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Monitoring of Habitats in a Coastal Dune System Within the "Arco Ionico" Site (Taranto, Apulia)

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Abstract: Although dune systems play a crucial ecological role and offer various ecosystem services, they are listed among the habitat types of community interest in the European Union that are undergoing the most severe conservation challenges. The subject of this study was the monitoring of habitat types protected under Directive 92/43/EEC (Habitats Directive) along the coastal dune systems of the Taranto Ionian Arc. Vegetation sociological surveys, GIS mapping, landscape metrics, NBR and dNBR indices were employed to assess the conservation status of the dune system and the impact of disturbance factors. Special attention was given to habitat 2250* (Coastal dunes with *Juniperus* spp.), revealing that it expanded from 2006 to 2019 but then significantly reduced between 2019 and 2022, with increasing fragmentation, mainly due to wildfires. The study also highlighted the impact of invasive species such as *Acacia saligna* and *Carpobrotus acinaciformis*, which compete for space and vital resources. These findings provide scientific evidence for the management and restoration of coastal dune ecosystems, emphasizing the need for targeted conservation strategies to mitigate the effects of these disturbances.

Keywords: costal environment; costal vegetation; habitats directive; remote sensing; phytosociology; alien species; Mediterranean flora; habitat mapping

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1. Introduction

The coastal environment is a transitional zone between sea and land. It is characterized by highly dynamic morphologies that continuously adapt to meteorological and marine forces, achieving a state of dynamic equilibrium [1]. Sediments of both alluvial and marine origin are constantly influenced by a combination of physical, chemical, and biological agents, which are fundamental to the formation and structuring of dunes [2]. The dune environment represents a system of microhabitats that are particularly hostile to plant life. The species that colonize these coastal areas are, therefore, highly specialized and adapted to occupy these unique environments [1,3]. These species often play a crucial role in the formation, stabilization, and geomorphological evolution of coastal dune systems, promoting the accumulation of sandy sediments, preventing their continuous inland advancement, and initiating pedogenetic processes. The vegetation landscape of the dunes thus represents a complex system governed by various ecological gradients, particularly related to wind and salinity, extending from the sea towards the interior. Along these gradients, environmental conditions change rapidly, defining a precise and well-defined spatial sequence of habitats, the so-called "standard zonation" [4–6]. Despite the ecological significance of dune systems and their associated services, dune habitats are among those of community interest that have been reported in the last EU Reporting as being in bad conservation state [7]. Therefore, their periodic and consistent monitoring in terms of extent, status, and changes is crucial, as it may provide an effective tool for environmental management [8].

Among the habitat types listed in Annex I of the 92/43/EEC Directive, the "Coastal dunes with *Juniperus* spp." (priority habitat 2250*) exemplifies the significant impact of the strong interrelationship between biotic and abiotic components on the presence and distribution of plant communities within dune systems. The occurrence of this habitat is indeed determined by factors arising from the presence of other species and habitats, such as substrate stabilization and protection from coastal erosion. Additionally, this habitat falls under "Types of natural habitats in danger of disappearing from the territory" (92/43/EEC Directive, Art. 1, sub. d [9]), and its conservation state has been assessed as "unfavorable-bad" in both Italy and the Mediterranean biogeographic region. Within the study area, the dominant species in the "Coastal dunes with *Juniperus* spp." is *Juniperus macrocarpa* Sm., a juniper species typical of Mediterranean coasts, ranging from SW Spain to western Turkey and from Morocco to Cyrenaica (Libya) up to the Black Sea and Syria [10,11]. The fragility of this species, primarily due to the low seed germination rate and the slow seedling development [12–14], makes habitat 2250* vulnerable to adverse effects from disturbance factors such as fires, coastal erosion, and other human activities.

The Ionian Arc of Taranto is a vast, arc-shaped area facing the Ionian side of the Apulian territory, extending almost entirely within the province of Taranto (southern Apulia). This area is characterized by an orographic formation marked by a succession of terraces descending from the Murge plateau to the sea. Along the coast, this site is characterized by some of the most extensive dune systems in southern Italy. The presence of several habitat types of community importance (according to the 92/43/EEC Directive [9]) has led to the institution of numerous conservation measures for biodiversity, as well as protected areas. Among the latter is the State Biogenetic Reserve "Stornara", located close west of Taranto, which is the subject of this study.

The present study aimed to investigate the dune system along a section of the coastal strip of the Ionian Arc (Figure 1), with particular attention to shrub formations dominated by *Juniperus macrocarpa*. The main objectives of this study were (a) to characterize the dune system in terms of vegetation and habitat types, (b) to identify the best indicators for defining the conservation status of habitats, and (c) to define the conservation status of habitat 2250* and identify the main disturbance factors affecting it.

Figure 1. Coastal dune system within the "Arco Ionico" Site. Scale 1:40,000. The red lines delimit the study area.

2. Materials and Methods

2.1. Study Area

The area of this study is the coastal strip of the Ionian Arc (Italy), extending 6 km from the mouth of the Tara River in the east to the western boundary of the "Patemisco Section" of the "Stornara" State Biogenetic Reserve. The nature reserve (1456 hectares) was established by a ministerial decree on 13 July 1977 in order to protect the coastal pine forest dominated by *Pinus halepensis* Mill., which extends over most of the reserve's area. In 1997, the Stornara Reserve merged into a single forest complex with the 45-hectare Marinella Stornara Reserve, which was also established in 1977. The coast is low and consists of Quaternary continental sediments, predominantly alluvial sands. The area falls within an upper thermo-Mediterranean lower dry bioclimatic belt [15], with arid periods lasting up to 5 months and low precipitation, averaging around 500 mm annually, concentrated in the winter months. These characteristics make it the second-largest area with minimal rainfall in Apulia and the entire Italian Peninsula [16]. The study area is characterized by an extensive dune system, where the most mature woody vegetation is represented by the *Juniperus macrocarpa* community and by *Pinus halepensis* pine forests, the latter mainly of anthropogenic origin [16].

2.2. Vegetation Analysis

In 2022–2023, vegetation data were collected with a dual purpose: (a) to characterize the plant communities present in the study area and (b) to validate the habitat map created through photointerpretation. The phytosociological survey was conducted according to the Zurich-Montpellier school [17]. The nomenclature of the species was based on "A second update to the checklist of the vascular flora native to Italy" [18] and on www.actaplantarum.org website, accessed on 14 November 2024 [19]. The plot sizes varied from 2 m^2 to 200 m^2, depending on the microtopography and vegetation type. Forty-seven phytosociological relevés were produced and distributed using a stratified random method within the study area. These relevés were then organized into a matrix consisting of 47 (objects) relevés × 58 (variables) taxa. Cover values were transformed according to the method proposed by van der Maarel [20] (Table 1), and the dataset was subsequently subjected to multivariate analysis (cluster analysis) using the flexible beta clustering method and Bray–Curtis coefficient [21]. The optimal number of clusters was identified using the Silhouette index calculated using the "cluster" package [22]. The statistical, hierarchical classification and diversity indices were performed using R 4.2.3 software [23]. In particular, the hierarchical classification was carried out using the "vegan" package [24]. Shannon index and Simpson index were calculated using incidence frequency data through iNEXT Online [25,26]. Using the multipatt function from the "indicspecies" package [27], we calculated Pearson's phi coefficient for each resulting group [28,29]. Indicator species for each cluster were identified based on the phi value. The resulting groups were assigned to specific vegetation types according to the most recent phytosociological literature available for the study area or the Italian peninsula [16,30–32]. Finally, using habitat interpretation manuals [33,34], each association was attributed to the corresponding habitat type according to the Annex I of the 92/43/EEC Directive. All relevés were geocoded using a World Geodetic System (WGS84) and integrated into a geodatabase using QGIS 3.28 [35], thus allowing for the verification and possible correction of the habitat distribution produced through photointerpretation. The higher rank syntaxa reported in the synyaxonomical scheme follow Mucina et al. [36], with the exception of the *Laguro ovati-Vulpion fasciculatae* Géhu et Biondi 1994 and of the *Cisto cretici-Micromerietea* Oberdorfer ex Horvatić 1958, for which we followed Brullo et al. (2001) [32] and Tomaselli et al. (2024) [37], respectively.

Table 1. Braun-Blanquet cover values and Van Der Maarel conversion values.

Categories	Coverage Value	Conversion Values
Rare species	r	1
Negligible coverage (<1%)	+	2
Coverage between 1% and 5%	1	3
Coverage between 6% and 25%	2	5
Coverage between 16% and 50%	3	7
Coverage between 51% and 75%	4	8
Coverage between 76% and 100%	5	9

2.3. Habitat Mapping

The study area was delineated using QGIS 3.28 software on orthophotos of the Apulian territory, retrieved from the website www.sit.puglia.it, accessed on 25 October 2023 via WMS (Web Map Service). Subsequently, a preliminary habitat map of the habitat types according to Annex I of the 92/43/EEC Directive present in the study area was created through photointerpretation. The cartographic reference system used was based on UTM (Universal Transverse Mercator) coordinates, specifically EPSG 32633. A diachronic analysis was then performed by using orthophotos dating back to the years 2006, 2013, 2019, and 2022 to map habitat 2250*; for the other habitats (2110, 2230, 2240, 2260, 2270*, 3150), the mapping was based on orthophotos from 2019 and 2022 (also obtained from www.sit.puglia.it, accessed on 25 October 2023).

Based on the produced habitat maps, various landscape metrics were calculated using the LecoS—Landscape Ecology Statistics plugin (ver. 3.0.1) [38] (Table 2), which is based on metrics from the spatial pattern analysis program FRAGSTATS [39,40]. For metric calculation, habitat maps were converted from vector to raster format, with pixel sizes of 1 m. Table 2 presents the calculated spatial metrics. Five raster layers were created:

- The first layer consisted of seven classes: Habitat 2110, Habitat 2230, Habitat 2240, Habitat 2250*, Habitat 2260, and Habitat 2270*, all referring to 2022.
- The remaining four layers consisted of two classes each: one including patches representing the potential distribution of habitat 2250*, i.e., areas that, due to abiotic and spatial features (distance from the sea, soil type, elevation, relationships with other habitats), could host this habitat, that is, its potential distribution area. The second class of each layer consisted of patches representing the actual distribution of habitat 2250*; these four layers refer to the years 2006, 2013, 2019, and 2022, respectively.

Table 2. Landscape metrics calculated for measuring habitat fragmentation.

