the plant communities with *Carex panormitana* in stream habitats on acidic substrates. **Results:** We described two phytosociological associations of the class *Phragmito-Magno-caricetea*, namely *Osmundo regalis*-*Caricetum panormitanae* and *Mentho aquaticae*-*Caricetum panormitanae*. The first association primarily occurs in northern Sardinia and is characterised by a higher proportion of mesophilous taxa, mostly herbaceous, rarely shrubs, being typical of hilly to low-mountain areas. The latter association is scattered across the island, although more frequent in central and southern Sardinia. *Mentho*-*Caricetum* exhibits a marked bioclimatic gradient, ranging from cooler areas of central Sardinia to lower stream stretches, and the warmer southern sectors of the island. Sardinian communities dominated and co-dominated by *Carex panormitana* are confirmed to be markedly different, both ecologically and floristically, from those previously described in Sicily, which are basiphilous, more sciaphilous, and often invaded by alien taxa. **Conclusions:** This study has provided a comprehensive understanding of the plant communities formed by *Carex panormitana* within Mediterranean watercourses characterised by pronounced seasonal hydrological fluctuations. Moreover, it represents a first step towards understanding the poorly known riparian communities of the order *Magnocaricetalia* in Sardinia.

Taxonomic reference: Euro+Med PlantBase (<https://europlusmed.org/>) [accessed 10 Feb 2026].

Syntaxonomic reference: FloraVeg (Chytrý et al. 2024) (<https://floraveg.eu/vegetation/>) [accessed 11 Feb 2026].

Abbreviations: ICPN = International Code of Phytosociological Nomenclature (Theurillat et al. 2021); MPO = Mediterranean Pluviseasonal Oceanic; NMDS = Non-metric multidimensional scaling; PCoA = Principal Component Analysis; UPGMA = Unweighted Pair-Group Method with Arithmetic mean.

Keywords

Carex panormitana, intermittent streams, *Phragmito-Magnocaricetea*, phytosociology, riverine vegetation, Sardinia, sedge communities, wetlands

Introduction

Watercourses in the Mediterranean Basin are characterised by flow regimes that are strongly controlled by climatic conditions (Córdoba-Ariza et al. 2025). Owing to generally mild and rainy autumn and winter seasons, followed by prolonged summer droughts, these systems typically experience periods of high discharge alternating with phases of stagnant or intermittent flow (Allam et al. 2020). Such hydrological patterns may be further exacerbated by extreme events, including flash floods, or intensified by prolonged droughts associated with climate change (Lind et al. 2018). Additional sources of disturbance arise from human activities, such as dam construction, channelisation, and riverbed diversion (Sharma et al. 2021), all of which can induce profound ecological and functional alterations within these fragile ecosystems (Bonada and Resh 2013).

In recent years, ecological and phytosociological studies focusing on Mediterranean watercourses have become increasingly common (Benchaiaba et al. 2025; Fortini et al. 2026; Šikuljak et al. 2026). However, although the syntaxonomic knowledge of riverine ecosystems is well developed in some regions, research in other regions is more unbalanced, focusing predominantly on gallery forests and shrub-dominated vegetation, whereas herbaceous communities have received considerably less attention. Sardinia represents a particularly illustrative example of this imbalance in vegetation knowledge. Over recent decades, studies on fluvial ecosystems have led to the description of several plant communities, particularly alder-dominated riparian formations (Sciandrello et al. 2023), or have focused on specific sectors of the island (Bacchetta et al. 2007; Angius and Bacchetta 2009). Furthermore, additional information on riverine woody vegetation is reported in broader studies addressing Sardinian forest formations (Bacchetta et al. 2009).

By contrast, detailed knowledge of herbaceous vegetation associated with riverine and stream systems remains limited. This applies to a wide range of communities, from hygro-rupicolous vegetation to reed beds belonging to the *Phragmito australis-Magnocaricetea elatae* (Landucci et al. 2020), for which specific studies are scarce and often restricted to marginal habitats or estuarine environments (Giau 1986; De Martis and Serri 2009). Among the few investigations conducted in Sardinia, none have specifically addressed inland communities belonging to the *Phragmito-Magnocaricetea* and, more specifically, to the *Magnocaricetalia* related syntaxa. However, other syntaxa previously attributed to this class and order, e.g., the alliance *Caricion microcarpae* (Bacchetta and Mossa 2004), are

currently referred to the alliance *Osmundo regalis-Alnion glutinosae* (class *Alno glutinosae-Populetea albae*, order *Populetaalia albae*) (Mucina et al. 2016). The extent of this knowledge gap is clearly reflected in recent national checklists of the *Magnocaricetalia* vegetation order (Venanzoni et al. 2018). Its resolution deserves particular attention, as several of the associated habitats are protected under the European Habitats Directive and consequently require a more robust ecological and syntaxonomic framework for their proper assessment, conservation, and management.

Among the taxa characterising some of these poorly studied habitats, *Carex panormitana* is an emblematic sedge endemic to intermittent streams of the central Mediterranean Basin, with a fragmented distribution across Sardinia, Sicily, and Tunisia (Jiménez-Mejías et al. 2014). Given its rarity, *Carex panormitana* has been listed as a priority species by the Habitats Directive (Council of the European Communities 1992).

In Sardinia, this species is relatively widespread at the local scale but occurs predominantly along stream sections in the eastern part of the island (Urbani et al. 2013). Despite its conservation and biogeographical significance, no comprehensive assessment of its distribution, ecology, and phytosociological characterisation has yet been undertaken at the regional scale. By contrast, this vegetation type has already been investigated in Sicily (Gianguzzi et al. 2013).

In this study, we aimed to: (i) assess *Carex panormitana* dominated and co-dominated communities of Sardinia; (ii) study their floristic and compositional differences; and (iii) compare *Carex panormitana* dominated and co-dominated communities of the two largest islands of the Mediterranean Basin, namely Sicily and Sardinia.

Study area

The island of Sardinia covers a total area of 24,090 km², and is the second largest island in the Mediterranean Basin after Sicily. The landscapes characterising the island's morphological profile are mainly hilly and low mountains, with plains and plateaus more frequent in the western half and southern areas, while steep and poorly accessible slopes characterise several parts of the eastern half and the south-western portion, despite their relatively low elevation. Sardinia lacks an alpine mountain range; its highest elevation is the Gennargentu Massif (1,834 m a.s.l.), followed by lower mountain systems, including Mount Corrasi (1,437 m) and Mount Limbara (1,359 m). Sardinian geology is more frequently composed of Variscan granitoid basement rocks in the eastern part, while effusive rocks are predominant in most of the western sectors

(Carmignani et al. 2016). Nonetheless, sedimentary carbonate outcrops, metamorphic rocks, and meta-limestones also represent important geological formations that can be found across the island from North to South (Carmignani et al. 2016).

