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Phytosociological Insights into Vegetation Shaped by Long-Term Military Use

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Abstract

This study presents the vegetation of a Mediterranean area in Croatia, abandoned by the military three decades ago after two centuries of use. From 2023 to 2025, 97 phytosociological relevés were taken using the Braun–Blanquet approach. Based on numerical classification, we identified seven plant associations, two subassociations, and two communities within nine floristically and ecologically distinct vegetation classes. Military presence shaped the landscape in several ways. Large parts of the peninsula remain near-natural, covered by high maquis with minimal disturbance. Plateau shooting ranges, formerly grasslands, now represent rare habitats due to ongoing succession. Within former barracks, plantings included low-maintenance species providing rapid greening and visual screening. Evergreen conifers were favored for year-round greenery, while deciduous trees and ornamental shrubs provided shade and aesthetic value. Given current neglect and ongoing successional trends, the site requires a carefully planned management program aimed at habitat restoration, control of shrub encroachment, and maintenance of open and semi-open vegetation to preserve biodiversity and landscape heterogeneity.

Keywords: Adriatic coast; flora richness; land use; NE Mediterranean; vegetation survey

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1. Introduction

While the flora of the Mediterranean zone of Croatia is relatively well-documented [1], the same cannot be asserted regarding the extent of understanding of their vegetation [2]. Although phytosociological research in Mediterranean Croatia began relatively early [3,4], many areas have remained understudied in terms of vegetation diversity, or at least have not been as thoroughly investigated as some other regions. Generally, the northern part of the Croatian coast, including its islands and islets, is better documented compared to the southern regions of the country [5].

Here, we fill gaps in the cenological knowledge of vegetation in the southernmost Croatian territory, which was under military influence for two centuries. Although it is difficult to reconstruct the exact types of military activities and the number of troops during that period, the literature data indicate that the impacts of military use are diverse and can affect the landscape and soil, potentially leading to deforestation, habitat destruction, and

fragmentation (for review, see [6]). The ecological responses to military disturbance are complex and variable [7]. Thus, the same type of training may result in positive, neutral, or negative impacts depending on the habitat or taxa involved [8]. Paradoxically, military presence and training methods may contribute to the preservation of natural habitats, highlighting their potential importance for conservation research in such areas [9].

In this study, target area has been used as operational military training base, which was abandoned by the military 33 years ago, after two centuries of military use. Military installations include facilities used to accommodate personnel, store equipment, and support training activities and tactical operations. The development of such infrastructure can have varying environmental effects, depending on the characteristics of the surrounding landscape and ecosystems, making these impacts highly location-specific [10–12]. Despite this, military training areas often represent valuable opportunities for biodiversity conservation. However, there remains a notable shortage of scientific research focused on these environments, especially within Europe.

This study presents new phytosociological data, together with an ecological framework and a classification of vegetation types. The objectives were to: (i) deliver a comprehensive phytosociological characterization and syntaxonomic classification of plant communities in the southernmost mainland region of Croatia; (ii) evaluate their ecological importance within the wider pattern of vegetation diversity along the eastern Adriatic coast; and (iii) identify vegetation types or habitats most closely associated with past military presence, thereby supporting conservation efforts and informing ecological restoration where needed.

2. Materials and Methods

2.1. Study Area

The Oštra Peninsula (0.933 km^2, max. altitude 65 m) is 2.5 km long, widest in the middle (480 m), and narrowest (170 m) on the western part (Figure 1). The coasts are rocky; southern coast consists of steep coastal cliffs (up to 30 m high), while the northern one is mostly low. The underlying bedrock is formed by highly permeable Cretaceous limestones, while calcaric cambisol represents the prevailing soil type [13,14].



Figure 1. The investigated Oštra Peninsula (0.933 km^2) represents the southeasternmost mainland part of the Croatian territory, and closes the western part of the entrance to Bay of Kotor in the southeastern Adriatic Sea, NE Mediterranean. Boxes in the two upper panels indicate the study area in a wider geographical context. Country abbreviations: I (Italy), SI (Slovenia), H (Hungary), HR (Croatia), BiH (Bosnia and Herzegovina), MNE (Montenegro).

The climate is Mediterranean, with a mean annual air temperature of 16.4 °C [15]. The highest mean monthly temperature occurs in August (30.1 °C), while the lowest occurs in January (4.9 °C). Mean annual precipitation amounts to 1326 mm. The area receives approximately 2666 h of sunshine per year (data from the Dubrovnik meteorological station, DHMZ). SSE and NNE winds are the most frequent [5]. Mean annual relative humidity is 71%. According to the Köppen climate classification [16,17], the study area belongs to the Csa climate type, characterized as a temperate climate with dry, hot summers [18].