Metric	Formula
Land cover	$LC = \sum_{j=1}^{n} aij$
	aij: area (m²) of patch j of class i
Edge length	$EL = \sum_{k=1}^{m} eik$
	eik: total length (m) of the edges of patch k of class i
Edge density	$ED = \frac{\sum_{k=1}^{m} eik}{A}(10,000)$
	A: total area of the landscape (m²)
Number of patches	$NP = ni$
	ni: number of patches of class i in the landscape

Table 2. *Cont.*

Metric	Formula
Patch density	$PD = \frac{ni}{A}(10,000)(100)$
Mean patch area	$MPA = \frac{\sum_{j=1}^{n} aij}{ni}$
Largest patch index	$LPI = \frac{max_{j=1}^{n} aij}{A}(100)$
Fractal Dimension Index	$FDI = \frac{\sum_{j=1}^{n} \frac{2\ln(025pij)}{lnaij}}{ni}$
	pij: perimeter (m) of patch *j* of class *i*
Mean patch shape ratio	$MSPR = \frac{\sum_{j=1}^{n}\left(\frac{0.25pij}{\sqrt{aij}}\right)}{ni}$
Patch cohesion index	$PCI = \left[1 - \frac{\sum_{j=1}^{n} pij^*}{\sum_{j=1}^{n} pij^* \sqrt{aij^*}}\right]\left(1 - \frac{1}{\sqrt{z}}\right)^{-1}(100)$
	pij∗: perimeter of patch *ij* in terms of the number of cells that compose its surface
	aij∗: area of patch *ij* in terms of the number of cells that compose its surface
	Z: total number of cells in the landscape

2.4. Conservation Status (Zonation)

To assess the conservation status of the vegetation along the dune belt, transects were performed in the field, following the guidelines provided by the Habitat Monitoring Italian Manual [41]. In the case of complex mosaics, such as dune systems, transect sampling is the most appropriate procedure to quantify vegetation heterogeneity along environmental gradients from the shoreline to inland areas [41]. Vegetation data were collected along a series of contiguous 2 × 2 m plots perpendicular to the coastline, using the "belt transect" method [42]. The plots were arranged from the vegetation zone closest to the shoreline to the more structurally complex dune vegetation found further inland, typically corresponding to the *Juniperus macrocarpa* vegetation (habitat 2250*). The positions of the first and last plots of each transect were georeferenced, and the transects were mapped using QGIS. In each plot, vegetation was recorded based on species composition and cover and then assigned to a habitat type in accordance with Annex I to the 92/43/EEC Directive. The sequence of habitats, from the closest to the sea to the most inland vegetation, was compared to the dune zonation model of Italian dunes [34], presented in Table 3, to evaluate the conservation status.

Table 3. Reference model for the habitat zonation, according to "Zonazione delle dune italiane" by Biondi (1999).

ID Zone	1	2	3	4	5	6
Vegetation	*Euphorbion peplis*	*Sporobolo-Elytrigenion juncei*	*Medicagini-Ammophiletion australis*	*Cracianellion maritimae*	*Malcolmietalia*	*Juniperion turbinatae*
Habitat code	1210	2110	2120	2130	2230	2250*

2.5. Assessment of Fire Impact

The Normalized Burned Ratio (NBR) and differenced Normalized Burn Ratio (dNBR) indices were calculated using LANDSAT TM/ETM+ satellite images to assess the impact of wildfires in the study area and determine the years when the most extensive and significant fire events occurred between 2000 and 2022. The Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) sensors are ideal for analyzing fire impacts because they record reflectance in the near-infrared (NIR) and shortwave infrared (SWIR) bands, corresponding to band 4 (B4) and band 7 (B7), respectively. Band 4 detects wavelengths between 0.76 µm and 0.90 µm, while band 7 covers the range between 2.08 µm and 2.35 µm [43].

Reflectance in band 4 of the Landsat TM/ETM+ sensors is mainly influenced by leaf structure and internal leaf discontinuities [44]. In contrast, band 7 is sensitive to soil and vegetation water content, lignin in non-photosynthetic plants, and the presence of hydrated minerals such as clay, oxides, and sulfates [45,46]. The selection of the Normalized Burn Ratio (NBR) and its derivative, the differenced Normalized Burn Ratio (dNBR), is particularly relevant for assessing habitat conditions, as these indices effectively capture changes in vegetation cover and moisture content after disturbances such as fires. As shown by Soverel et al. [43], NBR and dNBR are sensitive to the spectral reflectance characteristics of plant materials in the near-infrared and shortwave infrared bands, allowing for precise differentiation between burned and unburned areas [45].

The Normalized Burned Ratio (NBR) and differenced Normalized Burn Ratio (dNBR) indices are calculated as follows:

- **NBR** = (NIR − SWIR)/(NIR + SWIR);
- **dNBR** = (NBR pre-fire − NBR post-fire).

The dNBR can be used to estimate fire severity, also known as "burn severity". An increasing dNBR value indicates higher fire severity. Table 4 presents dNBR values in relation to burn severity, as proposed by the United States Geological Survey (USGS) [47].

Table 4. Severity level of fires obtained by calculating dNBR, as proposed by USGS.

Severity Level	dNBR Range (Multiplied by 10^3)
Unburned	−100 a 99
Low severity	+100 a +269
Moderate low severity	+270 a +439
Moderate high severity	+440 a +659
High severity	+660 a +1300

3. Results

3.1. Vegetation Analysis

The resulting dendrogram from the hierarchical cluster analysis (Figure 2) shows a first division into two main clusters: cluster A and cluster B. Cluster A includes vegetation dominated by annual and perennial herbaceous species. This cluster is further subdivided into two subgroups: A1 and A2. Cluster A1 includes vegetation types typical of the zones closest to the sea, characterized by both annual species (e.g., *Cakile maritima* Scop. subsp. *maritima*) and perennials (*Thinopyrium junceum* (L.) Á. Löve); cluster A2 consists of vegetation types typical of the so-called "therophytic grasslands", rich in annual herbaceous species that form mosaic with the perennial communities of the dune and backdune areas. Cluster B includes plant communities dominated by shrub species located in the more inland and stable zones of the dune systems. Table 5 illustrates the vegetation communities assigned to each group identified through the clustering analyses.

Figure 3 illustrates the results obtained from the silhouette analysis conducted to validate the group division; the average silhouette width of 0.33 obtained at a 10-group partition can be considered good. Table 5 lists the vegetation communities associated with each group.

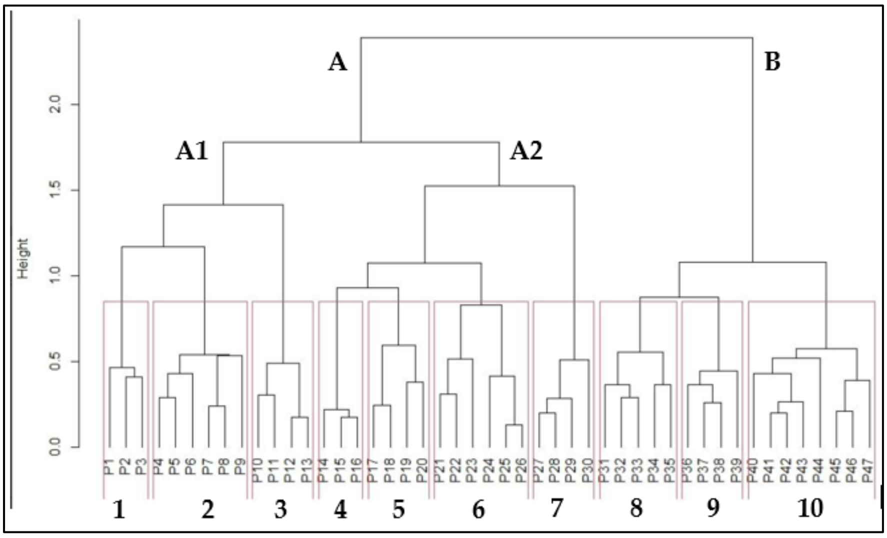

Figure 2. Dendrogram obtained from cluster analysis.

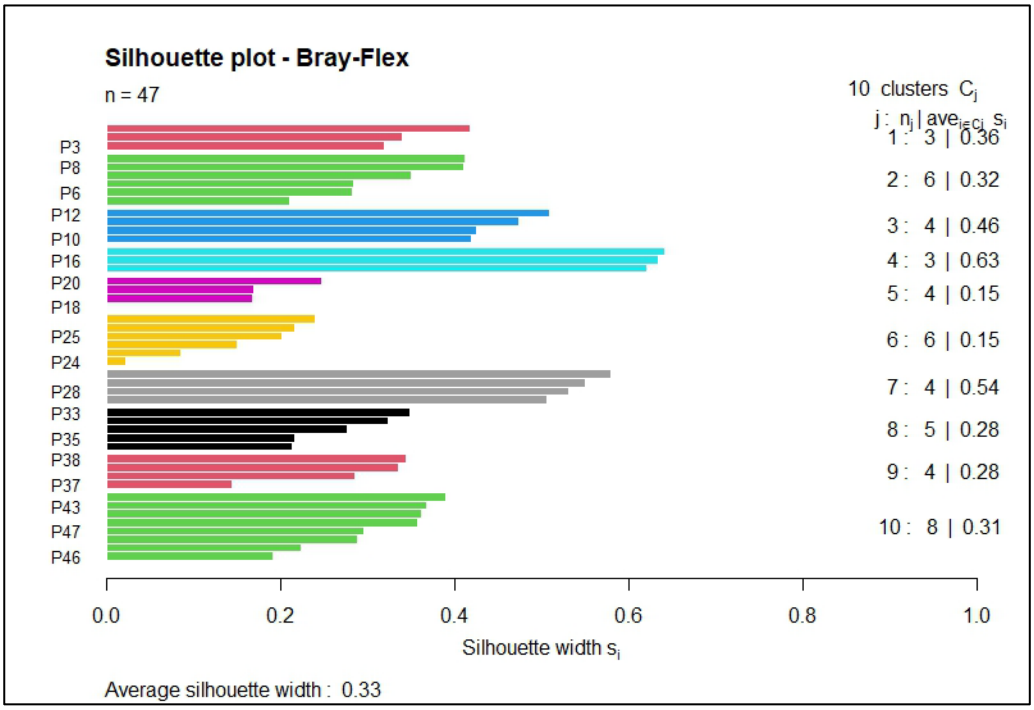

Figure 3. Silhouette plot of the Bray–Flexible beta clustering; each color identifies a different group, from 1 (top) to 10 (bottom).

Table 5. Vegetation communities assigned to the different groups obtained from cluster analysis.