Sardinia belongs to the Sardinian-Corsican biogeographic province, which is included within the Italo-Tyrrhenian super-province (Ladero Álvarez et al. 1987; Rivas-Martínez et al. 2011; Bacchetta et al. 2012). The island has been divided into six biogeographical sectors and 22 sub-sectors (Fenu et al. 2014) (Figure 1).

Most Sardinian elevational belts are influenced by the Mediterranean Pluviseasonal Oceanic (MPO) bioclimate, which is characterised by mild and humid winters, whereas summers are generally hot and dry (Bacchetta et al. 2009). Sardinian mean annual temperatures range from 11.6 °C to 18 °C, whereas annual precipitation is between

441 mm and 1,134 mm (Bacchetta et al. 2009). The mountain ranges of northern and central Sardinia are the only areas partly influenced by a sub-Mediterranean temperate bioclimate, whereas the summit zones of the highest peaks are characterised by an Oceanic temperate bioclimate (Canu et al. 2015; Pesaresi et al. 2017). Overall, in Sardinia two macro-bioclimate (*sensu* Rivas-Martínez et al. 2011), seven thermotypes, and 43 isobioclimates (Canu et al. 2015) were identified and mapped.

Municipalities and administrative provinces mentioned in this study follow the administrative framework established by Sardinian Regional Law no. 7/2021, which came into force on 1 June 2025. Under this legislation, Sardinia is divided into two metropolitan cities (Cagliari; Sassari) and six administrative provinces; among these, only Olbia-Tempio, Nuoro, and Ogliastra are relevant to the present study.

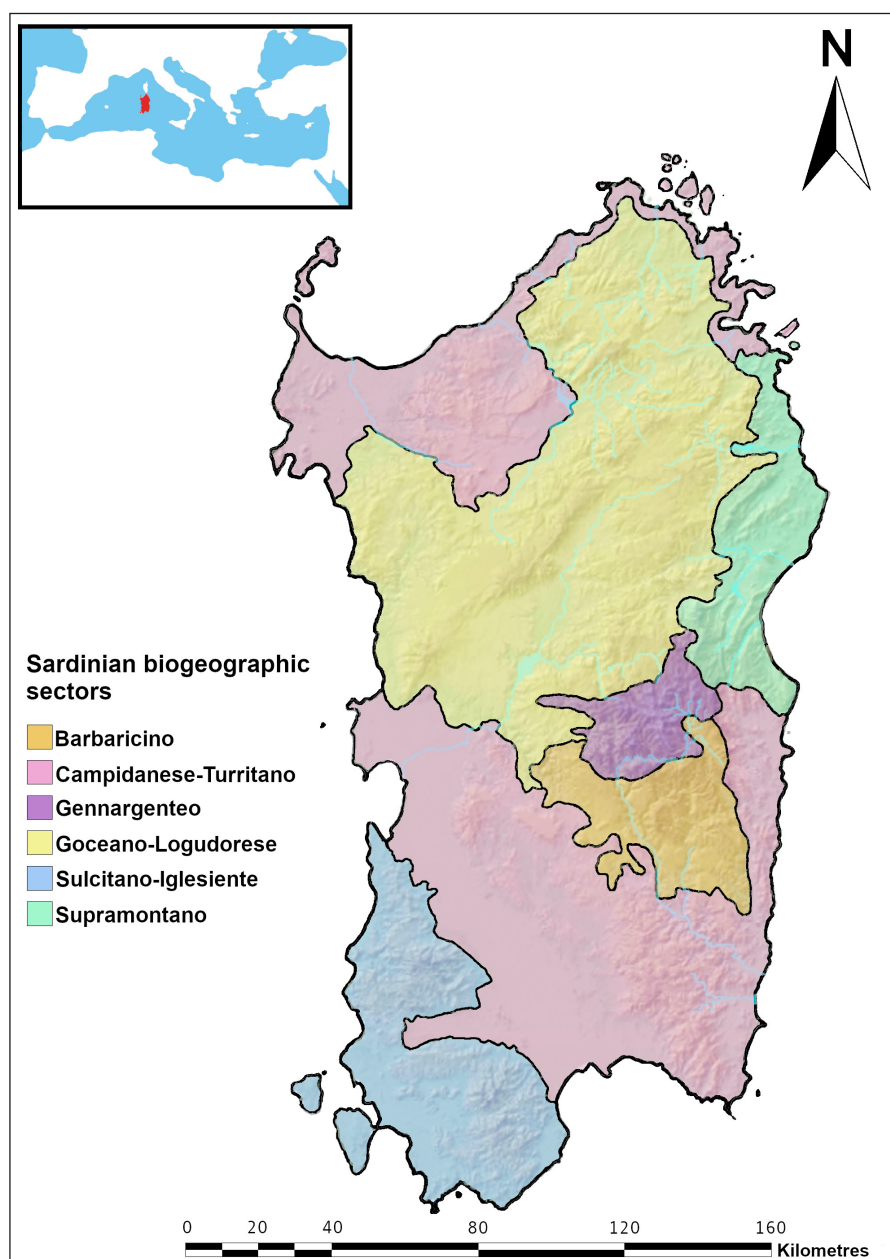


Figure 1. The study area and its repartition into six biogeographic sectors (according to Fenu et al. 2014).

Methods

Data collection

Carex panormitana (Cyperaceae) is a perennial sedge, typical of moist to periodically wet habitats, such as stream banks and beds, endemic to the central Mediterranean region.

The original description of the species was from Sicily, along the banks of the Oreto River, near Palermo (Gussone 1843). Its occurrence in Sicily is currently restricted within this watercourse. The syntaxonomic position of its communities has been documented by Gianguzzi et al. (2013). The species has also been recorded in Tunisia (Jiménez-Mejías et al. 2014), where it occurs in the Kroumirie region (Muller et al. 2025). However, no phytosociological studies are available at present. In Sardinia, the species was first observed by Moris (1829), and was subsequently recorded in several streams in the eastern Sardinia (Arrigoni 1984; Urbani et al. 1995; Urbani et al. 2013; Calvia and Ruggero 2020).

The distributional mapping of the communities was primarily based on published literature sources (e.g., Moris 1829; Nicotra 1896; Arrigoni 1984; Desfayes 2008). To refine the available information, we surveyed more than 60 streams and small watercourses across Sardinia during the years 1995–2025, characterised by Mediterranean climatic seasonality, rocky or stony banks, moderately to deeply incised V-shaped profile, and sparse to absent tree cover. These surveys included the localities previously reported in the literature as well as newly identified sites.