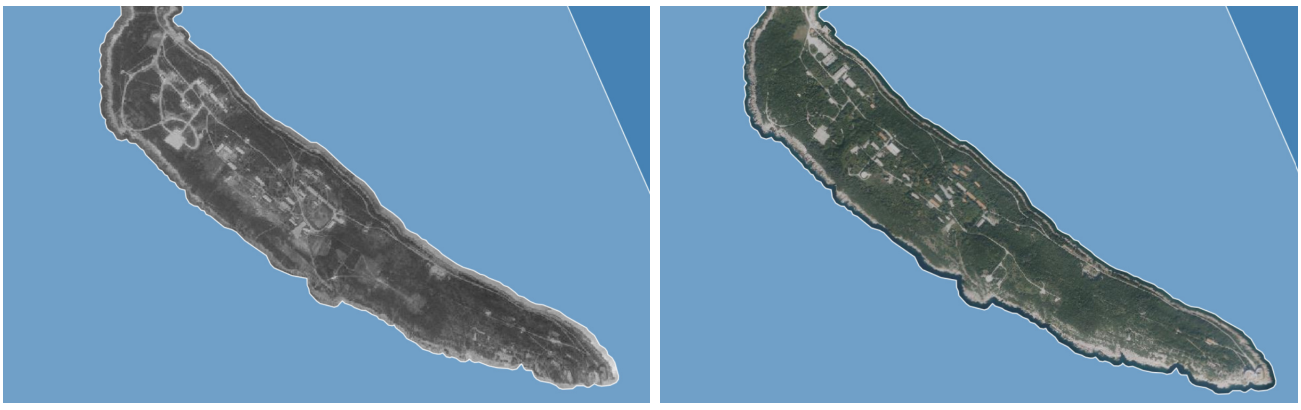
The area is phytogeographically characterized by meso-Mediterranean evergreen vegetation of the *Fraxino orni–Quercion ilicis* alliance, while the southern slopes support *Oleo-Ceratonion siliquae* communities [5].

2.2. Human Factor

Strategically located for controlling access to the Bay of Kotor, the peninsula has held considerable military importance throughout history. After the Republic of Dubrovnik expanded its rule to southern region (Konavle) in the early 15th century, the peninsula gained prominence as both a defensive outpost and a refuge for the local population during times of conflict [19]. During the Napoleonic Wars (1808–1813), the French were the first to establish military infrastructure on the peninsula. Under Austro-Hungarian rule in the mid-19th century, the Fort Oštra—still the most prominent structure on the peninsula—was constructed (Figure 1).

Civilians, mainly from the nearby village of Vitaljina, coexisted with the military, and the 1880 population census recorded permanent residents on the peninsula for the first time. However, this coexistence ended during World War I, when civilian access was restricted. In 1917, the army of the Kingdom of Serbs, Croats, and Slovenes prohibited the use of the land by Vitaljina villagers.

During World War II, the peninsula was successively occupied by Italian (1941–1943) and German (1943–1945) forces, who transformed it into a concentration camp, once again excluding civilians. In 1955, the Yugoslav Army took control of the peninsula, sealing it off from the public and expanding its military infrastructure. This included the construction of a port, numerous buildings (48 in total), a radar station, and a small-arms firing range, which remained operational until 1992 (Figure 2).



(**a**) (**b**)

Figure 2. Aerial view of the Oštra Peninsula during intensive military activity in 1968 provided by the State Geodetic Administration of the Republic of Croatia (**a**), and in 2024, 30 years after military abandonment (**b**), derived and adapted from Google Earth Pro, version 7.3. Mountain View, CA, USA: Google. Scale 1:10,000. The light-colored areas represent military infrastructure (helipad, red-roofed buildings, and roads), while green indicates vegetation cover.

Today, although the peninsula is uninhabited, it is a popular one-day tourist destination during the summer season. The nearest settlement is the village of Vitaljina, located 2 km from the peninsula, with 153 inhabitants according to the 2021 census. Residents of Vitaljina own land on the peninsula, including forests and olive groves. The olive groves are relatively young and are managed extensively. Among grazing animals, a large herd of goats roams the peninsula year-round, although the exact number of individuals is unknown.

2.3. Data Collection and Analyses

Field data were collected from 97 vegetation plots (phytosociological relevés) between November 2023 and June 2025, covering the entire area of the Oštra Peninsula and neighboring sea. The geographical coordinates of the relevés are provided in Table S1. Vegetation was studied according to the principles of the Braun–Blanquet approach [20,21], adopting the International Code of Phytosociological Nomenclature [22]. Plot sizes varied depending on vegetation type. For maquis, they ranged from 10 to 200 m^2 (mean 136 m^2), while garrigue plots covered 16–25 m^2 (mean 21.5 m^2), and grassland plots covered 10–25 m^2 (mean 21.3 m^2). Relevés of rocky and wall vegetation were conducted on smaller plots of 6–10 m^2 (mean 8 m^2), whereas nitrophilous vegetation was sampled on plots of 10–25 m^2 (mean 16.9 m^2). Similarly, rocky coastal vegetation was recorded using plots ranging from 10 to 25 m^2 (mean 16 m^2). Overall, these plot dimensions are largely consistent with previously recommended sizes for the respective vegetation types [23].

The nomenclature of higher-rank vegetation units follows the syntaxonomical system (EuroVegChecklist, EVC) proposed by Mucina et al. [24] and adopted by Škvorc et al. [25], with particular emphasis on the sequence of vegetation classes and their subordinate syntaxa as defined within this framework. Diagnostic species of phytosociological classes were determined using Mucina et al. [24] and an online database of European vegetation, habitats and flora [26,27]. The nomenclature of vascular plant taxa follows Plants of the World Online [28].

To gain insight into the diversity of bryophytes on the peninsula, we conducted a one-time bryophyte inventory, the first ever carried out on the peninsula. The nomenclature of bryophytes follows that outlined by Hodgetts et al. [29].

EUNIS habitat types were assigned following the framework proposed by Chytrý et al. [30], in combination with information obtained from an online database of European vegetation, habitats, and flora [27]. Marine habitat categories were defined according to the 2022 version of the EUNIS marine habitat classification, as provided by the EEA [31]. The correspondence between identified vegetation units (alliances) and habitat types listed in Annex I of the Habitats Directive (92/43/EEC) was established based on the official Croatian national list of NATURA 2000 habitat types [32].