Group	Association
1	*Salsolo kali-Cakiletum aegyptiacae*
2	*Echinophoro spinosae-Elymetum farcti*
3	*Helianthemum lippii* community
4	*Sileno otitis-Helianthemum lippii*
5	*Sileno coloratae-Vulpietum membranaceae*

Table 5. *Cont.*

Group	Association
6	*Sileno coloratae-Vulpietum membranaceae* var. *Medicago littoralis*
7	*Ancuso hybridae-Plantaginetum albicantis*
8	*Pistacio lentisci-Rhamnetum alaterni*
9	*Phillyrea angustifolia* community with *Acacia saligna*
10	*Asparago acutifolii-Juniperetum macrocarpae*

The syntaxonomic scheme and the descriptions of the plant communities corresponding to the different groups defined by the cluster analysis are provided below.

CAKILETEA MARITIMAE Tüxen & Preising ex Br.-Bl. & Tüxen 1952
THERO-ATRIPLICETALIA Pignatti 1953
EUPHORBION PEPLIDIS Tx. ex Oberd. 1952
Salsolo-Cakiletum maritimae Costa & Mansanet 1981 corr. Rivas-Martínez et al. 1992
AMMOPHILETEA Br.-Bl. et Tx. ex Westhoff et al. **1946**
AMMOPHILETALIA Br.-Bl. et Tx. ex Westhoff et al. 1946
AMMOPHILION Br.-Bl. 1921 *Echinophoro spinosae-Elymetum farcti* (Braun-Blanquet 1933) Géhu 1988
HELIANTHEMETEA GUTTATI Rivas Goday et Rivas-Mart. **1963**
MALCOLMIETALIA Rivas Goday 1958
LAGURO OVATI-VULPION FASCICULATAE Géhu et Biondi 1994
Ancuso hybridae-Plantaginetum albicantis Corbetta et al. 1989
Sileno coloratae-Vulpietum membranaceae (Pignatti 1953) Géhu & Scoppola 1984
Ononis variegata community
CISTO CRETICI-MICROMERIETEA Oberdorfer Ex Horvatić 1958
CISTO CRETICI-ERICETALIA MANIPULIFLORAE Horvatić 1958
CISTO CRETICI-ERICION MANIPULIFLORAE Horvatic 1958
Sileno otitis-Helianthemetum lippii Costanzo & Tomaselli 2024
QUERCETEA ILICIS Br.-Bl. ex A. Bolòs et O. de Bolòs in A. Bolòs y Vayreda 1950
PISTACIO LENTISCI-RHAMNETALIA ALATERNI Rivas-Martinez 1975
JUNIPERION TURBINATAE Rivas-Martinez 1975 corr. 1987
Asparago acutifolii-Juniperetum macrocarpae R. &R. Molinier ex O. Bolòs 1962
OLEO-CERATONION SILIQUAE Br.-Bl. ex Guinochet & Drouineau 1944 em. Riv.-Mart. 1975
Pistacio lentisci-Rhamnetum alaterni Rivas-Martínez 1975
Phillyrea angustifolia community

Vegetation Description

Salsolo kali-Cakiletum maritimae **Costa & Mansanet 1981, corr. Rivas-Martínez et al., 1992 (Table A1)**

Indicator species: *Cakile maritima* Scop. subsp. *maritima*, *Salsola tragus* L.

Structure and Ecology: This is a pioneer annual and ephemeral community, among the most widespread along the Mediterranean coasts. It is characterized by the presence of halophytic and nitrophilous therophytes with succulent habits, colonizing the initial part of the emerged beach where organic material deposited by the sea accumulates. This community is highly prevalent in areas subjected to significant anthropogenic activity [16,32].

Echinophoro spinosae-Elymetum farcti **(Braun-Blanquet 1933) Géhu 1988 (Table A2)**

Indicator species: *Thinopyrum junceum* (L.) Á. Löve, *Echinophora spinosa* L.

Structure and ecology: This is a perennial, psammophilous community of embryonic dunes characterized by the dominance of *Thinopyrum junceum*. During the field survey, this association was found in further inland than expected, with evidence of belt inversion. Additionally, in degraded areas, *Pancratium maritimum* L. was observed as a dominant species.

***Sileno coloratae-Vulpietum membranaceae* (Pignatti 1953) Géhu & Scoppola 1984 (Table A3)**

Indicator species: *Silene colorata* Poir., *Festuca pyramidata* Link

Structure and Ecology: This is an annual herbaceous plant community dominated by *Silene colorata* and *Festuca pyramidata*. It develops mostly on the backdune and forms mosaics with other associations, especially with the *Juniperus macrocarpa* communities. Two distinct aspects of this association were identified: one typical of steeper substrates, loose sands, and a more pioneer character; another in more sheltered stations with substrates richer in organic matter. The latter is characterized by the presence of *Medicago littoralis* Rohde ex Loisel. (see relevés 6–10, Table A3). This plant community belongs to the *Laguro ovati-Vulpion fasciculatae* Géhu et Biondi 1994, an alliance framed by its authors in the *Malcolmietalia* Rivas Goday 1958, where we believe it is correct to be maintained, contrary to what was proposed by Mucina et al. (2016).

***Ononis variegata* community (Table A4)**

Indicator and Ecology: This community is characterized by the presence of a few annual species, typical of therophytic grasslands, with a strong dominance of *Ononis variegata*. This vegetation occurs on stable dunes and in open areas, often forming mosaics with the *Ammophiletea* communities or with the shrub vegetation of the *Pistacio-Rhamnetalia alaterni*.

***Ancuso hybridae-Plantaginetum albicantis* Corbetta et al. 1989 (Table A5)**

Indicator Species: *Plantago albicans* L.

Structure and Ecology: This is a plant community rich in therophytes, physiognomically dominated by the suffruticose chamaephyte *Plantago albicans*, which often achieves high cover, forming extensive carpets. It is found in the more stable part of the dune, in dry depressions in the innermost sections of dune ridges, and even within the middle of the neighboring pine woods.

***Sileno otitis-Helianthemum lippii* Tomaselli & Costanzo 2014 (Table A6)**

Indicator species: *Silene otitis* (L.) Wibel, *Helianthemum lippii*

Structure and ecology: This is an open, chamaephytic shrub community, typically a garrigue, characterized by the presence and dominance of *Helianthemum lippii*. It is often accompanied by other small shrubs, such as *Cistus creticus* subsp. *Eriocephalus*, *Lotus creticus*, and hemicryptophytes such as *Silene otitis* and *Sixalix atropurpurea*. *Helianthemum lippii* is a species with a geographical distribution that extends from the southern Mediterranean to the Middle East and thrives on sandy substrates [48]. In the Italian peninsula, it is located along the coasts of the Ionian Arc in Apulia in the more stable sections of dune systems. These garrigues are usually in contact with *Juniperus macrocarpa* shrubs, often forming complex mosaics [37].

***Asparago acutifolii-Juniperetum macrocarpae* R. & R. Molinier ex O. Bolòs 1962 (Table A7)**

Indicator species: *Juniperus macrocarpa* Sm.

Structure and ecology: This is a dense shrub vegetation characterized by the presence of *Asparagus acutifolius* L., *Pistacia lentiscus* L., and *Rubia peregrina* L., with *Juniperus macrocarpa* as the dominant species. This association is widely distributed in Mediterranean territories, typically thriving on stable dunes [49]. In the study area, it typically occurs between the pine forests and the herbaceous and chamaephytic communities of the mobile dunes. In areas of significant coastal erosion, this association can be found at short distances from the sea.

***Pistacio lentisci-Rhamnetum alaterni* Rivas-Martínez 1975 (Table A8)**

Indicator species: *Pistacia lentiscus* L., *Rhamnus alaternus* L.

Structure and ecology: The shrub vegetation of the Mediterranean maquis is dominated by *Pistacia lentiscus* and *Rhamnus alaternus*. It is typically found on the more stable and inner dune ridges, between juniper thickets and pine forests. This vegetation represents the most mature successional stage of the dune ridge ecosystem.

Maquis vegetation with *Acacia saligna*

Structure and ecology: This shrub community, physiognomically structured by *Phillyrea angustifolia*, shows the structure and floristic composition typical of Mediterranean maquis but is distinguished by the presence and dominance of *Acacia saligna* (Labill) H.L.Wendl., an invasive alien species. *Acacia saligna* often takes over maquis communities that are subjected to significant disturbance factors, such as wildfires. This community has been found in areas typically occupied by *Asparago acutifolii-Juniperetum macrocarpae* and *Pistacio lentisci-Rhamnetum alaterni* associations, where it displaces them due to the rapid colonization and growth abilities of *Acacia saligna*.

3.2. Conservation Status (Zonation)

When comparing the observed transects to the reference model, the most frequent deviation is the absence of habitats typical of the inland dune zones. These habitats have been replaced by vegetation types capable of growing and spreading following disturbance events (e.g., fires), such as the maquis with *Acacia saligna* (Transects 8 and 10; Figure 4). Additionally, a limited presence or complete absence of habitats typical of areas closer to the sea, specifically habitat 1210 and habitat 2110, was observed (Transects 6 and 8; Figure 4). In fact, these transects were made in areas characterized by severe coastal erosion or areas previously affected by fires. This reflects the overall conditions of the study area, which alternates between sections in good conservation status and areas severely impacted by disturbance agents. Figure 4 shows the spatial distribution of the transects conducted within the study area, while Figure 5 provides a graphic and concise representation of the sequence of communities and habitats identified along the transects. Each plot is represented by a box, the color of wich corresponds to the habitat identified in that specific plot; a legend is also provided, associating the different colors with the community (indicated by the dominant species) and the corresponding habitat type.

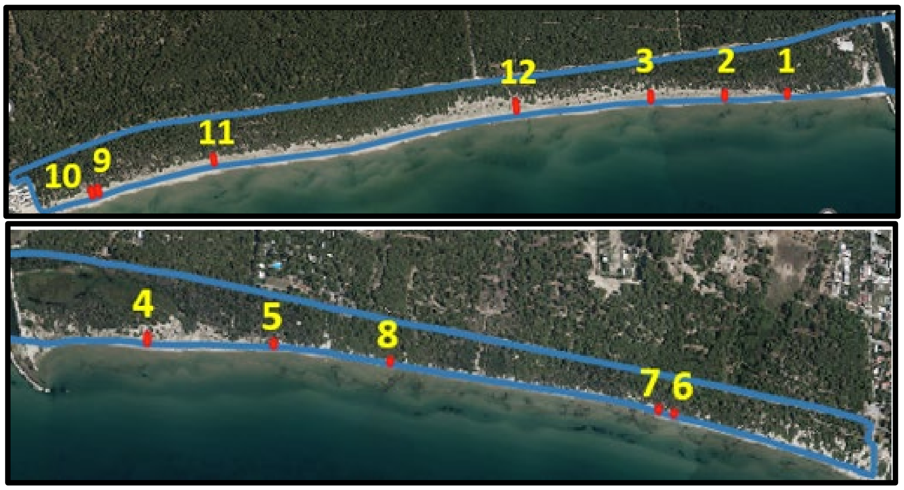

Figure 4. Transects mapped on orthophotos of the eastern and western sections of the study area at a 1:20,000 scale, obtained from www.sit.puglia.it, accessed on 25 October 2023. The numbers refer to the chronological order in which the transects were performed.