We recorded 203 vegetation plots (relevés) following the Zürich-Montpellier method (Braun-Blanquet 1951; Rivas-Martínez 2005) from 26 water bodies in which we recorded the vertical projection of species. Plots were selected in streambank or streambed sites with a herbaceous cover exceeding 50%. Accordingly, all the woody species present in our vegetation plots were seedlings (0.1–0.5 m) or shrubs (0.5–5 m), while trees were absent. According to the size of the area covered by the herbaceous vegetation, we performed plots from 3 m² to 50 m². Additionally, to characterise the ecology of our focal communities, we recorded environmental features, including elevation, slope, and aspect. The geographic coordinates of each plot were recorded using a Garmin GPSMAP 62st. For syntaxonomic nomenclature, we followed the fourth edition of the International Code of Phytosociological Nomenclature (ICPN) (Theurillat et al. 2021). Names of syntaxa in the text are according to FloraVeg (Chytrý et al. 2024). We identified all vascular plant taxa using Arrigoni (2006–2015), Jeanmonod and Gamisans (2013), and Pignatti et al. (2017–2019). The plant names and alien status follow Euro+Med PlantBase (2006–2026).

Data preparation and analyses

To examine the variation in species composition among the Sardinian *Carex panormitana* communities, species cover-abundance data were converted from Braun-Blanquet

classes to numeric values ($r = 0.1$, $+$ = 0.5, $1 = 2.5$, $2 = 12.5$, $3 = 37.5$, $4 = 62.5$, $5 = 87.5$). Before the analysis, we combined the cover values of these taxa in a single layer, following the assumption that covers can overlap and that they do so independently of each other (Tichý and Chytrý 2006).

To investigate the differences in species composition of Sardinian *Carex panormitana* communities, we used the original 203 vegetation plots of our survey compared to the 15 plots published in Sicily (Gianguzzi et al. 2013). Prior to multivariate analyses, the community matrix (218 plots $\times$ 158 species variables) was Hellinger-transformed to reduce the influence of dominant species and to improve the suitability of Bray-Curtis dissimilarity (Legendre and Gallagher 2001; Vukov et al. 2026) for both ordination and hierarchical classification. Compositional dissimilarity among plots was quantified using Bray-Curtis distance, and hierarchical cluster analysis was performed using the unweighted pair-group method with arithmetic mean (UPGMA) (Belbin and McDonald 1993; Wesche et al. 2005; Babar et al. 2011). The optimal number of clusters was evaluated using mean silhouette width across a range of k values ($k = 2$ –10), and the value maximising silhouette width was retained for subsequent analyses (Saputra et al. 2020; Shahapure and Nicholas 2020).

Non-metric multidimensional scaling (NMDS) (Clarke 1993; Bottin et al. 2020) was used to visualise compositional differences among plots in reduced-dimensional space using three dimensions ($k = 3$) and multiple random starts to ensure convergence on a stable solution, with stress values used to assess ordination quality.

Differences in species composition between clusters were tested using permutational multivariate analysis of variance (PERMANOVA) with 999 permutations (Anderson 2001), and homogeneity of multivariate dispersion was assessed using PERMDISP (betadisper) (Anderson 2006) followed by 999 permutation tests to evaluate whether significant PERMANOVA results were influenced by differences in within-group dispersion. A combined approach allowed the identification of species characterising each cluster in terms of fidelity, constancy, and structural dominance. Diagnostic species associated with each cluster were identified using the *IndVal.g* statistic with 999 permutations, expressed as percentages, retaining only species significantly associated with a single cluster ($p < 0.05$). Constant species were defined based on their frequency of occurrence within each cluster and expressed as the percentage of plots in which each species was present. Dominant species were identified using the Importance Value (IV), calculated as the mean of relative frequency and relative cover within each cluster, both expressed as percentages.

To explore internal ecological heterogeneity within clusters, we restricted ordination analyses to the plots assigned to this group. Non-metric multidimensional scaling (NMDS) based on Bray-Curtis dissimilarity was used to visualise within-cluster variation, and environmental variables describing vegetation structure and topography were fitted onto the ordination using permutation-based vector fitting (*envfit*; 999 permutations).

All analyses were performed in R (v. 4.4.2, R Core Team 2024) using the packages *vegan* (ordination, PERMANOVA, dispersion), *cluster* (silhouette analysis), *indicspecies* (indicator species analysis), and *dendextend* (dendrogram visualisation) (De Cáceres and Legendre 2009; Galili 2015; Maechler et al. 2026; Oksanen et al. 2026).

Besides reporting diagnostic species identified through the *IndVal.g* analysis, plant communities were characterised using synoptic tables summarising species percentage constancy across clusters. Species constancy was calculated as the percentage of plots in which each species occurred within each vegetation unit. Diagnostic species were identified using the *IndVal.g* index ($p < 0.05$), while dominant species were determined based on their Importance Value (IV).

Results

The *Carex panormitana* dominated and co-dominated communities currently known in Sardinia have been recorded in 36 watercourses. They are almost exclusively concentrated in the eastern sectors of the island. Their distribution spans a broad elevational range, from a few metres above sea level to about 900 m.

An initial clustering analysis including both Sardinian and Sicilian plots identified two main groups. The data were supported by the highest mean silhouette width at $k = 2$. NMDS ordination of the full dataset (stress value

$= 0.239$) showed a broad regional separation between Sardinian and Sicilian clusters. The PERMANOVA confirmed that species composition differed significantly between the Sardinian and Sicilian plots ($F = 23.951$, $R^2 = 0.100$, $p = 0.001$). Betadisper analysis also revealed significant differences in multivariate dispersion between Sardinian and Sicilian plots ($F = 53.567$, $p = 0.001$), indicating that the observed regional differentiation was associated not only with centroid separation but also with unequal within-group heterogeneity. In the PCoA ordination of multivariate dispersion, Sardinian plots occupied a much larger ordination space, whereas Sicilian plots formed a compact cluster with limited dispersion around their centroid. This pattern was reflected by the larger convex hull and the greater spread of Sardinian plots compared with those from Sicily.

The hierarchical classification based on Bray-Curtis dissimilarity calculated from Hellinger-transformed species data revealed a clear floristic separation between the Sardinian and Sicilian plots (Figure 2). All Sicilian plots clustered together in a single branch of the dendrogram (*Caricetum pendulo-panormitanae*), whereas the Sardinian plots formed a distinct and independent group made up by two sub-branches (*Osmundo regalis-Caricetum panormitanae* ass. nov. hoc loco, and *Mentho aquaticae-Caricetum panormitanae* ass. nov. hoc loco).