Numerical techniques were employed to classify vegetation patterns, and the results were evaluated in relation to the conventional syntaxonomic framework. The dataset included 334 taxa recorded in 97 relevés. Cover-abundance estimates originally assigned according to the Braun–Blanquet scale [20] were recoded into a 1–9 ordinal scale prior to analysis [21]. Vegetation types were identified using agglomerative hierarchical clustering based on Bray–Curtis dissimilarity, with Ward's linkage method used to define cluster structure [33]. To minimise the influence of overall cover on similarity relationships, the data were subjected to both power ($y' = y\hat{}w$) and logarithmic [$y' = \log(y + 1)$] transformations before clustering. Statistical differences among the identified groups were assessed using analysis of similarities (ANOSIM). All computations were carried out in PC-ORD (version 5, Gleneden Beach, Oregon) and PRIMER (version 7, Plymouth, UK) [33,34].

3. Results

From a total of 97 vegetation relevés (rels.) collected on the Oštra Peninsula and in the adjacent coastal area, 44 were recorded in maquis vegetation, 4 in garrigue, 12 in grasslands, 3 in marine vegetation, 16 in halophilous communities on bare or very shallow soils, 6 in rocky cliffs, crevices and walls, and 12 in ruderal vegetation.

The dendrogram obtained from the hierarchical clustering analysis of the data matrix makes it possible to distinguish two main clusters (A, B) of associations (Figure 3). The first cluster (A) exclusively comprises perennial seagrass meadow vegetation (I). The second cluster (B) includes terrestrial vegetation and is divided into two subclusters (B1 and B2). Subcluster B1 mainly includes maquis of the *Quercetea ilicis* class (B1a1) and *Artemisietea vulgaris* (B1a2), and more open habitats, such as garrigue, grasslands and ruderal communities (B1b). ANOSIM analysis revealed significant differences between clusters A and B (R = 0.76, p = 0.001) and between subclusters B1 and B2 (R = 0.55, p = 0.001), using a cumulative contribution threshold of W = 0.5.

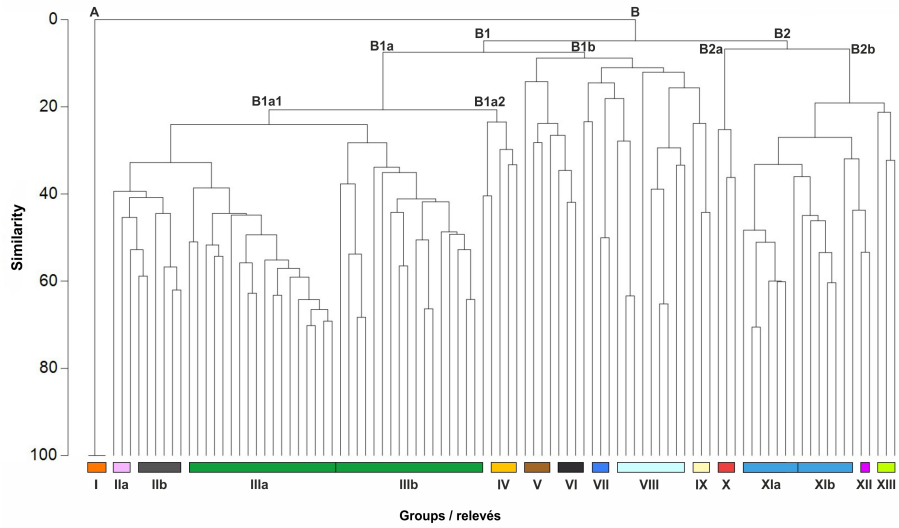


Figure 3. Hierarchical cluster analysis dendrogram based on Bray–Curtis similarity distance and Ward's minimum variance method of the data matrix of 334 taxa × 97 samples (relevés). Groups of relevés: I—*Posidonietum oceanicae*; IIa—*Pistacio lentisci-Juniperetum turbinatae*; IIb—*Myrto communis-Pistacietum lentisci*; IIIa,b—*Myrto communis-Quercetum ilicis*; IV—*Arundinetum plinianae*; V—*Erico manipuliflorae-Cistetum cretici*; VI—*Hyparrhenia hirta* community; VII—*Cynodon dactylon* community; VIII—group composed of only one or two relevés; IX—*Hordeetum leporini*; X—*Seslerio robustae-Putorietum calabricae*; XIa—*Limonietum anfracti typicum*; XIb—*Limonietum anfracti seslerietosum robustae*; XII—relevés of coastal shingle beach vegetation; XIII—relevés of vegetation on walls.

Subcluster B1a comprises several maquis groups: predominantly low maquis occurring on the southern slopes of the peninsula (groups IIa and IIb of relevés); high maquis covering the largest area of the peninsula (IIIa); and maquis on heavily disturbed former military sites, which markedly differs from the preceding group in physiognomy and floristic composition (IIIb). Low shrub stands dominated by *Arundo plinii*, also occurring in disturbed areas, are assigned to subcluster B1a2 (group IV).