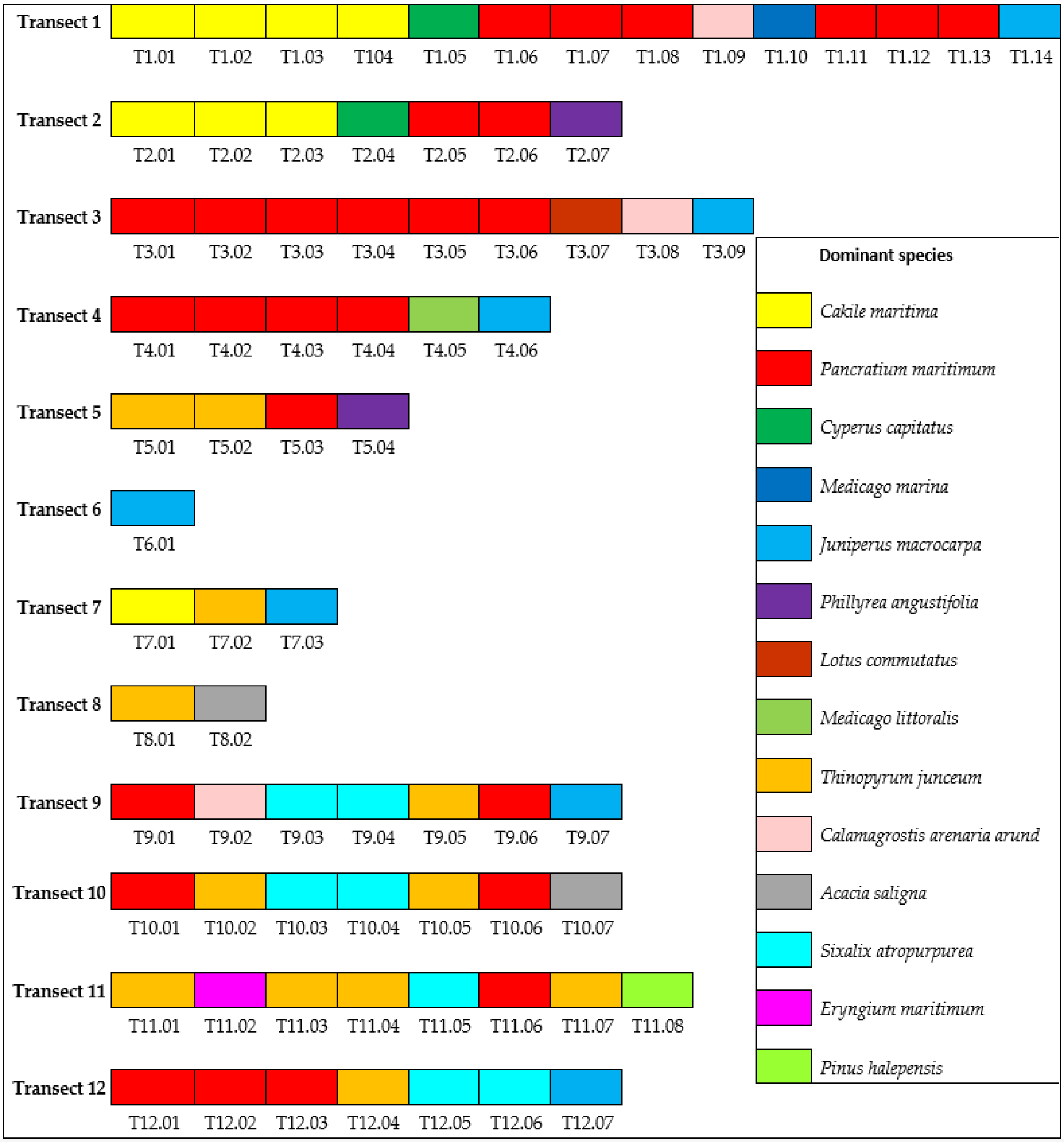

Figure 5. Chart showing the sequences of plant communities identified through the transects.

3.3. Habitat Mapping

Figure 6 presents the habitat map of the study area, which covers a total surface of 74 hectares. Of this area, 70% is occupied by habitats listed in Annex I of the Habitats Directive.

Habitat 2270* covers 25% of the area and consists of *Pinus halepensis* pine forests, primarily located in backdune areas; in coastal stretches severely affected by erosion, this habitat is found in close proximity to the sea.

Habitat 2260 occupies approximately 23% of the surface and is represented by scrub and garrigue vegetation, primarily situated on stabilized dunes between juniper shrubs and pine forests.

Habitat 2110 covers 9.6% of the area and is found on embryonic dunes, representing the habitat closest to the sea in most of the studied area.

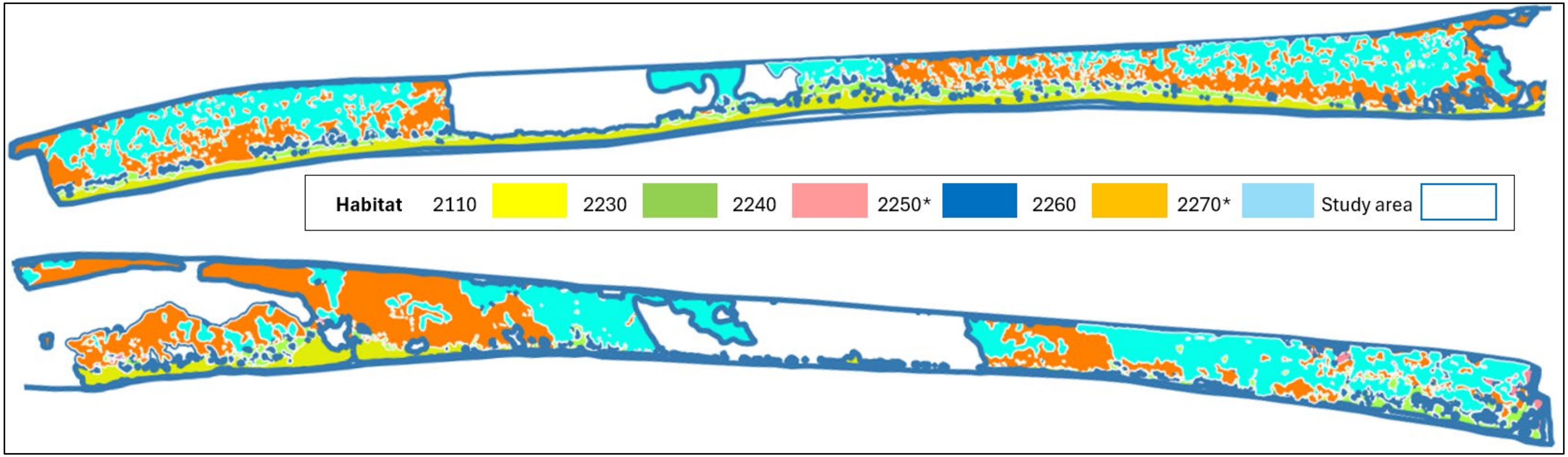

Figure 6. Western section and eastern section of the habitat map of the study area. Scale 1:8000.

Habitat 2230 accounts for 6% of the surface and includes therophytic grasslands that often form mosaics with the vegetation of other habitats located either inland or near the sea, depending on the degree of coastal erosion.

Habitat 2250* is present on 3.8% of the area and occurs on stabilized dunes, often in contact with pine forests and scrub communities on the more inland side and with *Thinopyrum* grasslands and therophytic meadows on the seaward side.

Habitat 2240 covers only 0.67% of the area and is primarily found in inland locations, often within pine forests.

Habitat 1210, although present at the site, is extremely fragmented and occupies such small surfaces that it could not be mapped.

Habitat 2120 is represented by a few isolated nuclei of *Calamagrostis arenaria* (L.) Roth subsp. *arundinacea* (Husn.) Banfi, Galasso & Bartolucci (=*Ammophila arenaria* (L.) Link), which also could not be mapped.

3.4. Diachronic Analysis of Habitat 2250 (2006–2022) and Class Metrics*

Figure 7 shows the distribution maps for habitat 2250* for the years 2006, 2013, 2019, and 2022, while Table 6 presents the values of several class metrics for the same observation periods. The most notable finding is the increase in surface area (LC) of this habitat from 2006 to 2019, followed by a decline, likely due to wildfires occurring between 2019 and 2022. This trend is highlighted by an increase in the number of patches (NP) and patch density (PD) from 2006 to 2013, followed by a decline between 2019 and 2022. The rise in the number of patches (NP) from 2006 to 2013 was accompanied by a reduction in the mean patch area (MPA). However, MPA increased from 2013 to 2022. This suggests that individual juniper vegetation patches, where not affected by wildfires, underwent expansion during the 2019–2022 period.

Table 6. Results of the calculated metrics for habitat 2250* for the years 2006, 2013, 2019, and 2022.

Year	Land Cover (m^2)	Edge Length (m)	Edge Density (m/ha)	Number of Patches	Patch density (No/m^2)	Mean Patch Area (m^2)	Largest Patch Index (%)	Fractal Dimension Index	Mean Patch Shape Ratio	Patch Cohesion Index
2006	20,526	7756	0.066	86	0.00073	238.67	1.03	1.133	0.00019	9.471
2013	22,366	8546	0.072	101	0.00085	221.45	1.05	1.127	0.46161	9.479
2019	31,522	10,344	0.087	100	0.00085	315.22	1.38	1.134	0.40623	9.560
2022	28,256	8804	0.074	78	0.00066	362.26	1.45	1.134	0.00017	9.589

Further evidence of this is provided by the increase in the Largest Patch Index (LPI) from 2006 to 2022, indicating a growing dominance of this habitat within the area. Additionally, the Patch Cohesion Index (PCI), which measures the aggregation of patches, also increased from 2006 to 2022. This indicates enhanced physical connectivity between patches, likely due to an increase in the covered area in non-fire-affected zones.

The Edge Density (ED) and Edge Length (EL), as well as the Fractal Dimension Index (FDI), assess the geometric complexity of the class in question. ED and EL consistently increased until 2019 and then declined between 2019 and 2022, probably as a result of large juniper areas being destroyed by the fires.

The rise in the Fractal Dimension Index (FDI) from 2013 to 2022 reflects a constant increase in the complexity of patch shapes, probably deriving from the alternating processes of patch expansion and fire events.