The same pattern emerged from the NMDS ordination (stress = 0.184), in which the three vegetation associations occupied well-defined regions of the ordination space

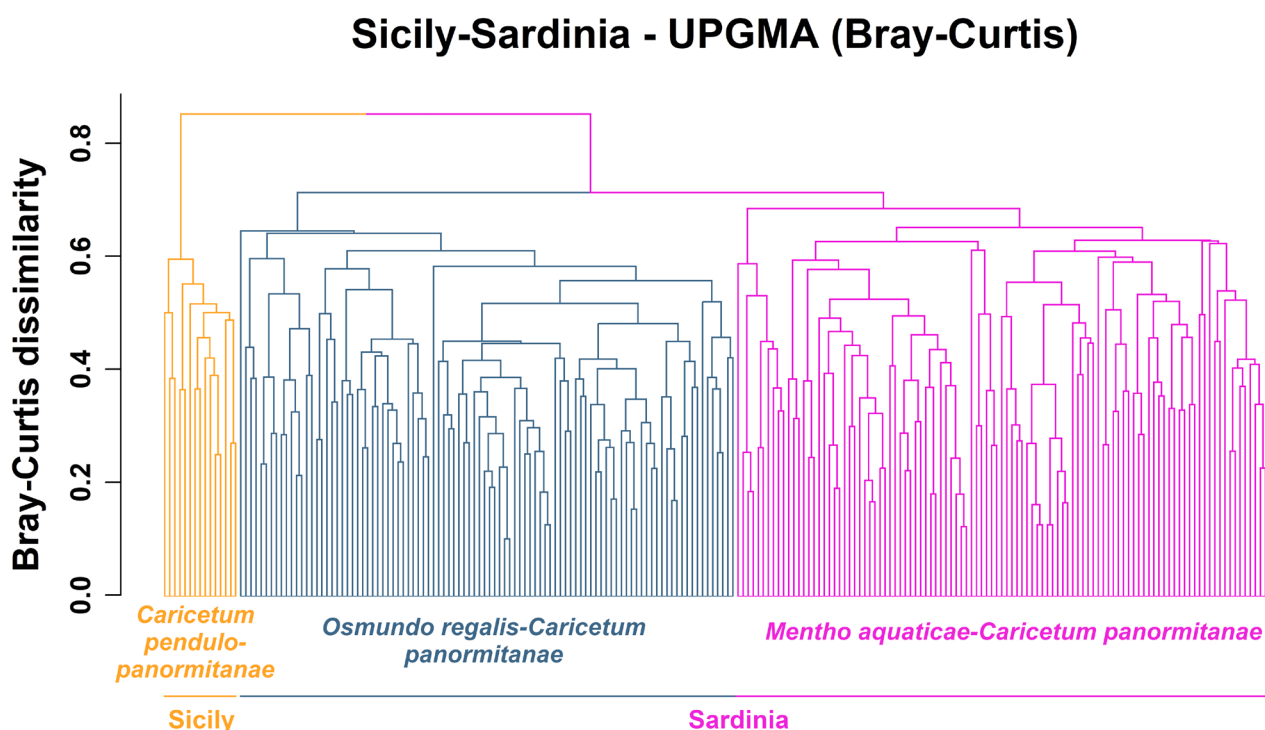


Figure 2. Hierarchical clustering (UPGMA) of Sardinian and Sicilian plots based on Bray-Curtis dissimilarity of the Hellinger-transformed species-layer matrix. The dendrogram separates the plots into two clusters ($k = 2$), corresponding to the Sicilian (orange) and Sardinian (blue/magenta). The second division separates the relevés corresponding to the *Osmundo regalis-Caricetum panormitanae* (blue, 98 plots) and *Mentho aquaticae-Caricetum panormitanae* (magenta, 105 plots). Branch colours indicate cluster membership; the y-axis represents Bray-Curtis dissimilarity.

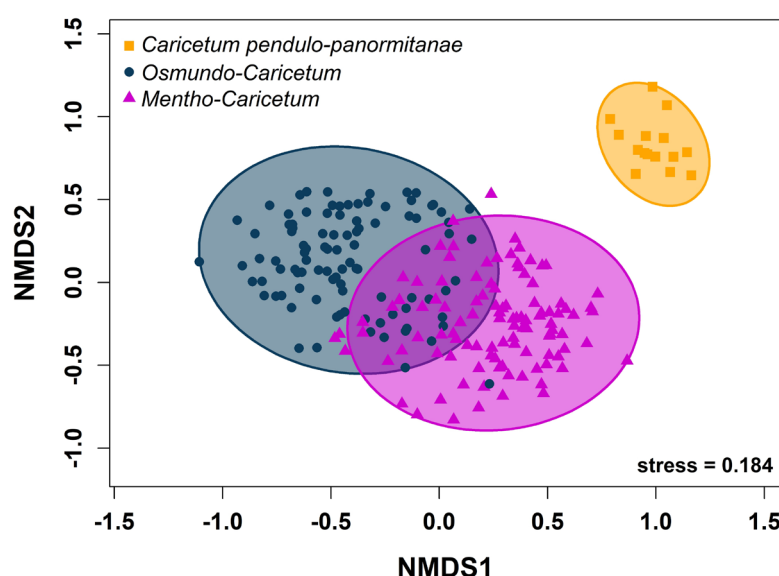


Figure 3. Non-metric Multidimensional Scaling (NMDS) ordination of the complete dataset based on Bray-Curtis dissimilarity calculated from Hellinger-transformed species data (stress = 0.184). Symbols represent the three vegetation associations: *Caricetum pendulo-panormitanae* (orange squares), *Osmundo regalis-Caricetum panormitanae* (blue circles), and *Mentho aquaticae-Caricetum panormitanae* (magenta triangles). Shaded polygons represent standard deviation ellipses (95% confidence scaling) around group centroids.

(Figure 3). *Caricetum pendulo-panormitanae* formed a compact and clearly isolated cluster, whereas *Osmundo-Caricetum* and *Mentho-Caricetum* occupied adjacent areas with only a limited overlap between their standard deviation ellipses.

When restricted to the Sardinian dataset, the hierarchical classification identified two major floristic groups comprising 98 and 105 plots, corresponding to *Osmundo-Caricetum* and *Mentho-Caricetum*, respectively (Figure 3). This differentiation was consistently reflected by the NMDS ordination. Plots of *Osmundo-Caricetum* were mainly distributed along the negative side of the first ordination axis (NMDS1), whereas those of *Mentho-Caricetum* were concentrated on the positive side. Although the standard deviation ellipses showed a limited overlap in the central portion of the ordination space, the two associations remained clearly differentiated.

The observed separation was statistically supported by PERMANOVA, which detected significant differences in floristic composition between the two associations (pseudo- $F = 42.628$, $R^2 = 0.175$, $P = 0.001$). Differences were also found in the dispersion of plots around their respective centroids (ANOVA: $F = 16.404$, $P < 0.001$; permutation test: $P = 0.001$), indicating that the two associations differed both in floristic composition and in the variability of their vegetation plots.

On this basis, the Sardinian plots were interpreted as belonging to two main floristically distinct groups, corresponding to the new associations *Osmundo regalis-Caricetum panormitanae* and *Mentho aquaticae-Caricetum panormitanae* (Figures 4, 5).