Subcluster B1b (Figure 3) comprises four relevés of garrigue (group V), four relevés of grassland (group VI), and three relevés each of ruderal communities dominated by *Cynodon dactylon* (VII) and *Hordeum murinum* subsp. *leporinum* (IX). In addition, this subcluster comprises relevés of several open habitats that are poorly represented on the peninsula; some stands (communities) are documented by only one relevé (four in total) or two relevés (eight in total) (group VIII). In such cases, a formal syntaxonomic assignment based on one or two relevés was not attempted in this study. However, their floristic

composition is provided in Supplementary Table S5 (relevés 15–16) and Table S8, and is briefly discussed below.

The last subcluster (B2) includes four groups of relevés collected (i) in vegetation of rocky cliffs largely not influenced by seawater wave action (group X); (ii) in the salt-spray zone along the rocky coastline (groups XIa and XIb); (iii) on coastal shingle beaches (XII); and (iv) on man-made walls (XIII).

Based on the relevé data, a vegetation distribution map of the peninsula was constructed (Figure 4). The map indicates that the relevés assigned to groups IIIb and IV occur in the central part of the peninsula, corresponding to areas with the highest density of buildings and military infrastructure.



Figure 4. Vegetation distribution map of the Oštra Peninsula (0.933 km^2) based on a phytosociological survey conducted between 2023 and 2025; areas shown in different colours represent stands of woody, garrigue and coastal associations. The legend contains numbers indicating the area corresponding to each vegetation type or association: 1 = more or less impenetrable stands of *Myrto communis–Quercetum ilicis*; 2 = anthropogenically altered stands of *Myrto communis-Quercetum ilicis* around military facilities and infrastructure; 3 = *Myrto communis-Pistacietum lentisci*; 4 = *Pistacio lentisci-Juniperetum turbinatae*; 5 = garrigue stands of the *Erico manipuliflorae-Cistetum cretici* association; 6 = the salt-spray zone along the rocky coastline representing the habitat of the *Limonietum anfracti* association.

The vertical (altitudinal) distribution of vegetation from sea level to the highest elevation (0–65 m a.s.l.) of the peninsula, with particular reference to its southern part, is illustrated in Figure 5.

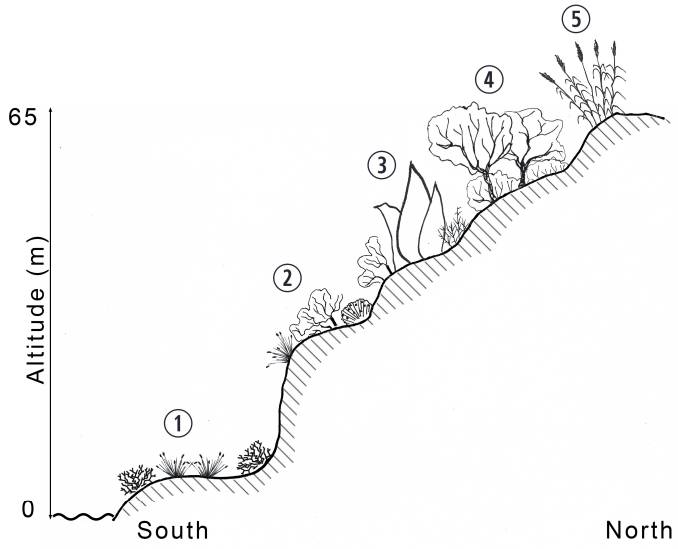


Figure 5. Altitudinal distribution of the vegetation from sea level to the highest elevation (0–65 m a.s.l.) in the southern part of the peninsula. Legend: 1 = *Limonietum anfracti seslerietosum robustae*; 2 = *Myrto communis-Pistacietum lentisci*; 3 = *Pistacio lentisci-Juniperetum turbinatae*; 4 = *Myrto communis-Quercetum ilicis*; 5 = *Arundinetum plinianae*.

The results were interpreted from a syntaxonomic perspective, and the corresponding syntaxonomic scheme is presented below.

Syntaxonomic scheme

***QUERCETEA ILICIS* Br.-Bl. ex A. Bolós et O. de Bolòs in A. Bolòs y Vayreda 1950**

***Quercetalia ilicis* Br.-Bl. ex Molinier 1934**

Fraxino orni-Quercion ilicis Biondi, Casavecchia et Gigante in Biondi et al. 2013

Myrto communis-Quercetum ilicis (Horvatić 1963) Trinajstić (1976) 1985

***Pistacio lentisci-Rhamnetalia alaterni* Rivas-Mart. 1975**

Oleo-Ceratonion siliquae Br.-Bl. ex Guinochet et Drouineau 1944

Pistacio lentisci-Juniperetum turbinatae Trinajstić 1987 ex Asensi, Díez-Garretas et Quézel 2007

Myrto communis-Pistacietum lentisci (Molinier 1954) Rivas-Mart. 1975

***ONONIDO-ROSMARINETEA* Br.-Bl. in A. Bolòs y Vayreda 1950**

***Cisto-Micromerietalia julianae* Oberd. 1954**

Cisto cretici-Ericion manipuliflorae Horvatić 1958

Erico manipuliflorae-Cistetum cretici Horvatić 1958

LYGEO SPARTI-STIPETEA TENACISSIMAE* Rivas-Mart. 1978 *nom. conserv. propos

Hyparrhenia hirta community

***CRITHMO-STATICETEA* Br.-Bl. in Br.-Bl. et al. 1952**

***Crithmo-Staticetalia* Molinier 1934**

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

Limonietum anfracti Ilijanić et S. Hećimović 1982

helichrysetosum italici Jasprica 2015

seslerietosum robustae Jasprica, Dolina et Sabovljević, subass. nov. *hoc loco*

***ASPLENIETEA TRICHOMANIS* (Br.-Bl. in Meier et Br.-Bl. 1934) Oberd. 1977**

Centaureo dalmaticae-Campanuletalia pyramidalis Trinajstić ex Terzi et Di Pietro 2016