The trend for habitat 2250* indicates an expansion in both the number of patches and the area they cover. However, this expansion is observed only in areas where the habitat patches have not been impacted by wildfires. The occurrence of fires during the period from 2019 to 2022 resulted in a reduction of the total area covered by the habitat, thereby interrupting this positive trend.

Year	2006	2013	2019	2022	2022	
Habitat 2250*					Burned area	

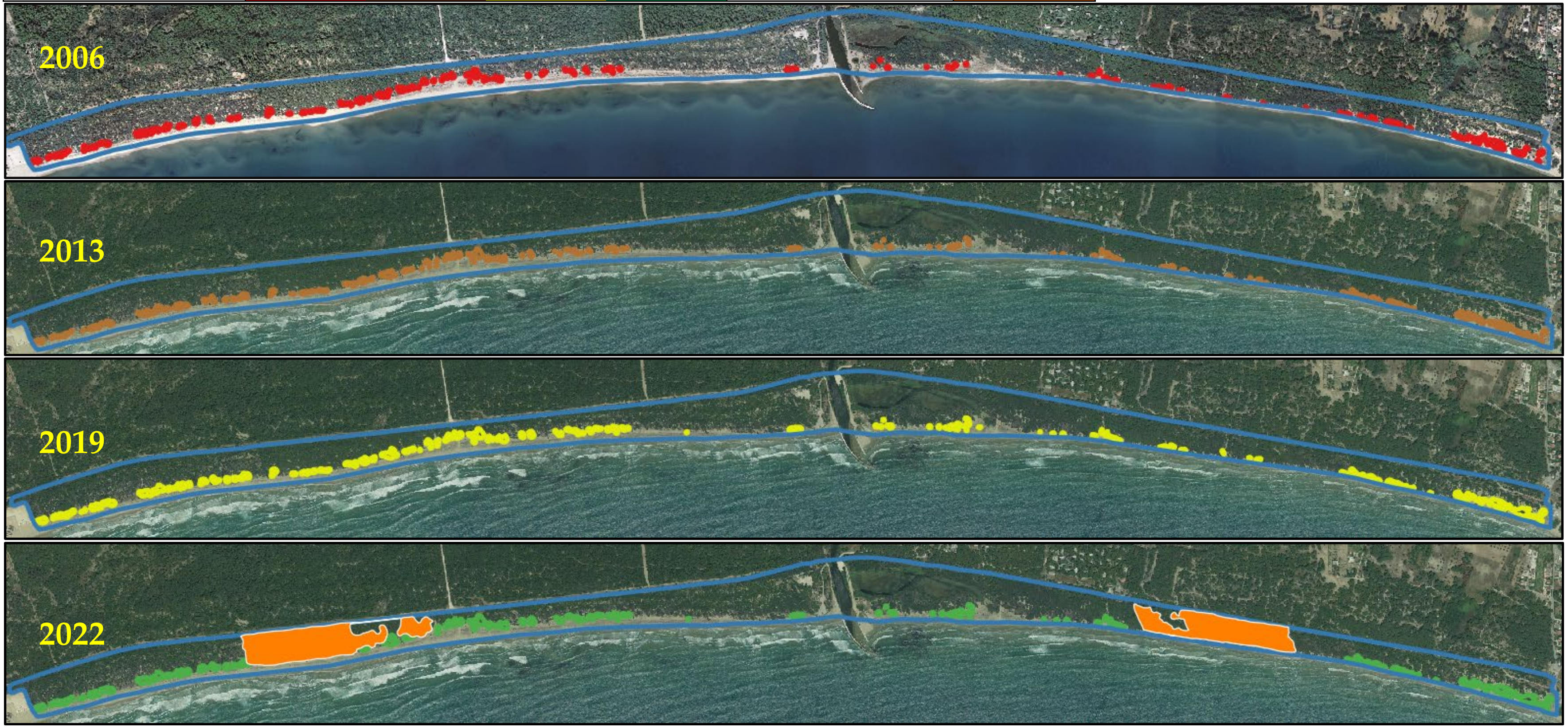

Figure 7. Habitat 2250* maps created using orthophotos obtained from www.sit.puglia.it, accessed on 25 October 2023 from 2006, 2013, 2019, and 2022; the blue line bounds the study area.

Figures 8–10 summarize the trends of the various landscape metrics considered.

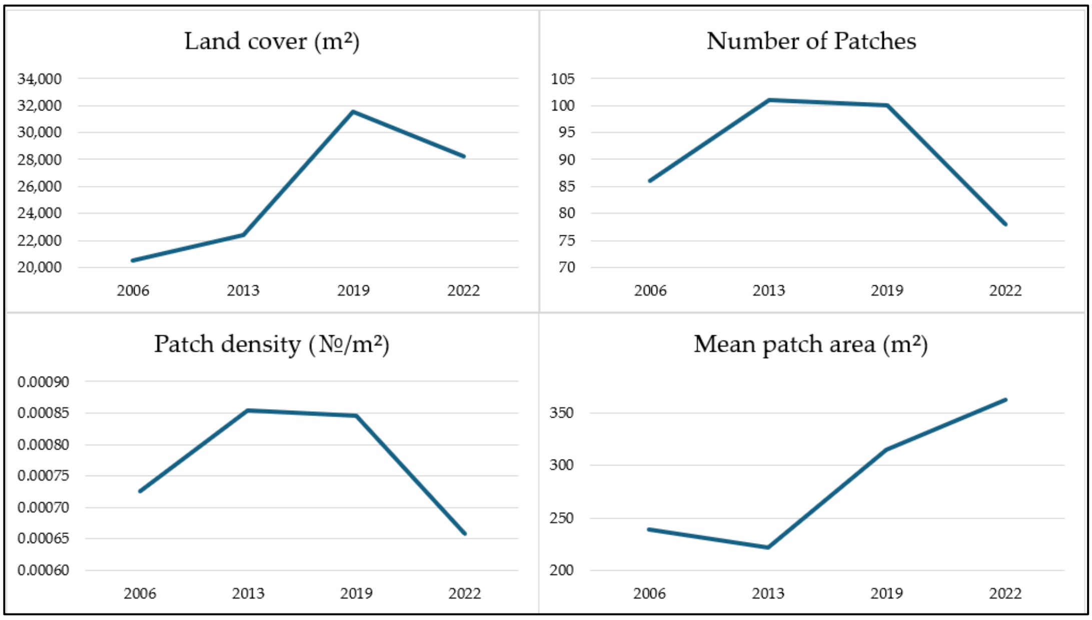

Figure 8. Trends in the values of LC, NP, PD, and MPA for habitat 2250* over the period 2006–2022.

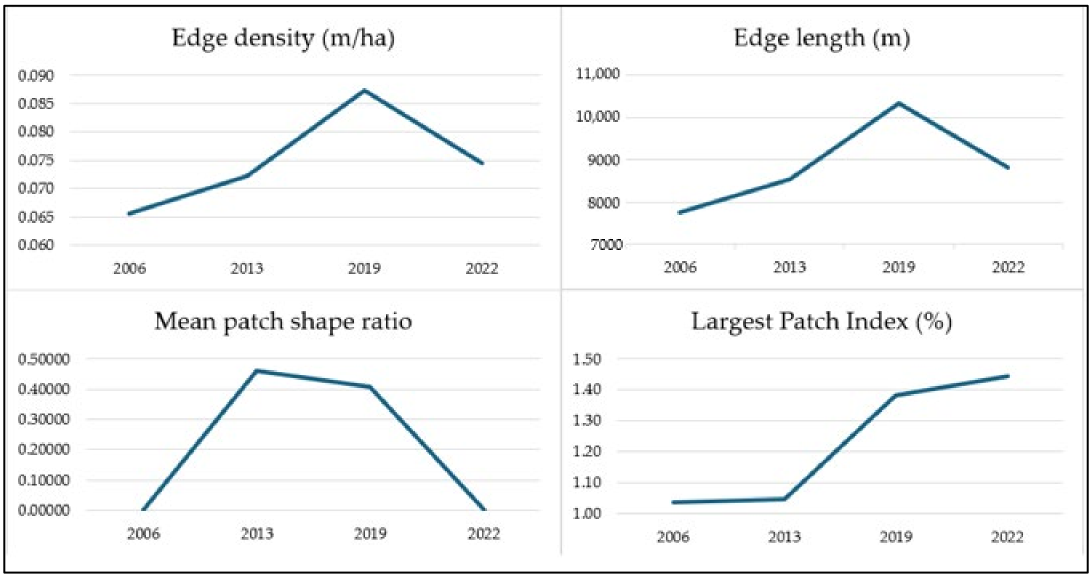

Figure 9. Trends in the values of ED, EL, MPSR, and LPI for habitat 2250* over the period 2006–2022.

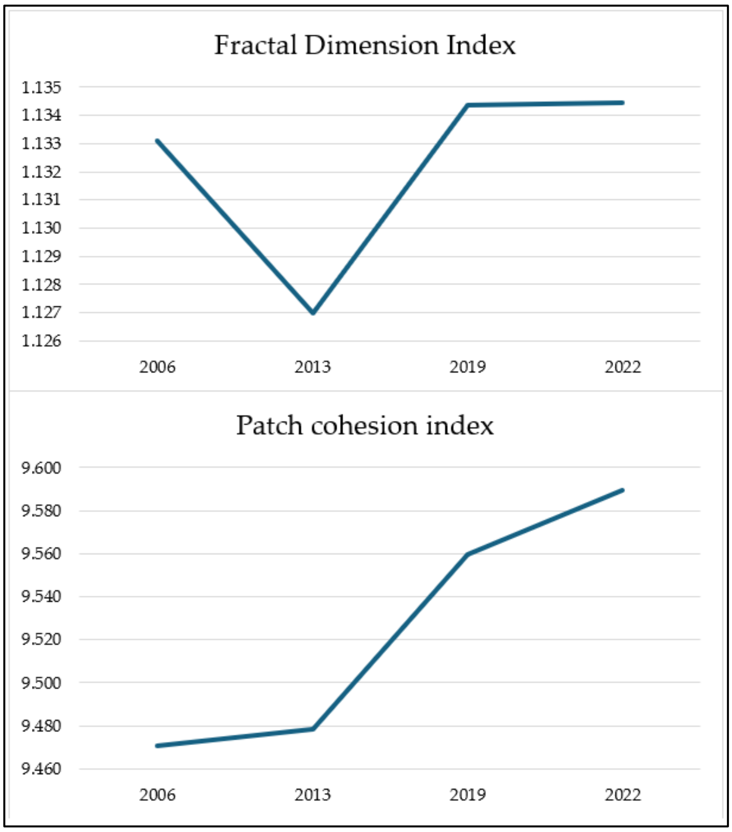

Figure 10. Trends in the values of FDI and PCI for habitat 2250* over the period 2006–2022.