Floristic differences were summarised in an abbreviated synoptic table (Table 1), which also includes, for comparison, *Cladietum marisci* Allorge 1921, the only

Magnocaricetalia association unequivocally recognised in Sardinia through published plots (Giau 1986). The tables including all the original plots and taxa representing the two newly described syntaxa are provided in Suppl. material 1 and Suppl. material 2, whereas the table with the header data is provided in Suppl. material 3. The complete synoptic table, including all recorded species, is provided in Suppl. material 4.

Discussion

Distribution and ecological patterns of *Carex panormitana* communities

The currently known communities dominated and co-dominated by *Carex panormitana* in Sardinia occur along 26 watercourses and are almost entirely concentrated in the eastern part of the island. They follow an elevation gradient varying from a few metres above sea level up to 900 m a.s.l. on Mount Limbara (Calvia and Ruggero 2020).

Ecologically, Sardinian communities dominated by *Carex panormitana* substantially differ from those described in Sicily. In the latter island, these communities appear to be basiphilous, and their elevation gradient is limited to a stream stretch from 55 to 155 m a.s.l. (Gianguzzi et al. 2013). By contrast, in Sardinia these communities show a clear calcifuge behaviour, preferentially developing along the rocky banks and beds of temporary streams on granitoid substrates and, more rarely, on Palaeozoic schists (Urbani et al. 2013). Moreover, these communities consistently avoid calcareous substrates, even in the vicinity of limestone massifs.

Table 1. Synoptic table showing the percentage constancy (%) of species across the vegetation units identified by hierarchical clustering (UPGMA based on Bray-Curtis dissimilarity). Columns represent the vegetation units *Osmundo regalis*-*Caricetum panormitanae* (Or-Cp, 98 plots), *Mentha aquatica*-*Caricetum panormitanae* (Ma-Cp, 105 plots), *Caricetum pendulo-panormitanae* (Cp-p, 15 plots), and, only for comparison, *Cladietum marisci* from Sardinia (CM, 27 plots). Diagnostic species were identified using the *Indval.g* index ($p < 0.05$) and are highlighted in grey. The abbreviated table includes diagnostic species and companion taxa with an overall constancy $\geq 20\%$ or *Indval.g* $\geq 40\%$.

Association	Or-Cp	Ma-Cp	Cp-p	CM
Number of plots	98	105	15	27
<i>Carex panormitana</i>	100	100	100	.
<i>Dittrichia viscosa</i>	83	39	.	7
<i>Osmunda regalis</i>	72	10	.	.
<i>Erica terminalis</i>	52	10	.	.
<i>Hypericum hircinum</i>	50	3	.	.
<i>Spiranthes aestivalis</i>	44	8	.	.
<i>Bellium bellidioides</i>	39	22	.	.
<i>Solenopsis corsica</i>	36	1	.	.
<i>Samolus valerandi</i>	22	3	20	.
<i>Cladium mariscus</i>	22	.	.	100
<i>Mentha aquatica</i>	27	86	.	.
<i>Oenanthe crocata</i>	8	38	.	.
<i>Cyperus badius</i>	4	29	80	.
<i>Nerium oleander</i>	.	21	.	.
<i>Carex pendula</i>	.	.	87	.
<i>Bidens frondosa</i>	.	.	67	.
<i>Scrophularia umbrosa</i>	.	.	60	.
Characteristic taxa of Phragmito-Magnocaricetea				
<i>Lythrum salicaria</i>	24	23	47	37
<i>Phragmites australis</i>	1	2	.	100
<i>Eupatorium cannabinum</i>	.	13	40	.
<i>Pulicaria dysenterica</i>	.	1	67	.
<i>Nasturtium officinale</i>	.	1	27	.
<i>Helosciadium nodiflorum</i>	.	.	93	.
<i>Equisetum telmateja</i>	.	.	80	.
<i>Scrophularia auriculata</i>	.	.	27	.
Characteristic taxa of Alno-Populetea				
<i>Alnus glutinosa</i>	30	32	.	.
<i>Brachypodium sylvaticum</i>	6	4	53	.
<i>Ficus carica</i>	5	7	33	.
<i>Fraxinus angustifolia</i>	.	.	47	.
<i>Hedera helix</i>	.	.	27	.
Characteristic taxa of Salicetea purpureae				
<i>Salix atrocinerea</i>	31	21	.	.
<i>Salix alba</i>	.	.	60	.
Characteristic taxa of Armerietea vulgaris				
<i>Melissa officinalis</i> subsp. <i>altissima</i>	.	.	40	.
<i>Urtica dioica</i>	.	.	40	.
<i>Piptatherum miliaceum</i>	.	.	27	.
Characteristic taxa of Molinio-Arrhenatheretea				
<i>Scirpoides holoschoenus</i>	9	17	47	.
<i>Polypogon viridis</i>	.	17	73	.
<i>Plantago major</i>	.	1	80	4
<i>Symphyotrichum squamatum</i>	.	1	40	.
<i>Mentha suaveolens</i> subsp. <i>suaveolens</i>	.	.	67	.
<i>Lythrum junceum</i>	.	.	40	.
Characteristic taxa of Quercetea ilicis				
<i>Rubus ulmifolius</i>	34	13	.	.
<i>Smilax aspera</i>	27	7	.	.

Association	Or-Cp	Ma-Cp	Cp-p	CM
Number of plots	98	105	15	27
Other taxa				
<i>Juncus articulatus</i>	22	15	.	.
<i>Sonchus oleraceus</i>	1	1	33	.
<i>Persicaria maculosa</i>	.	.	53	.
<i>Erigeron sumatrensis</i>	.	.	47	.
<i>Parietaria judaica</i>	.	.	40	.
<i>Carex divulsa</i>	.	.	33	.
<i>Helminthotheca echioides</i>	.	.	27	.
<i>Solanum lycopersicum</i>	.	.	27	.
<i>Atriplex prostrata</i> subsp. <i>triangularis</i>	.	.	27	.
<i>Trachelium caeruleum</i>	.	.	27	.

In addition, in Sardinia these communities are heliophilous and generally more abundant in streams lacking riparian tree cover. Occasionally, they can develop in partially shaded environments, such as *Alnus glutinosa* gallery forest margins, although we did not survey them in this study. In the southern part of the island, these herb dominated communities can be found within stream corridors dominated by *Nerium oleander* thickets. On the contrary, Sicilian communities appeared to be more shade tolerant, developing under abundant *Arundo donax* formations and dense gallery forests dominated by *Salix pedicellata*, *Platanus orientalis*, and *Populus nigra* (Gianguzzi et al. 2013). However, Sardinian communities dominated and co-dominated by *Carex panormitana* tend to disappear where both *Arundo donax* and *Phragmites australis* become dominant.