Centaureo cuspidatae-Portenschlagiellion ramosissimae Trinajstić ex Terzi et Di Pietro 2016

Seslerio robustae-Putorietum calabricae Horvatić ex Birač 1973

***CYMBALARIO-PARIETARIETEA DIFFUSAE* Oberd. 1969**

***Tortulo-Cymbalarietalia* Segal 1969**

Galio valantiae-Parietarion judaicae Rivas-Mart. ex de Bolos 1967
***ZOSTERETEA* Pignatti 1953**
***Posidonietalia oceanicae* Den Hartog ex Mucina in Mucina et al. 2016**
Posidonion oceanicae Br.-Bl. ex Molinier 1960
Posidonietum oceanicae (Funk 1927) Molinier 1958
***POLYGONO-POETEA ANNUAE* Rivas-Mart. 1975**
Cynodon dactylon community
***CHENOPODIETEA* Br.-Bl. in Br.-Bl. et al. 1952**
***Brometalia rubenti-tectorum* (Rivas Goday et Rivas-Mart. 1973) Rivas-Mart. et Izco 1977 nom. conserv. propos.**
Hordeion murini Br.-Bl. in Br.-Bl. et al. 1936
Hordeetum leporini Br.-Bl. 1936
***ARTEMISIETEA VULGARIS* Lohmeyer et al. in Tx. ex von Rochow 1951**
***Elytrigio repentis-Dittrichietalia viscosae* Mucina 2016**
Inulo viscosae-Agropyrion repentis Biondi et Allegrezza 1996
Arundinetum plinianae Biondi, Brugiapaglia, Allegrezza et Ballelli 1992

Seven vegetation alliances (*Fraxino orni-Quercion ilicis*, *Oleo-Ceratonion siliquae*, *Cisto cretici-Ericion manipuliflorae*, *Limonion anfracti-cancellati*, *Centaureo cuspidatae-Portenschlagiellion ramosissimae*, *Galio valantiae-Parietarion judaicae* and *Posidonion oceanicae*) recorded in the study area correspond to several EUNIS habitat types, including Mediterranean evergreen Quercus forests, maquis and garrigue vegetation, Mediterranean rocky sea cliffs and inland cliffs, and Posidonia oceanica beds, some of which also match habitat types listed in Annex I of the Habitats Directive (92/43/EEC) [30–32].

4. Discussion

4.1. Maquis

Based on the results, the following associations and plant communities have been recognized:

- *Myrto communis-Quercetum ilicis* (Table S2, Figure 3: groups IIIa and IIIb)

Among the holm-oak woody vegetation along the eastern Adriatic, the *Myrto communis-Quercetum ilicis* association occurs in warmer and drier areas [35]. It occupies the largest part of the peninsula (0.79 km^2), representing 85% of its woody area.

Two stand types were distinguished based on physiognomy and floristic composition. Group IIIa (Table S2: relevés 1–23) consists of tall (2–8 m, mean 5 m), dense, and nearly impenetrable maquis, with a typical floristic composition of the eastern Adriatic coast [5]. Group IIIb (Table S2: relevés 24–35) comprises lower maquis (2–7 m, mean 4 m) with a pronounced abundance of non-native species, including *Ligustrum lucidum*, *Ailanthus altissima*, *Cupressus sempervirens*, *Prunus cerasifera*, and *Pinus pinaster*. These stands also include transgressive or ingressive species from the *Lygeo sparti-Stipetea tenacissimae* and *Artemisietea vulgaris* classes.

Group IIIb shows the strongest anthropogenic impact, mainly from military activities. Historical records suggest that plantings depended on personnel preferences rather than systematic schemes [36]. Former open areas, such as shooting grounds, now support stands dominated by *Hyparrhenia hirta* or *Arundo plinii*, along with maquis elements (*Calicotome infesta*). By contrast, the southern peninsula margin facing the sea has remained largely unchanged, as preserving natural vegetation was essential for camouflaging defensive structures.

Mediterranean maquis are generally characterized by lower species richness, primarily due to extremely limited light availability, particularly in the ground layer, as well as

the physiological constraints of evergreen woody species under low winter air temperatures [37,38]. In parts of the peninsula that were not subjected to prolonged anthropogenic disturbance—largely due to the concealment of military installations—the maquis of the *Myrto communis-Quercetum ilicis* association exhibits a more natural structure, characterised by higher frequency and cover of character species (e.g., *Quercus ilex*, *Myrtus communis*, *Pistacia lentiscus*, *Juniperus turbinata*) and lianas (*Smilax aspera*, *Rubia peregrina*, *Lonicera implexa*). In contrast, areas affected by military activities show a decline in native woody species, accompanied by an increase in ruderal and open-habitat species. However, plant species richness did not differ between these two "variants" of the association (mean 20 taxa). In contrast, both showed significantly lower values compared to sites without human disturbance on islands in the central and southeastern Adriatic (25–50 taxa; mean 33.7) [39]. It is important to note that two other common drivers of human impact in Mediterranean maquis ecosystems—overgrazing and wildfires—have not been recorded in the study area over the past several decades.