3.5. Class Metrics of Dune Habitats

Table 7 summarizes the values of the class metrics for all the habitat types identified in the study area in 2022. The main observations are listed below.

Table 7. Results of the calculated metrics for each habitat identified in the study area.

Habitat	Land Cover (m^2)	Landcover (%)	Edge Length (m)	Edge Density (m/ha)	Number of Patches	Patch Density (No/m^2)	Mean Patch Area (m^2)	Largest Patch Index (%)	Fractal Dimension Index	Mean Patch Shape Ratio	Patch Cohesion Index
No Habitat	230,144	30.81	35,928	0.048	172	0.000230	1338.05	12.10	1.10	2.7092	9.921
2110	71,776	9.61	11,944	0.016	28	0.000037	2563.43	6.91	1.21	0.0006	9.893
2230	44,920	6.01	23,600	0.032	369	0.000494	121.73	1.68	1.17	0.0011	9.676
2240	5040	0.67	2856	0.004	59	0.000079	85.42	0.10	1.18	0.0009	8.793
2250*	28,240	3.78	8580	0.011	73	0.000098	386.85	0.23	1.13	0.0003	9.224
2260	179,136	23.98	39,312	0.053	153	0.000205	1170.82	6.05	1.19	0.0006	9.856
2270*	187,684	25.13	29,848	0.040	71	0.000095	2643.44	5.90	1.16	0.0004	9.864

In the study area, Habitat 2110 has the fewest patches (NP) and low Patch Density (PD) but the largest Mean Patch Area (MPA). Habitat 2230, found across all dune zones, has the highest number of patches and PD due to its inclusion of vegetation mosaics. Habitat 2240 has the smallest coverage and very few patches, with a low PD and small MPA. Habitat 2250* also has low coverage (LC) and a high degree of fragmentation, with few patches and a low MPA. Habitat 2260, which covers a large area, shows high dominance with numerous patches, high PD, and a large MPA. Habitat 2270*,located mainly in the backdune zone, has the highest LC and MPA but fewer patches than Habitat 2260.

3.6. Burn Severity

Using satellite orthophotos from the period 2001–2023, two fires were identified in the study area (Figure 11), both occurring during the 2020–2021 period.

Figure 11. Burned areas within the study area, labeled as A and B.

Figure 12 illustrates the severity of these fires, enabling the assessment of their impact at specific points within the study area. The different colors, as indicated in the legend, represent varying degrees of severity:

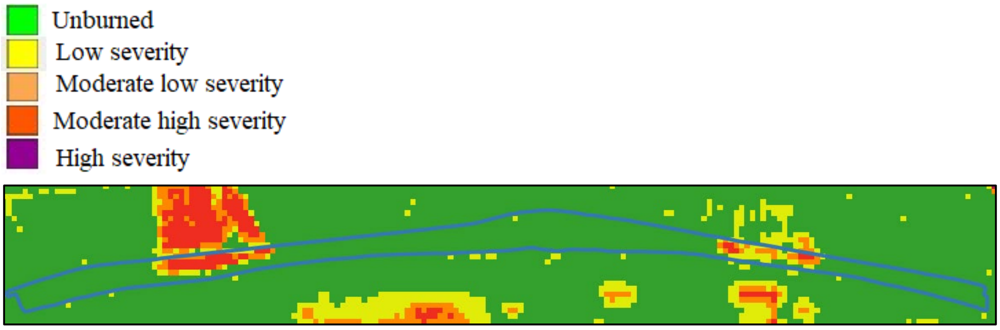

Figure 12. Visual representation of the Burn severity calculated for the 2020–2021 period. Areas with the highest burn severity are highlighted in red, while areas not affected by fire are indicated in green. The blue line delineates the study area.

The vegetation most affected by both wildfires is located in the more internal sections of the dune cordon (areas colored in red), specifically the woody vegetation associated with habitats 2250*, 2260, and 2270*. Field observations revealed that the species with the highest recovery rate in the burned areas is *Acacia saligna*. This recovery occurs at the expense of the species that typically characterize the interior dunes.

3.7. Plant Diversity Analysis

The sampling process yielded an overall coverage of 90.4%. In Figure 13, the species diversity analysis is based on the Hill numbers and species accumulation curves for the plant communities investigated. Diversity curves were constructed using rarefaction (solid lines) and extrapolation (dashed lines) with estimations based on sample size. Shaded areas represent 95% confidence intervals obtained using a Bootstrap method with 100 replications. The lowest coverage was recorded in the *Sileno otitis-Helianthemum lippii*, where only 81% of the species were reported, while the highest was observed in the *Asparago acutifolii-Juniperetum macrocarpae*, with a coverage of 95% (Figure 13). The average species richness (q = 0) across the study area was found to be 16.3 taxa. The *Asparago acutifolii-Juniperetum macrocarpae* demonstrated the most remarkable species richness, hosting 27 observed species, with an estimated range of 13 to 29 species. The eight vegetation plots sampled in this community accounted for 95% of the estimated Sample Coverage (SC). Similarly, the *Pistacio lentisci-Rhamnetum alaterni* showed 21 observed species, with an estimated range between 13 and 29 species, while the maquis with *Acacia saligna* followed closely with 22 species, within an interval of 11 to 21 species (Figure 13). Conversely, the lowest species richness was observed in the *Sileno otitis-Helianthemum lippii* association, which contained only eight species, with a confidence interval ranging from five to eleven species. This was followed by the *Salsolo kali-Cakiletum aegyptiacae*, where 10 species were recorded, within a range of six to ten, and notably, for this association, the species richness recorded from three vegetation plots represented 93% of the estimated SC, indicating that nearly all species present were sampled. Concerning Shannon diversity (q = 1), the *Asparago acutifolii-Juniperetum macrocarpae* was again the most diverse association, with 22 effective species, falling within a confidence interval of 11.49 to 23.65. Moreover, the *Pistacio lentisci-Rhamnetum alaterni* shows a very similar diversity with 17 effective species. In contrast, the least diverse associations were *Sileno otitis-Helianthemum lippii* and *Salsolo kali-Cakiletum aegyptiacae*, with seven and nine effective species, respectively. Other sites exhibited moderate levels of diversity, with species counts ranging from 9 to 19 (Figure 13). Regarding the Simpson diversity (q = 2), the *Asparago acutifolii-Juniperetum macrocarpae* again had the highest number of dominant species, totaling 19, followed closely by the *Pistacio lentisci-Rhamnetum alaterni*, with 17 species. Finally, the *Sileno otitis-Helianthemum lippii* and *Salsolo kali-Cakiletum aegyptiacae* associations exhibited the lowest dominance, with only six and eight dominant species, respectively (Figure 13). In other sites, overlapping confidence intervals indicated similar numbers of dominant species, ranging from 10 to 16.

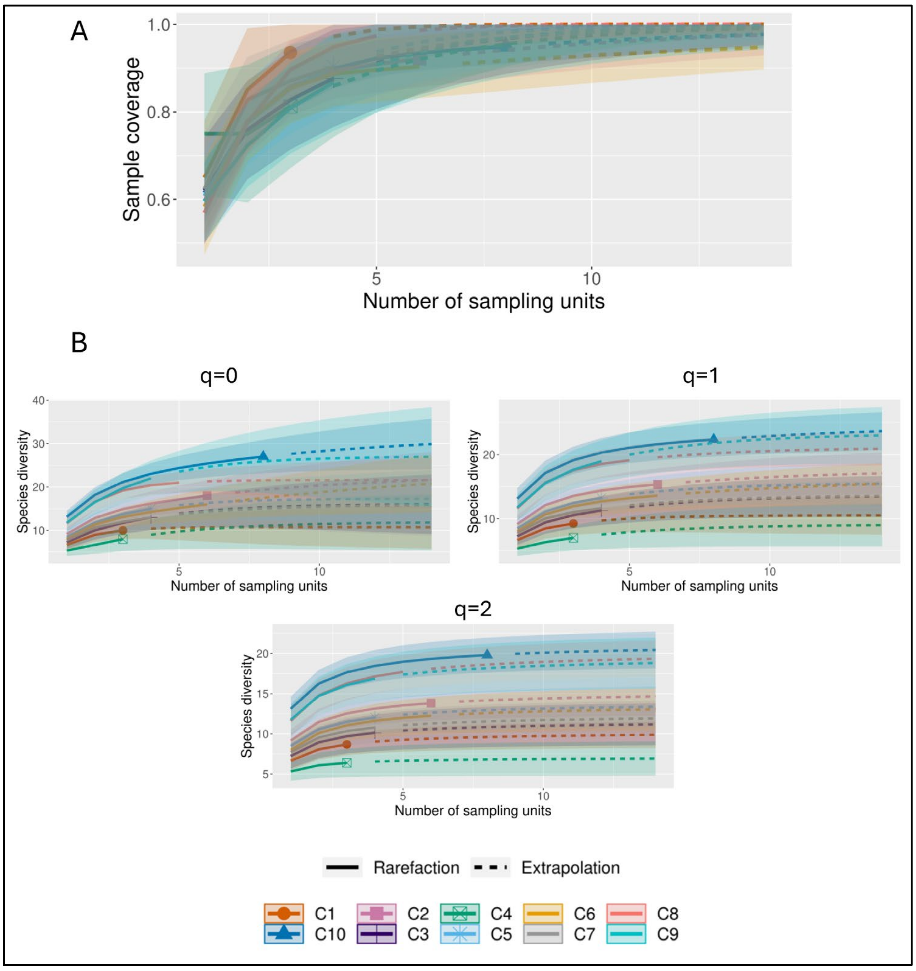

Figure 13. Species diversity analysis based on the Hill numbers and species accumulation curves for the plant communities investigated. (**A**) Sample completeness curve; (**B**) Sample-size-based rarefaction and extrapolation sampling curve: species richness (q = 0); Shannon's index (q = 1) and Simpson's index (q = 2). C1 = *Salsolo kali-Cakiletum aegyptiacae*, C2 = *Echinophoro spinosae-Elymetum farcti*, C3 = *Helianthemum lippii community*, C4 = *Sileno otitis-Helianthemum lippii*, C5 = *Sileno coloratae-Vulpietum membranaceae*, C6 = *Sileno coloratae-Vulpietum membranaceae var. Medicago littoralis*, C7 = *Ancuso hybridae-Plantaginetum albicantis*; C8 = *Pistacio lentisci-Rhamnetum alaterni*, C9 = maquis with *Acacia saligna*, C10 = *Asparago acutifolii-Juniperetum macrocarpae*.

4. Discussion

The study area is characterized by 70% cover of habitat types of community interest. The remaining 30% is largely occupied by vegetation dominated by the invasive alien species *Acacia saligna* or is devoid of vegetation due to fire damage. *Acacia saligna* is known for its rapid spread through suckers and prolific seed production, with its growth particularly favored after disturbance events, especially fires. This proliferation occurs at the detriment of species native to these dune areas, depriving them of resources and, crucially, space to thrive.