Classification

The association described for Sicily was named *Caricetum pendulo-panormitanae*, and was classified in the alliance *Phragmition communis* (order *Phragmitetalia*, class *Phragmito-Magnocaricetea*) (Gianguzzi et al. 2013). These authors reported several species characteristic of this class (e.g., *Cyperus badius*, *Helosciadium nodiflorum*, *Lycopus europaeus*, and *Nasturtium officinale*). However, within their plots, they also recorded elements belonging to the classes *Alno glutinosae-Populetea albae*, *Epilobietea angustifolii*, *Molinio-Arrhenatheretea*, and *Papaveretea rhoeadis*.

Interestingly, this association hosts a high percentage of non-native taxa, being 12 out of 66, thus accounting to 18% of the recorded taxa (Gianguzzi et al. 2013). Among them, the most relevant were *Bidens frondosa* (which was classified as characteristic of the association), *Erigeron sumatrensis*, *Symphyotrichum squamatum*, and *Solanum lycopersicum*, whereas the invasive *Arundo donax* was described as a dominant species of most streambanks. According to the authors, *Caricetum pendulo-panormitanae* represents a nemoral, semi-sciaphilous, basiphilous, hygro-nitrophilous and edapho-hygrophilous association with a vernal optimum generally extending from the second half of April to the end of June.

This association was later reported as doubtfully present also in Sardinia (Venanzoni et al. 2018). However, the

Sardinian formations are clearly differentiated from the Sicilian ones, primarily from an ecological perspective, being strictly calcifuge, non-hygro-nitrophilous, and for their typically heliophilous character, earlier vernal optimum, but extending from late March to late July.

Most northern Sardinian rhizophytic communities dominated by *Carex panormitana* were previously attributed to the alliance *Caricion microcarpae* (currently synonymised to *Osmundo-Alnion glutinosae*) (Urbani et al. 2013). However, considering more accurately the environmental requirements of the species, the communities should instead be referred to tall-sedge formations along streambanks, classified to the alliance *Magnocaricion elatae* (order *Magnocaricetalia*, class *Phragmito-Magnocaricetea*). In specific contexts, these communities show close floristic and spatial relationships with aspects of the alliance *Osmundo-Alnion glutinosae*. However, despite the frequent occurrence of diagnostic species of this class (e.g., *Hypericum hircinum*, *Osmunda regalis*), these formations develop in fully open environments lacking tree cover and suitable conditions for the establishment of riparian forests. Rather than representing degraded stages of riparian gallery forests, they should therefore be interpreted as distinct syntaxa belonging to two different classes that display catenal relationships along the Mediterranean stream systems. In this framework, formations of the *Magnocaricetea* preferentially occupy stream reaches with rocky and steep banks, whereas communities of *Alno glutinosae-Populetea albae* develop along wider streambeds with deeper soils and fewer rocky outcrops.

Likewise, communities from south-eastern Sardinia were initially assigned to shrub communities of the alliance *Nerio oleandri-Salicion purpureae* (currently not recognised in FloraVeg), and to riparian forest communities of the alliance *Salicion albae*, both within the class *Salicetea purpureae* (order *Salicetalia purpureae*) (Urbani et al. 2013). Our numerical classification, however, allowed most of these communities to be more accurately referred to the alliance *Magnocaricion elatae*. Nonetheless, in particular conditions and along the southernmost streams, *Carex panormitana* can also be found within the alliance *Rubio ulmifolii-Nerion oleandri* (class *Nerio-Tamaricetea*, order *Tamaricetalia africanae*).

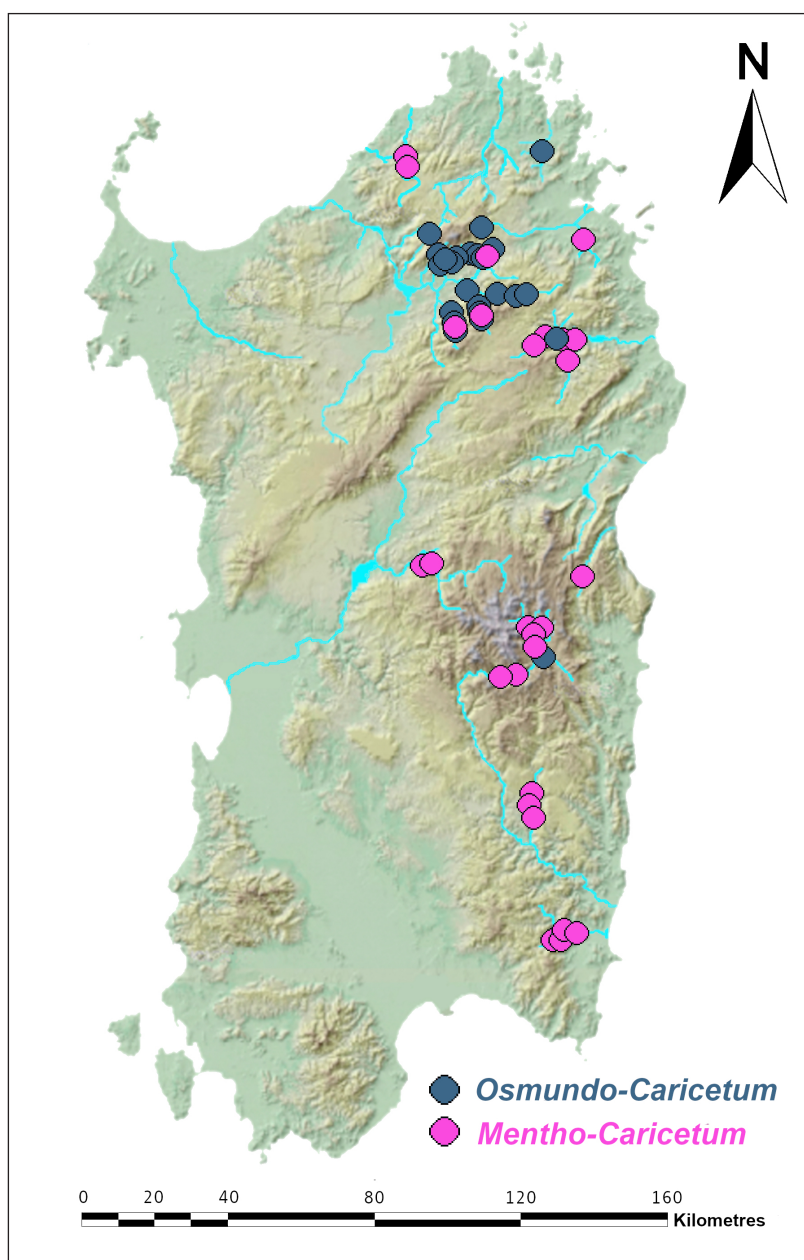


Figure 4. The distribution of the two Sardinian communities (*Osmundo regalis*-*Caricetum panormitanae* and *Mentho aquatica*-*Caricetum panormitanae*) based on our analyses.