- *Pistacio lentisci-Juniperetum turbinatae* (Table S2, Figure 3: group IIa)

This xerothermic mainly low and often impassable maquis, known from islands along the Adriatic coast and also reported from Naxos in the Aegean Sea (Cyclades), develops through natural succession of forest vegetation under very dry and warm conditions, and may also arise following the abandonment of agricultural land, such as vineyards [39]. In Croatia, *Juniperus turbinata* predominantly colonises islands and islets, irrespective of site exposure. In the present study, this community mainly occurs on the southern slopes of the peninsula, with a vegetation cover of 90–100%. It is characterised by the dominance of a limited number of species, with 11–25 taxa per relevé (mean 16). Species richness is comparable to that reported for the island of Unije in the northern Adriatic (10–15 taxa; mean 12.3), but considerably lower than values recorded along the coast and on islands in the southern Adriatic (15–30 taxa; mean 22.8) [40,41].

However, the literature data [39–41] indicate that the development of this association may follow different successional pathways, either towards forest communities such as *Querco ilicis–Pinetum halepensis* or along an alternative successional trajectory leading to *Fraxino orni–Quercetum ilicis*. The course of these processes largely depends on the geographic position of the stands and the associated climatic conditions of the area.

- *Myrto communis-Pistacietum lentisci* (Table S2, Figure 3: group IIb)

This plant community, consisting of dense shrubs 1–2 m in height, is distributed along Mediterranean coastlines from the western Mediterranean (Spain) to Croatia. In Croatia, it is typically restricted to the hottest and driest habitats, mainly on south-facing slopes of islands and islets, where it is strongly influenced by marine aerosols [39]. In the study area, it occurs along the exposed southern coastline of the peninsula, beyond the halophytic belt, and was not subject to military disturbance. Characteristic species of the class *Crithmo-Staticetea*, including *Sesleria robusta*, contribute to the floristic composition. Species richness is relatively low (10–15 taxa; mean = 11.5), which is consistent with previous findings from the eastern Adriatic [42].

4.2. Garrigue

- *Erico manipuliflorae-Cistetum cretici* (Table S3, Figure 3: group V)

This low-growing secondary evergreen shrublands (garrigue) are a secondary stage on cleared holm-oak forests [43]. In general, the garrigue is discontinuous and occurs on a drier soil than maquis [37]. In Croatia, the floristic composition of garrigue is highly variable, depending on geographical–climatic factors and altitudinal gradients [44]. However, it is

primarily determined by the intensity of direct and indirect human impacts, as well as by the degree of soil degradation at specific sites.

Stands of the *Erico manipuliflorae–Cistetum cretici* association represent the most common type of garrigue in the central and southern eastern Adriatic. In the Middle Adriatic, the number of taxa per relevé varies considerably, ranging from 31–50 [41] to 15–23 on Brač [45] and 10–32 on Olib (mean 19.6) to 23–27 on Zlarin (mean 25) [46,47]. In the present study, although based on only four relevés, garrigue exhibited approximately twice the species richness (19–75 taxa; mean 48), likely due to the presence of species from open habitats (*Festuco–Brometea* and *Stipo–Trachynietea distachyae*) and ruderal vegetation (*Chenopodietea*). Trinajstić [45] related species richness to grazing intensity.

4.3. Dry Grassland

- *Hyparrhenia hirta* community (Table S4, Figure 3: VI)

This perennial grassland mainly occurs on former pastures [48,49] and shows higher species richness (mean 37 taxa) than the *Brachypodio retusi–Cymbopogonetum hirti* Horvatić 1961 association, a similar community previously reported from Croatia (mean 17.6 taxa) [50]. Ruderal species from *Chenopodietea* and *Artemisietea vulgaris* are frequent. Following grazing abandonment, evergreen shrubs colonize these stands. Without formal management, succession towards forest vegetation is expected.

Our results (Figures 2a and 4) show that the establishment of military training areas leads to a transition from open habitats (grasslands and ruderal vegetation) toward increased woody vegetation in currently abandoned areas. Caudal and Gallet [6] emphasize that the level of disturbance is determined by the intensity rather than the type of training. The decline of grassland areas should be considered in a broader context, as these habitats are essential for overall biodiversity (e.g., birds, butterflies). Based on the present vegetation patterns, the disturbance level corresponds to category II sensu Zentelis et al. [9], i.e., areas with medium military impact, where major landscape elements persist in reduced form, the impact of training remains evident, boundaries are indistinct, and topography is unchanged.

4.4. Low Rocky Coastal Vegetation

- *Limonietum anfracti* (Table S5, Figure 3: XIa, XIb)

Rocky coasts host the low-spreading endemic shrub (*Limonium dictyophorum*) [51]. On the peninsula, stands of this association exhibit low species richness (4–19 taxa per relevé; mean 9), which is very similar to the diversity reported on small islands in the southern Adriatic (5–18 taxa) [52,53].

In this study, three belts are distinguished by distance from the sea (Figure 5), with *Sesleria robusta* dominant in the outermost belt. This species defines the new subassociation *seslerietum robustae* [54–56] (see Appendix A.1. for holotypus).

4.5. Cliff and Dry-Wall Chasmophytic Vegetation (Table S6, Figure 3: X, XIII)

Calcareous rocky slopes (*Asplenietea trichomanis*) and walls (*Cymbalario–Parietarietea diffusae*) are scarce habitats on the peninsula. Although walls generally show characteristics similar to rocky surfaces in natural environments, species richness is higher on walls (mean 22 taxa) than on rocky vegetation (mean 13), with 13 species shared between them. Rocky vegetation is dominated by *Sesleria robusta* and *Putoria calabrica*, corresponding to the *Seslerio robustae–Putorietum calabricae* association [55].