Relevant differences in species richness were found between plant communities. The lowest species richness was observed in the *Sileno otitis-Helianthemum lippii* and *Salsolo kali-Cakiletum aegyptiacae* associations. In coastal dunes, the harsh environmental conditions and the pronounced sea-to-land gradients influence the abundance of species and have a significant impact on coastal biodiversity [50,51]. The study area is heavily impacted by anthropogenic disturbance, but studies have shown that when such disturbance is limited in Mediterranean dune ecosystems, plant diversity tends to distribute according to the abiotic tolerances of species, regardless of habitat [52]. This suggests that biodiversity may increase if management actions are implemented. Currently, the plant coastal dune diversity in the study area is shaped by human pressure (e.g., trampling), invasion by alien species (*Acacia saligna* and *Carpobrotus acinaciformis*), and, more generally, tourism and urban development. All these factors have been proven to be crucial elements in shaping dunes [53–55]. In particular, it is well established that the expansion of *Acacia saligna* has negative ecological impacts on the conservation status of habitat 2250* [56].

The high coverage and broad distribution of Habitat 2230, which often occupies open areas and regions devoid of vegetation from other habitats, may indicate the persistence of disturbance factors contributing to the degradation and fragmentation of the dune vegetation. Much of the landscape's features have indeed been shaped by human activities: the area is subjected to significant pressure from beach and tourism activities, resulting in trampling that restricts the spread or causes the fragmentation of habitat types of coastal dune zonation. This is evident in the case of Habitat 1210, which occurs only in limited and fragmented patches within the site so that could not be mapped, or in the case of Habitat 2120, which is only represented by a few sporadic stands of *Calamagrostis arenaria* subsp. *arundinacea* (= *Ammophila arenaria*).

Data obtained from the transects revealed significant differences in the conservation status between different sections of the study area. While a large part of the area shows a habitat distribution very similar to the zonation model used as a reference [34], indicating good conservation status, some stretches exhibit substantial discrepancies from this model. Notably, these degraded conditions were mainly observed in the section east of the Patemisco river mouth, which is the area furthest from the "Sezione Patemisco" of the "Stornara" State Biogenetic Reserve and most heavily used for touristic beach activities, as well as being closest to the city of Taranto. In this area, transects revealed a complete absence of mobile dune vegetation, likely due to erosion or intense trampling. This was accompanied by the loss of typical shrubland vegetation, which has been replaced by *Acacia saligna*, following fire events. The habitats 2250* and 2260, frequently affected by fires and, in some stretches, dominated by the presence of *Acacia saligna* (often widely spread), show a higher degree of fragmentation compared with the more inland habitats, like 2270*. The conservation status of stabilized dune habitat types is closely linked to the presence and maintenance of mobile dune vegetation, which, in the study area, is sometimes sparse or absent due to erosion.

The diachronic analysis of Habitat 2250* within the study area revealed a consistent increase in patch extent from 2006 to 2022. However, a reduction in the number of patches was observed during the 2019–2022 period, attributed to fires. Overall, the trend for this habitat in areas not affected by fire over the past 15–20 years suggests an improved patch extent and connectivity. To further evaluate this trend, it would be useful to monitor, in the coming years, whether juniper vegetation is able to reclaim some of the areas lost due to recent fires or whether these spaces will be completely colonized by *Acacia saligna*.

Fragmentation caused by disturbance factors is particularly detrimental to *Juniperus macrocarpa*, as this dioecious species may face difficulties in pollination due to increased distances between individuals [14]. These factors also facilitate the spread of more resilient and rapidly expanding invasive alien species, such as *Carpobrotus acinaciformis* and *Acacia saligna*, which outcompete junipers for resources and space. In the study site, it has been observed that in some sections of the dune belt, corresponding to areas potentially classified as habitat 2250*, juniper has been completely replaced by *Carpobrotus acinaciformis* or *Acacia saligna* shrubland. Therefore, recurring monitoring activities are necessary to assess the ecological trends within the habitat and to plan appropriate management and restoration actions, including potential eradication and control measures for invasive species.

The present study was conducted within a limited geographical area. The methodology employed can be scaled up to encompass larger regions, such as the entire Ionian Arc, and potentially applied to other sites in southern Italy. Furthermore, future studies could utilize more extensive time series of satellite imagery with higher temporal resolution. Additionally, it would be beneficial to replicate the same monitoring protocol in the same area, with regular time intervals, to assess future developments.

5. Conclusions

The analyses carried out in the study area revealed a notable richness of habitats of community interest, with most of the dune system aligning to the reference standard zonation. However, exceptions were observed in areas impacted by disturbances, particularly from tourism and wildfires. The application of NBR and dNBR indices was instrumental in assessing the conservation status of these habitats, effectively revealing the effects of wildfires on vegetation. Additionally, landscape metrics such as NP, PD, FDI, and MPA proved valuable for evaluating the distribution, extent, and shape complexity of habitat patches, facilitating a comprehensive understanding of the landscape structure. These findings highlight the importance of integrating remote sensing and landscape metrics in conservation assessments to inform effective management strategies.

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Appendix A

Table A1. Salsolo-Cakiletum maritimae.

Relevé number	1	2	3
Area (mq)	10	7	8
Cover (%)	50	40	50
Inclination (°)	-	10	-
Exposition	-	S	-
Soil	Sand	Sand	Sand
Average height of vegetation (cm)	25	25	30
Altitude (m)	0.5	0.5	0.5

Table A1. *Cont.*

Characteristic species of association			
Cakile maritima Scop.	1	3	2
Salsola tragus L.	2	1	2
Characteristic species of *Thero-Atriplicetalia*			
Euphorbia peplis L.	-	1	-
Other species			
Pancratium maritimum L.	+	1	1
Echinophora spinosa L.	1	2	-
Eryngium maritimum L.	+	2	-
Thinopyrum junceum (L.) Á.Löve	-	+	1
Sporobolus virginicus (L.) Kunth	-	1	-
Medicago marina L.	-	+	+
Cyperus capitatus Vand.	+	-	-

Table A2. *Echinophoro spinosae-Elymetum farcti*.

Relevé number	1	2	3	4	5
Area (mq)	10	40	15	20	10
Cover (%)	70	80	75	60	55
Inclination (°)	-	5	25	20	10
Exposition	-	N	S	S.	N
Soil	Sand	Sand	Sand	Sand	Sand
Average height of vegetation (cm)	60	50	40	50	60
Altitude (m)	3	1.5	2	2	1.5
Characteristic species of association					
Echinophora spinosa L.	+	-	2	-	1
Characteristic species of *Agropyrion juncei*					
Thinopyrum junceum (L.) Á.Löve	2	4	2	3	4
Characteristic species of *Ammophiletalia*					
Medicago marina L.	2	2	1	-	-
Cyperus capitatus Vand.	1	-	-	+	+
Characteristic species of *Ammophiletea*					
Pancratium maritimum L.	4	1	4	1	2
Sporobolus virginicus (L.) Kunth	+	+	+	-	+
Eryngium maritimum L.	+	+	+	+	-
Calamagrostis arenaria (L.) Roth	-	-	2	1	1
Convolvulus soldanella L.	+	1	-	-	-
Cutandia maritima (L.) Benth. ex Barbey	+	-	-	-	-
Other species					
Sixalix atropurpurea (L.) Greuter & Burdet	3	1	1	3	3
Silene colorata Poir.	+	-	+	-	-
Hedypnois rhagadioloides (L.) F.W.Schmidt	-	1	-	-	+
Hypochaeris radicata L.	-	1	-	-	-
Xanthium orientale L.	-	+	-	-	-
Daucus pumilus (L.) Hoffmanns. & Link	-	-	+	+	-

Table A3. *Sileno coloratae-Vulpietum membranaceae* (relevés 1–5). *Sileno coloratae-Vulpietum membranaceae* var. *Medicago littoralis* (relevés 6–10).

Relevé number	1	2	3	4	5	6	7	8	9
Area (mq)	5	2	3	3	2	3	2	4	4
Cover (%)	60	70	35	40	80	65	70	65	70
Inclination (°)	15	-	10	10	-	-	5	5	10
Exposition	W	-	S	N	-	-	S-E	N	N
Soil	Sand	Sand	Sand	Sand	Sand	Sand	Sand	Sand	Sand
Average height of vegetation (cm)	20	20	13	15	15	12	10	20	10
Altitude (m)	11	13	10	9	8	4	4	3	3

Table A3. *Cont.*

Characteristic species of association									
Festuca pyramidata Link	2	2	1	2	4	3	1	-	2
Silene colorata Poir.	2	1	1	1	+	2	2	1	1
Char. species *Malcolmietalia* and *Laguro ovati-Vulpion membrabaceae*									
Daucus pumilus (L.) Hoffmanns. & Link	+	+	2	2	-	2	2	2	1
Medicago littoralis Rohde ex Loisel.	-	+	-	-	-	1	1	3	3
Ononis variegata L.	-	-	1	1	+	-	2	1	-
Maresia nana (DC.) Batt.	1	-	2	2	+	-	-	-	-
Ononis diffusa Ten.	+	-	-	-	-	-	-	-	-
Characteristic species of *Helianthemetea guttati*									
Festuca myuros L.	1	3	-	-	1	-	-	-	-
Arenaria leptoclados (Rchb.) Guss.	-	+	-	-	-	-	-	-	+
Other species									
Polycarpon tetraphyllum (L.) L.	+	-	-	+	1	-	-	-	-
Sixalix atropurpurea (L.) Greuter & Burdet	-	-	-	-	+	-	+	-	+
Pancratium maritimum L.	-	-	-	-	-	-	+	+	1
Crepis neglecta L.	+	+	-	-	+	-	-	-	-
Cerastium glomeratum Thuill	+	+	-	+	-	-	-	-	-
Helianthemum lippii (L.) Dum.Cours.	-	-	+	+	+	-	-	-	-
Anisantha madritensis (L.) Nevski	-	-	-	-	-	1	1	-	-
Cyperus capitatus Vand.	-	-	-	-	-	-	-	-	+
Sporobolus virginicus (L.) Kunth	-	-	-	-	-	-	+	+	-
Catapodium pauciflorum (Merino) Brullo, Giusso, Miniss. & Spamp.	+	+	-	-	-	-	-	-	-
Hedypnois rhagadioloides (L.) F.W.Schmidt	-	-	-	-	-	-	-	-	1
Lotus creticus L.	-	-	-	-	-	1	-	-	-
Euphorbia paralias L.	-	-	-	-	-	-	-	-	+
Hypochaeris radicata L.	-	-	-	-	-	-	-	+	-
Sonchus bulbosus (L.) N.Kilian & Greuter	-	-	-	-	-	-	+	-	-

Table A4. *Ononis variegata* communities.