Differently from the Sicilian plots, the Sardinian ones showed a more natural floristic composition, with a poorer presence of non-native taxa. These were totally absent in the *Osmundo-Caricetum*, whilst in the *Mentho-Caricetum* they were six out of 101 and principally concentrated along a single partly degraded stream. Only *Paspalum distichum* was recorded in a few other sites, being found in nine out of 105 plots. Conversely, within the Sardinian communities we recorded nine endemic taxa, with *Bellium bellidioides* being the most frequent.

Finally, the new associations are strongly differentiated from the only syntaxon belonging to the order *Magnocaricetalia* previously reported for Sardinia through published plots (Giau 1986), namely *Cladietum marisci*. The latter association is characterised by a constant presence

of *Phragmites australis* and is overall paucispecific, being more typical of almost permanently swamped shores of standing waters.

Description of new associations

Osmundo regalis*-*Caricetum panormitanae Calvia, Urbani, Mascia, Bertotto, Genduso et Bonari ass. nov. hoc loco Suppl. material 1: table S1, plots 1–98 (Figures 2, 4, 5A, B).

Holotypus: Plot 68 in Suppl. material 1: table S1 [locality: Alà dei Sardi (Olbia-Tempio) Rio Cantares de Uda (Italy); 5 October 2022; coordinates: WGS84, 40.710654°N, 9.244523°E; Area: 10 m²; elevation: 392 m a.s.l.; aspect:



Figure 5. Pictures depicting the two Sardinian associations with *Carex panormitana*. *Osmundo regalis*-*Caricetum panormitanae*, A (Oschiri, Su Rizzolu, 06/10/2022), B (Berchidda, Rio Terramala, 30/06/2022); *Mentho aquatica*-*Caricetum panormitanae*, C (Seui, Flumendosa, 19/07/2023), D (Burcei, Rio Picocca, 07/04/2023). Photo credits: G. Calvia.

351 N; slope: 5°; *Carex panormitana* 3, *Dittrichia viscosa* 1, *Osmunda regalis* 1, *Erica terminalis* 2, *Hypericum hircinum* 1, *Spiranthes aestivalis* +, *Solenopsis corsica* +, *Rubus ulmifolius* 2, *Juncus articulatus* +, *Samolus valerandi* +, *Cladium mariscus* 3, *Schoenus nigricans* 1].

Diagnostic species (Constancy >20%, *IndVal.g* >40%): *Carex panormitana*, *Osmunda regalis*, *Dittrichia viscosa*, *Hypericum hircinum*, *Erica terminalis*, *Spiranthes aestivalis*, *Solenopsis corsica*, *Bellium bellidioides*, *Cladium mariscus*, *Samolus valerandi* (Table 1).

Structure: Mixed vegetation dominated primarily by herbaceous taxa and, more rarely, by shrubby elements of low to medium stature (50 cm to ca. 2.5 m), chiefly *Osmunda regalis* and *Carex panormitana*, with local occurrences of other Cyperaceae such as *Cladium mariscus* and *Schoenus nigricans*. These assemblages develop on moist rocks and cliffs near riparian banks or within streambeds, often forming dense clumps. Tree species are usually absent, whereas a shrubby component may be represented by *Erica terminalis*, *Hypericum hircinum*, and more rarely *Myrtus communis*. Within these shrub patches, the presence of rare or endemic species such as *Spiranthes aestivalis*, *Bellium bellidioides*, and *Solenopsis corsica* is frequent.

Ecology: The association develops along the middle reaches of intermittent streams flowing over intrusive

igneous substrates, typically occupying rocky and stony microsites along the banks or within the streambeds. It mainly occurs between 190 and 750 m a.s.l., although in rare cases it may reach 900 m a.s.l. The geology of the sites is linked to homogeneous monzogranites and leucogranites (Carmignani et al. 2016). The prevailing bioclimate corresponds to the MPO type, ranging from Lower Meso-Mediterranean, Lower Subhumid, Weakly Eu-oceanic to Upper Meso-Mediterranean, Upper Sub-humid, Weakly Eu-oceanic conditions in the southern sectors of Mount Limbara, where the highest stands occur (Canu et al. 2015).

Dynamics: The association is heliophilous and edapho-hygrophilous, occurring in poorly developed, nutrient-poor soils, often in rocky and structurally degraded environments.

Syntaxonomy: The association is classified within the alliance *Magnocaricion elatae*, order *Magnocaricetalia*, and class *Phragmito-Magnocaricetea*.

Chorology: This association comprises formations dominated by the endemic *Carex panormitana* and *Osmunda regalis*, growing mostly on granitic substrates of north-eastern Sardinia, mostly within the Coghinas hydrographic basin, Goceano-Logudorese biogeographic sector and the Gallurese sub-sector (Fenu et al. 2014), from lowlands to low mountain areas.

Variability: Based on our analyses, two main variants can be distinguished within this association. The first is more typical of mid- to high-hill belts, although it may occasionally occur at lower elevations. In this variant, the characteristic species almost invariably include *Carex panormitana*, *Osmunda regalis*, and *Dittrichia viscosa*, with frequent occurrences of *Erica terminalis* and the sporadic appearance of shrubby *Salix atrocinerea*. Rare or endemic herbaceous species such as *Spiranthes aestivalis*, *Bellium bellidioides*, *Solenopsis corsica*, and occasionally *Carex microcarpa* are more commonly encountered. The tree layer is generally absent, with only sporadic occurrences of *Alnus glutinosa* and *Salix atrocinerea*.

The second variant is more frequently observed in low-hill environments, where species such as *Cladium mariscus* or *Lotus rectus* are more frequent, while *Erica terminalis* becomes less common and woody riparian shrubs (*Salix* spp. and *Alnus glutinosa*) are mostly absent.

***Mentha aquatica*-*Caricetum panormitanae* Calvia, Urbani, Bertotto, Genduso et Bonari ass. nov. hoc loco**
Suppl. material 2: table S2, plots 1–105 (Figures 2, 4, 5C, D).

Holotypus: Plot 39 in Suppl. material 2: table S2 [locality: Padru (Olbia-Tempio) Rio Neolti (Italy); 22 July 2023; coordinates: WGS84, 40.663213°N, 9.461415°E; Area: 10 m²; elevation: 172 m a.s.l.; aspect: n/a; slope: 0°; *Carex panormitana* 4; *Mentha aquatica* 3; *Dittrichia viscosa* 2; *Oenanthe crocata* 2; *Cyperus badius* 3; *Agrostis stolonifera* 3; *Potentilla reptans* +; *Dorycnium rectum* 2; *Juncus acutus* 2].

Diagnostic species (Constancy >20%, IndVal.g >40%): *Carex panormitana*, *Mentha aquatica*, *Oenanthe crocata*, *Cyperus badius*, *Nerium oleander* (Table 1).