Wall communities contain a greater proportion of species from *Chenopodietea*, *Crithmo-Staticetea*, and *Stipo–Trachynietea distachyae*. Taxa such as *Phillyrea latifolia* and *Pistacia lentiscus* indicate a relationship with the *Quercetea ilicis* [57].

4.6. Posidonia Meadows

- *Posidonietum oceanicae* (Figure 3: group I)

Seagrass meadows occur at 1.5–15 m depth, providing key ecosystem services. Main pressures are anchoring and maritime traffic [58,59].

4.7. Ruderal Communities (Table S7, Figure 3: VII, IX)

Stands of the *Cynodon dactylon* community occupy dry soils near salt-spray vegetation or annual halophyte habitats (mean 15 taxa) [60,61]. *Hordeetum leporini* occurs along paths and roadsides near former military sites, dominated by *Hordeum murinum* subsp. *leporinum* and annuals from *Chenopodietea* and *Artemisietea vulgaris* [62].

- *Arundinetum plinianae* (Table S7, Figure 3: IV)

In the eastern Adriatic Basin, *Arundo plinii*-dominated stands appears along the coastal belt from southern Croatia southwards to central Albania mainly on habitats exposed to disturbances [63]. In our study, this dense shrub formation develops in heavily disturbed areas, i.e., areas formerly subjected to intensive military activities (see Figure 5). In this study, the number of species per relevé ranged from 12 to 25 (mean 17), which corresponds to the species richness reported for other eastern Adriatic stands [63]. However, this association can occur in different vegetation types: one predominantly herbaceous (*Inulo viscosae–Agropyrion repentis*), although occasionally including shrubs, and another characterized by sclerophyllous shrub vegetation (*Quercetea ilicis*), which is richer in woody species, as observed in our case. Accordingly, this association may be interpreted as an ecotone between herbaceous and shrub vegetation [63–65].

4.8. Other Stands

Open and semi-open habitats are very limited on the peninsula, so some vegetation types are represented by only one or two relevés (Tables S5 and S8; Figure 3: groups VIII, XII). Single-relevé stands are dominated by *Bromus erectus*, *Festuca myuros*, *Asphodelus fistulosus*, and *Scandix pecten-veneris* with *Tordylium apulum*. Two-relevé stands comprise *Narcissus tazetta* with *Asphodelus ramosus*, *Dactylis glomerata* subsp. *hispanica* with *Elymus repens*, and *Oloptum miliaceum*. Coastal shingle vegetation is dominated by halophytes *Crithmum maritimum* and *Limbarda crithmoides* and lacks characteristic species of the eastern Adriatic association *Euphorbio-Glaucietum flavi* Horvatić 1934.

Although spatially limited, these stands contribute disproportionately to the peninsula's plant biodiversity. They enhance habitat heterogeneity and local floristic diversity, highlighting their conservation importance in a landscape strongly influenced by past and present human activities.

Photos of all stands found on the peninsula are shown in Figure S1.

4.9. Remarks on the Vascular Flora and Bryophytes

Of 334 taxa recorded, 15 are on the Croatian Red List [1], (see Appendix A.2.). Ten taxa are endemic (Appendix A.3.), mostly Illyrian–Adriatic. Orchid species reported by Studniczka [66] in the peninsula's maquis (e.g., *Serapias*, *Ophrys*) remain present. A notable share of the area is occupied by *Ailanthus altissima* and *Opuntia ficus-indica* within the maquis, as well as by invasive species in open, mainly ruderal, habitats (e.g., *Erigeron* spp., *Sorghum halepense*, *Xanthium strumarium*).

Bryophytes (47 species, Table S9) show a strong Mediterranean character. Rare species include *Tortella commutata*, *Syntrichia calcicola*, *Tortula brevissima*, and *Trichostomum meridionale* [67,68]. Liverworts were not surveyed but should be documented in future studies.

Bryophytes, among the earliest land plants, are an important functional component of vegetation, but their distribution is primarily driven by microhabitat conditions rather than

vascular plant communities [69]. As they usually contribute little to total biomass, they are often omitted from general vegetation studies; therefore, following Marstaller [70], they are presented here as a species list rather than included in relevés.

Due to their high sensitivity to environmental change, bryophytes reflect climatic conditions and habitat heterogeneity, and can indicate ecosystem integrity [71–73]. In Mediterranean forests, they serve as indicators of long-term vegetation continuity, although they are less studied than in central and northern Europe [74].

We expect bryophyte diversity in the study area to increase with ongoing vegetation development and conservation, which will enhance microhabitat availability and stability.

5. Conclusions

This study investigates the vegetation of an area abandoned by the military three decades ago after nearly two centuries of occupation, addressing gaps in phytosociological knowledge of the southernmost mainland region of Croatia. Due to the small size of the study area, geological substrate and climatic conditions are largely uniform; therefore, vegetation diversity and species richness are mainly driven by slope exposure and distance from the sea, with human impact representing the dominant source of heterogeneity.

The analysis of vegetation types revealed a mosaic of successional stages shaped by both progressive and degradative processes, reflecting differences in past management and local ecological conditions. Although succession in Mediterranean ecosystems is generally slow, vegetation dynamics can be significantly intensified by anthropogenic disturbance [75].