Relevé number	1	2	3
Area (mq)	4	4	5
Cover (%)	50	60	70
Inclination (°)	5	2	-
Exposition	W	S-E	-
Soil	Sand	Sand	Sand
Average height of vegetation (cm)	25	20	20
Altitude (m)	8	7	8
Dominating species			
Ononis variegata L.	3	4	4
Char. species *Malcolmietalia* and *Laguro ovati-Vulpion membrabaceae*			
Daucus pumilus (L.) Hoffmanns. & Link	1	+	+
Silene colorata Poir.	+	+	+
Festuca pyramidata Link	-	+	-
Characteristic species of *Tuberarietea guttatae*			
Festuca myuros L.	-	-	+
Other species			
Pancratium maritimum L.	+	+	+
Sixalix atropurpurea (L.) Greuter & Burdet	+	-	-
Cyperus capitatus Vand.	-	-	+

Table A5. *Ancuso hybridae-Plantaginetum albicantis.*

Relevé number	1	2	3	4
Area (mq)	10	8	20	15
Cover (%)	85	90	95	80
Inclination (°)	40	35	20	10
Exposition	W	SW	S	S
Soil	Sand	Sand	Sand	Sand
Average height of vegetation (cm)	15	10	15	17
Altitude (m)	3	3	2	3
Characteristic species of association				
Plantago albicans L.	5	5	4	4
Char. species *Malcolmietalia* and *Laguro ovati-Vulpion membrabaceae*				
Festuca pyramidata Link	1	+	+	1
Daucus pumilus (L.) Hoffmanns. & Link	+	-	-	-
Medicago littoralis Rohde ex Loise L.	+	-	-	-
Other species				
Cyperus capitatus Vand.	+	+	2	-
Pancratium maritimum L.	+	+	1	-
Anisantha madritensis (L.) Nevski	+	-	+	1
Sixalix atropurpurea (L.) Greuter & Burdet	+	+	+	-
Silene colorata Poir.	+	+	+	-
Lotus creticus L.	+	-	1	-
Hypochaeris radicata L.	-	+	-	+
Asparagus acutifolius L.	-	+	-	-
Cistus creticus L. subsp. *eriocephalus* (Viv.) Greuter & Burdet	-	-	-	+

Table A6. *Sileno otitis-Helianthemum lippii.*

Relevé number	1	2	3	4
Area (mq)	10	6	10	12
Cover (%)	80	80	65	75
Inclination (°)	-	-	2	25
Exposition	-	-	N	N
Soil	Sand	Sand	Sand	Sand
Average height of vegetation (cm)	30	30	20	20
Altitude (m)	6	10		
Characteristic species of association				
Helianthemum lippii (L.) Dum.Cours.	4	4	3	3
Silene otites (L.) Wibel	-	-	1	1.2
Characteristic species of *Cisto-Ericion* and *Cisto-Micromerietea*				
Cistus creticus L. subsp. *eriocephalus* (Viv.) Greuter & Burdet	1	-	1	+
Lotus creticus L.	+	-	-	-
Other species				
Sixalix atropurpurea (L.) Greuter & Burdet	1	1	+	2
Silene colorata Poir.	+	+	+	+
Pancratium maritimum L.	-	1	1	1
Thinopyrum junceum (L.) Á.Löve	+	+	-	-
Cyperus capitatus Vand.	+	+	-	-
Smilax aspera L.	-	-	1	-
Sporobolus virginicus (L.) Kunth	1	-	-	-
Pinus halepensis Mill.	-	+	-	-
Daucus pumilus (L.) Hoffmanns. & Link	+	-	-	-
Ononis variegata L.	-	-	+	-

Table A7. *Asparago acutifolii-Juniperetum macrocarpae.*

Relevé number	1	2	3	4	5	6	7	8
Area (mq)	80	60	80	70	60	100	90	40
Cover (%)	95	100	100	100	100	100	95	100
Inclination (°)	25	-	10	10	10	-	35	45
Exposition	S	-	N-W	N	E	-	N	S
Soil	Sand	Sand	Sand	Sand	Sand	Sand	Sand	Sand
Average height of vegetation (cm)	200	200	250	300	250	250	200	200
Altitude (m)	9	7	5	6	6	7	5	2.5
Characteristic species of Association								
Juniperus macrocarpa Sm.	5	5	5	5	4	5	5	5
Characteristic species of *Oleo-Ceratonion and Pistacio-Rhamentalia alaterni*								
Phillyrea angustifolia L.	1	+	1	2	2	1	-	1
Pistacia lentiscus L.	1	2	-	1	-	-	-	+
Rhamnus alaternus L.	-	1	1	1	-	-	-	1
Stachys major (L.) Bartolucci & Peruzzi	1	+	-	+	-	-	-	-
Myrtus communis L.	1	-	-	-	-	-	-	-
Characteristic species of *Quercetea ilicis*								
Rubia peregrina L.	2	1	2	1	1	-	2	1
Smilax aspera L.	1	1	2	2	1	+	-	-
Asparagus acutifolius L.	1	+	+	1	+	+	-	+
Lonicera implexa Aiton	+	-	-	+	1	-	-	+
Other species								
Pancratium maritimum L.	1	2	+	+	+	+	1	+
Sixalix atropurpurea (L.) Greuter & Burdet	+	+	+	+	+	1	1	+
Cistus creticus L. subsp. *eriocephalus* (Viv.) Greuter & Burdet	-	+	1	1	1	-	-	+
Acacia saligna (Labill) H.L.Wendl.	1	-	-	2	2	1	-	-
Pinus halepensis Mill.	-	+	-	-	2	-	+	2
Matthiola sinuata (L.) W.T.Aiton	+	+	+	-	-	-	-	+
Carpobrotus acinaciformis (L.) L.Bolus	-	-	-	1	+	1	-	-
Silene otites (L.) Wibel	-	-	+	+	+	-	-	-
Thinopyrum junceum (L.) Á.Löve	-	-	-	+	-	+	-	-
Lotus creticus L.	-	-	-	-	+	+	-	-
Silene colorata Poir.	-	-	-	-	-	+	+	-
Lotus hirsutus L.	-	-	-	+	+	-	-	-
Reichardia picroides (L.) Roth	+	-	-	-	-	-	-	-
Cyperus capitatus Vand.	+	-	-	-	-	-	-	-
Eryngium maritimum L.	+	-	-	-	-	-	-	-
Sonchus bulbosus (L.) N.Kilian & Greuter	-	+	-	-	-	-	-	-
Helianthemum lippii (L.) Dum.Cours.	-	-	+	-	-	-	-	-
Hypochaeris radicata L.	-	-	-	-	-	-	+	-

Table A8. *Pistacio lentisci-Rhamnetum alaterni.*

Relevé number	1	2	3	4	5
Area (mq)	25	50	45	200	70
Cover (%)	100	100	100	100	80
Inclination (°)	10	25	30	-	-
Exposition	S	E	S	-	-
Soil	Sand	Sand	Sand	Sand	Sand
Average height of vegetation (cm)	250	250	250	260	160
Altitude (m)	7	8	8	6	5
Characteristic species of association					
Pistacia lentiscus L.	2	3	2	3	2

Table A8. *Cont.*

Rhamnus alaternus L.	1	-	-	1	-
Characteristic species of *Oleo-Ceratonion and Pistacio-Rhamentalia alaterni*					
Phillyrea angustifolia L.	4	4	4	4	3
Characteristic species of *Quercetea ilicis*					
Smilax aspera L.	-	-	+	2	3
Lonicera implexa Aiton	1	-	+	-	+
Daphne gnidium L.	+	+	-	-	-
Rubia peregrina L.	-	+	+	-	-
Asparagus acutifolius L.	-	-	-	+	+
Other species					
Pinus halepensis Mill.	2	2	+	+	1
Sixalix atropurpurea (L.) Greuter & Burdet	-	+	+	2	1
Salvia rosmarinus Spenn.	-	2	1	+	-
Lotus creticus L.	1	+	+	-	-
Thinopyrum junceum (L.) *Á. Löve*	-	+	-	1	1
Cistus creticus L. subsp. *eriocephalus* (Viv.) Greuter & Burdet	-	+	+	-	2
Lotus hirsutus L.	+	-	+	-	+
Silene otites (L.) Wibel	+	-	+	+	-
Medicago littoralis Rohde ex Loisel.	-	-	-	1	+
Juniperus macrocarpa Sm.	-	+	-	-	+
Sporobolus virginicus (L.) Kunth	-	-	-	+	-
Festuca myuros L.	-	-	-	+	-
Pancratium maritimum L.	-	-	-	+	-

Table A9. *Phillyrea angustifolia* community with *Acacia saligna*.

Relevé number	1	2	3	4
Area (mq)	80	75	90	25
Cover (%)	100	95	90	80
Inclination (°)	-	30	25	20
Exposition	-	N	N	S
Soil	Sand	Sand	Sand	Sand
Average height of vegetation (cm)	180	200	200	150
Altitude (m)	4	4	3	5
Dominating species				
Acacia saligna (Labill) H.L.Wendl.	4	3	4	4
Characteristic species of *Oleo-Ceratonion and Pistacio lentisci-Rhamnetalia alaterni*				
Phillyrea angustifolia L.	3	3	3	2
Pistacia lentiscus L.	1	3	-	-
Rhamnus alaternus L.	1	-	1	-
Stachys major (L.) Bartolucci & Peruzzi	-	+	+	-
Characteristic species of *Quercetea ilicis*				
Smilax aspera L.	3	-	+	2
Rubia peregrina L.	2	2	2	-
Lonicera implexa Aiton	+	-	-	-
Asparagus acutifolius L.	1	1	1	1
Juniperus macrocarpa Sm.	+	-	-	-
Other species				
Pancratium maritimum L.	+	+	+	+
Sixalix atropurpurea (L.) Greuter & Burdet	+	+	+	+
Pinus halepensis Mill.	-	1	1	-
Thinopyrum junceum (L.) Á.Löve	+	1	-	-
Lotus creticus L.	+	-	-	+

Table A9. *Cont.*

Sporobolus virginicus (L.) Kunth	+	-	-	-
Crepis neglecta L.	+	-	-	-
Urospermum dalechampii (L.) Scop. ex F.W.Schmidt	+	-	-	-
Helianthemum lippii (L.) Dum.Cours.	-	+	-	-
Matthiola sinuata (L.) W.T.Aiton	-	-	+	-
Hypochaeris radicata L.	-	-	-	+
Cistus salviifolius L.	-	-	+	-

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