Structure: Low herbaceous tussocks growing on rocky streambanks and streambeds, locally forming a mosaic with riparian shrublands of torrential watercourses (herbaceous layer 40 cm to 1.2 m tall; shrub layer 1–5 m tall). The herbaceous layer is primarily dominated by *Carex panormitana* and *Mentha aquatica*, which often form bi-specific to holo-specific tussocks on stony islands and rocky riverbanks (Figure 5C). The woody layer, where present, is represented by sparse shrubs of species such as *Nerium oleander*, *Alnus glutinosa*, and *Salix* spp. This vegetation type is heliophilous and frequently develops at the margins of riparian scrub formations. The accompanying herbaceous layer typically includes wetland species such as *Cyperus badius*, *Oenanthe crocata*, *Lythrum salicaria*, *Polypogon viridis*, and *Scirpoides holoschoenus*, while the occurrence of species such as *Bellium bellidioides*, *Solenopsis corsica*, and *Spiranthes aestivalis* is comparatively reduced.

Ecology: The association typically develops along watercourses with abundant stony substrates on the banks or within the streambed, where persistent soil moisture locally allows the establishment of shrubs and small trees. It occurs from approximately 70 to nearly 900 m a.s.l. The geological substrates are mainly granitoids and Palaeozoic schists (Carmignani et al. 2016). The prevailing

bioclimate belongs to the MPO zone, ranging from Upper Thermo-Mediterranean belt, Lower Dry ombrotype, Semihyperoceanic Weak conditions in lowland and southernmost sectors, to Upper Meso-Mediterranean belt, Upper Humid ombrotype, Eu-oceanic weak conditions at higher elevations, near the foothills of Gennargentu massif (Canu et al. 2015).

Dynamics: The association is calcifuge and heliophilous, with a scattered presence of shrubs. It spans a gradient from fully open, well-lit environments to the margins of pioneer stands of *Alnus glutinosa*, where the development of a true gallery forest is constrained by the rocky nature of the streambanks. It preferentially occupies stony banks of low-flow temporary streams, both under natural conditions and in regimented sections such as those along the middle reach of River Flumendosa.

Syntaxonomy: The association is classified within the alliance *Magnocaricion elatae*, order *Magnocaricetalia*, and class *Phragmito-Magnocaricetea*.

Chorology: This association comprises endemic formations dominated by *Carex panormitana* and *Mentha aquatica*, occurring on siliceous substrates in south-eastern and central-eastern Sardinia, whereas in northern Sardinia it is restricted to scattered localities, ranging from sub-coastal zones to low-mountain streams.

Variability: Two variants can be found one typical of the sectors of northern and central Sardinia, which is mostly characterised by herbs with very few shrubs, and another occurring mainly in southern sectors and at lower elevations under warmer climatic conditions, favouring the development of *Nerium oleander* formations.

Conclusion

Herbaceous vegetation of Sardinian rocky and stony streambanks and streambeds has received little phytosociological attention despite its high degree of naturalness and conservation value. This study provides the first comprehensive numerical classification of plant communities dominated and co-dominated by *Carex panormitana* in Sardinia, clarifying the ecology and distribution of this Habitats Directive priority endemic species. Numerical analyses clearly distinguished the Sardinian communities from the Sicilian *Caricetum pendulo-panormitanae*, supporting the recognition of two new associations, *Osmunda regalis*-*Caricetum panormitanae* and *Mentha aquatica*-*Caricetum panormitanae* in the alliance *Magnocaricion elatae*. However, phytosociological analyses of the riverine communities formed by this species in Tunisia are still lacking. Both Sardinian associations are referred to the alliance *Magnocaricion elatae* within the class *Phragmito-Magnocaricetea*, expanding the knowledge of a syntaxonomic group that has so far been largely overlooked in Sardinia. Many communities associated to *Carex panormitana* occur outside protected areas and are increasingly exposed to hydrological alterations and other anthropogenic pressures, such as prolonged drought periods, flash floods, dam construction

projects, intense grazing by free livestock, and expansion of invasive alien species. Therefore, the recognition and characterisation of these vegetation types represent an essential step towards improving habitat assessment, conservation planning (through the creation of new protected areas, reduction of impacts from free grazing and alien species), and future monitoring of Mediterranean seasonal stream ecosystems.

Syntaxonomic scheme

PHRAGMITO–MAGNOCARICETEA Klika in Klika et Novák 1941

MAGNOCARICETALIA Pignatti 1953

MAGNOCARICION ELATAE Koch 1926

Osmundo regalis–Caricetum panormitanae Calvia, Urbani, Bertotto, Genduso et Bonari in Calvia et al. 2026 ass. nov. hoc loco

Mentho aquaticae–Caricetum panormitanae Calvia, Urbani, Bertotto, Genduso et Bonari in Calvia et al. 2026 ass. nov. hoc loco

PHRAGMITION COMMUNIS Koch 1926

Caricetum pendulo–panormitanae Gianguzzi, Cusimano, Ilardi et Romano 2013 in Gianguzzi et al. 2013

Acknowledgements

The authors are grateful to all the people that in different ways helped them in this research. We thank Antonello Batzu, Pasqualina Carta, Alessandro Di Giacomo, Rossella Filigheddu, Silvia Macis, Maria Teresa Pinna Urbani, Alessandro Ruggero, Andrea Ruiiu, Alessandro Sanna, Philipp Schramm, Alessia Tatti, and Gabriella Vacca for providing support during field excursions across various parts of Sardinia.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical issues are associated with this work.

Artificial Intelligence (AI) use

AI-assisted tools were used exclusively for language editing and readability improvements. All scientific content, interpretations, and conclusions were developed and verified by the authors.

Funding

This research received no external funding.

Author contributions

Conceptualisation: GC, MU, GBo; Data curation: GC; Investigation: GC, MU, GBe, EG; Analysis: GC; Methodology: GC, GBo; Visualisation: GC; Writing (original draft): GC; Writing (review and editing): all authors. GC identified the plants.

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Data availability

The vegetation plot data underlying this study are provided as Supplementary Material associated with this article. The dataset generated during the study, including the synoptic tables, is also included as Supplementary Material. The data are also included in the CircumMed database (GIVD: EU-00-026).

Supplementary material

Supplementary material 1

table S1. Ordered plot table of the *Osmundo regalis*-*Caricetum panormitanae* (.xlsx).

Link: <https://doi.org/10.3897/VCS.196138.suppl1>

Supplementary material 2

table S2. Ordered plot table of the *Mentho aquaticae*-*Caricetum panormitanae* (.xlsx).

Link: <https://doi.org/10.3897/VCS.196138.suppl2>

Supplementary material 3

Additional data to the tables S1, S2 with the geographic references, dates and collector of each plot (.pdf).

Link: <https://doi.org/10.3897/VCS.196138.suppl3>

Supplementary material 4

Complete synoptic table (.xlsx).

Link: <https://doi.org/10.3897/VCS.196138.suppl4>