Long-term military presence on the peninsula produced contrasting effects. On the one hand, large parts of the area remained relatively undisturbed and preserved in a near-natural state, covered by vegetation close to the potential natural stage (high maquis), as military infrastructure was largely integrated into the existing vegetation. On the other hand, former shooting ranges situated on the plateau were maintained as grasslands, which today represent rare habitats on the peninsula because succession has advanced since military abandonment.

Within the former Yugoslav Army barracks, plantings mainly consisted of low-maintenance species intended for rapid greening and visual screening of facilities. Evergreen conifers, particularly *Cupressus sempervirens* and *Pinus* spp., were commonly used, together with deciduous trees such as *Ligustrum lucidum* and *Prunus cerasifera*, as well as ornamental shrubs and succulents (e.g., *Opuntia* spp., *Agave americana*).

Given the ongoing successional trends and the currently neglected state of the area, the site would benefit from a carefully designed management strategy aimed at restoring and maintaining open and semi-open habitats, controlling shrub encroachment, and preserving biodiversity and landscape heterogeneity in line with Natura 2000 conservation objectives.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/land15040598/s1, Figure S1: Photo of the vegetation types; Table S1: Number of relevés, dates and coordinates; Table S2: Phytosociological relevés of the *Myrto communis-Quercetum ilicis* (rels. 1–35), *Pistacio lentisci-Juniperetum turbinatae* (rels. 36–38), and *Myrto communis-Pistacietum lentisci* (rels. 39–44) associations on the Oštra Peninsula; Table S3: Phytosociological relevés of the *Erico manipuliflorae-Cistetum cretici* association on the Oštra Peninsula; Table S4: Phytosociological relevés of the *Hyparrhenia hirta*-dominated community on the Oštra Peninsula; Table S5: Phytosociological relevés of the *Limonietum anfracti seslerietosum robustae* (rels. 1–7), *Limonietum anfracti typicum* (rels. 8–14), and the vegetation of the coastal shingle beach (rels. 15–16) on the Oštra Peninsula.; Table S6: Phytosociological relevés of the *Asplenietea trichomanis* (rels. 1–3) and *Cymbalario-Parietarietea diffusae* (rels. 4–6) vegetation on the Oštra Peninsula; Table S7: Phytosociological relevés of the *Cynodon dactylon* community (rels. 1–3), and *Hordeetum leporini* (rels. 4–6) and

Arundinetum plinianae (rel. 7–10) associations on the Oštra Peninsula; Table S8: Phytosociological table of the stands documented by only one or two relevés: *Dactylis glomerata* subsp. *hispanica* and *Elymus repens* (rels. 1–2); *Oloptum miliaceum* (rels. 3–4); *Asphodelus fistulosus* (rel. 5); *Scandix pecten-veneris and Tordylium apulum* (rel. 6); *Bromus erectus* (rel. 7); *Narcissus tazetta* and *Asphodelus ramosus* (rels. 8–9); *Festuca myuros* (rel. 10) on the Oštra Peninsula; Table S9: List of bryophytes collected and recorded on the Oštra Peninsula, 3 May 2025.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Appendix A.1. Holotypus of the Limonietum anfracti seslerietosum robustae Jasprica, Dolina et Sabovljević subass. nov. hoc loco

Limonietum anfracti seslerietosum robustae Jasprica, Dolina et Sabovljević subass. nov. *hoc loco* [locality: Croatia, Dubrovnik-Neretva County, Konavle Municipality, the Oštra Peninsula; holotypus: Supplementary Table S5, original relevé no. 75; altitude 10 m a.s.l.; aspect SW; slope 45°; plot size 25 m^2; vegetation cover 30%; date 13.05.2025.; coordinate: 42.395811° N, 18.519127° E] is as follows: *Sesleria robusta*, 3; *Crithmum maritimum*, 2; *Limonium dictyophorum*, 1; *Allium commutatum*, +; *Centaurium erythraea*, +; *Dittrichia viscosa*, +; *Gladiolus illyricus*, +; *Lotus hirsutus*, +; *Silene vulgaris* subsp. *angustifolia*, +; *Vincetoxicum hirundinaria* subsp. *adriaticum*, +.

Appendix A.2. Taxa Recorded on the Oštra Peninsula That Are Listed in the Croatian Red List [1]

Endangered (EN) taxa: *Anthyllis vulneraria* subsp. *weldeniana*, *Carex extensa*, *Ophrys apifera*; Vulnerable (VU): *Fritillaria messanensis* subsp. *gracilis*, *Parapholis incurva*; Nearly Threatened (NT): *Centaurea glaberrima*, *Chaerophyllum coloratum*, *Aegilops neglecta*, *Narcissus tazetta*, *Thinopyrum acutum*; Least Concern (LC): *Iris pallida* subsp. *illyrica*, *Limonium dictyophorum*, *Posidonia oceanica*; Data Deficient (DD): *Arundo plinii*, *Carduus pycnocephalus*.

Appendix A.3. List of the Endemic Taxa Recorded on the Oštra Peninsula (See [1,28,51])

Carduus nutans subsp. *micropterus*, *Centaurea glaberrima*, *Chaerophyllum coloratum*, *Iris pallida* subsp. *illyrica*, *Limonium dictyophorum*, *Onosma echioides* subsp. *dalmatica*, *Petteria ramentacea*, *Portenschlagiella ramosissima*, *Tanacetum cinerariifolium*, *Vincetoxicum hirundinaria*.

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