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*Habitat 91Eo\* Foreste alluvionali di Alnus  
glutinosa e Fraxinus excelsior (Alno-Padion,  
Alnion incanae, Salicion albae)*

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# Environmental assessment and conservation status of the Habitats of the Calabria Region

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## **Abstract**

Today, one of the main objectives for the conservation of animal and plant species is to identify the factors that limit the viability of populations, the quality and quantity of the habitat in which they are present.

Quantifying the conservation status of plant and animal populations and their habitats is a challenging and often difficult task both practically and politically.

Today the mapping of habitats and vegetation is fundamental for the conservation of biodiversity. Nature map provided for by law (394/91) is defined as a tool capable of providing knowledge about the territory, based on the identification, mapping of environmental units and their evaluation.

This PhD research focused its attention on the conservation status of the habitats of the Calabria Region through the study of vegetation, and the creation of ecological networks through landscape analysis (GIS) to promote connectivity and biodiversity conservation. The recognition, interpretation and ecological assessment of the natural and semi-natural habitats of EEC Directive 43/92 were therefore the focal points of this research.

This research work has actively contributed to the creation of Nature Map, delimiting and interpreting the various polygons through GIS and field activities for the identification of the various types of mapped habitats.

Subsequently, analyses were applied in order to identify more reliable methodologies in predictive terms, for the assessment of the state of conservation and the creation of an ecological network on the study area of interest.

In particular, for vegetation ecological indices and diversity indices were applied, while parameters for fragmentation (Fragstats), Morphological Spatial Pattern Analysis (MSPA) and circuit theory (Linkage Mapper) were applied for environmental landscape analysis.

The results obtained made it possible to interpret and evaluate the naturalness of the habitats, and their degree of fragmentation. The creation of the Ecological Network has allowed us to identify the ecological corridors for the movement of animal and plant species both inside and outside the Natura 2000 network and the areas of greatest resistance.

The study showed that the application of diversity indices related to landscape analysis are therefore suitable for identifying the causes of alteration and disturbance, and can also be used to monitor fragmentation and assess the conservation status of habitats of community interest. Finally, the mapping of habitats is a fundamental process for the planning of action to protect the territory.

## Riassunto

Oggi uno degli obiettivi principali per la conservazione delle specie animali e vegetali, consiste nell'identificare i fattori che limitano la vitalità delle popolazioni, la qualità e quantità dell'habitat in cui sono presenti.

Quantificare lo stato di conservazione delle popolazioni di piante e animali, e dei loro habitat risulta un compito impegnativo e spesso difficile sia a livello pratico che politico.

Oggi la mappatura degli habitat e della vegetazione risultano fondamentali per la conservazione della biodiversità. Carta natura prevista dalla legge (394/91) viene definita come uno strumento in grado di fornire conoscenze sul territorio, basato sull'individuazione, cartografia di unità ambientali e loro valutazione.

La presente ricerca di Dottorato ha focalizzato la sua attenzione proprio sullo stato di conservazione degli habitat della Regione Calabria attraverso lo studio della vegetazione, e la realizzazione di rete ecologiche mediante analisi del paesaggio (GIS) per favorire la connettività e la conservazione della biodiversità. Il riconoscimento, l'interpretazione e la valutazione ecologica degli habitat naturali e seminaturali di Direttiva CEE 43/92 dunque sono stati i punti focali di questa ricerca.

Il presente lavoro di ricerca ha contribuito attivamente alla realizzazione di carta natura, delimitando e interpretando i vari poligoni attraverso il GIS, e attività di campo per l'individuazione delle varie tipologie di habitat mappati.

Successivamente sono state applicate delle analisi al fine di individuare metodologie più affidabili in termini predittivi, per la valutazione dello stato di conservazione e la realizzazione di una rete ecologica sull'area di studio d'interesse.

In particolare, per la vegetazione sono stati applicati indici di diversità e indici ecologici, mentre per l'analisi del paesaggio ambientale sono stati applicati parametri per la frammentazione (Fragstats), Morphological Spatial Pattern Analysis (MSPA); teoria dei circuiti (Linkage Mapper).

I risultati ottenuti hanno permesso di interpretare e valutare la naturalità degli habitat, e il loro grado di frammentazione. La realizzazione delle Rete ecologica ci ha permesso di identificare i corridoi ecologici per il movimento delle specie animali e vegetali sia all'interno che all'esterno della rete Natura 2000 e le aree a maggiore resistenza.

Dal studio proposto è emerso che l'applicazione di indici di diversità legati all'analisi del paesaggio sono quindi adatti a identificare le cause di alterazione e di disturbo, e possono essere utilizzati anche per monitorare la frammentazione e valutare lo stato di conservazione degli habitat di interesse comunitario. Infine la mappatura degli habitat è un processo fondamentale per la pianificazione di azione di salvaguardia del territorio.

## CHAPTER 1. Introduction

### 1.1. Landscape ecology

Some of the concepts, theories and methodologies tested in this work have their scientific basis in the discipline of Landscape Ecology.

Some of these topics have been explored in depth during this research project that aims to provide a double contribution: one in the field of methodologies for phytosociological analysis through the study of vegetation and the other in the field of the application of Landscape Ecology to the conservation and management of biodiversity, through the ecological assessment of habitats.

General ecology (Whittaker, 1975) defines the landscape as a spatial framework for communities (or ecosystems), that is, as a geographical gradient capable of acting on ecological processes and structures at the level of organisms, populations and communities. The term landscape ecology was introduced by the German biogeographer Carl Troll (1939), deriving from the European traditions of regional geography, vegetation science and aerial photography. Landscape ecology is a branch of ecology, which aims to study the interactions that exist between the spatial pattern and ecological processes in a territorial mosaic. Landscape ecology is a fairly recent scientific subject, but already well articulated by theoretical principles and investigation tools that allow for investigations and assessments of the structure and state of ecological functionality of the landscape. A new field of research such as landscape ecology opens the door to the study of integrated ecology (Allen and Hoekstra, 1992), from the organism to the biosphere, in which the anthropic component also finds its correct location. In 1989, the ecologist Howard Thomas Odum defined landscape as "the level of organization of environmental systems interposed between the ecosystem and the biome". Modern landscape ecology since the 1980s has become a highly interdisciplinary and comprehensive scientific endeavor, with multiple definitions

and interpretations (Risser et al. 1984; Turner 1989; Forman 1995; Pickett & Cadenasso 1995; Wiens & Moss 2005; Wu 2006; Wu & Hobbs 2007; Turner and Gardner 2015). It is widely accepted that landscape ecology focuses on the relationship between landscape model and ecological processes.

Landscape ecology can be defined as that part of ecology that studies the landscape in the sense of biological organization, and thereby contributes to the advancement of integrated ecology and spatial planning. Landscape ecology thus becomes indispensable for biological conservation and must be considered as one of the basic chapters of integrated ecology.

We can define the landscape as a heterogeneous portion of territory composed of sets of interacting ecosystems and which repeats itself with a recognizable structure, framed in a certain climatic and geomorphological zone and with a certain regime of disturbances (natural and anthropic) (Forman and Godron 1986). Landscape Ecology studies the causes and consequences of the spatial heterogeneity of the mosaic of ecosystems present in a territory at different spatial and temporal scales (Turner et al. 2001, Gergel & Turner 2002). Two fundamental aspects identify Landscape Ecology from other ecological disciplines. First, Landscape Ecology emphasizes the relevance of spatial configuration on ecological processes. In particular, Landscape Ecology describes the landscape as "a mosaic of land uses and ecosystems that repeats itself according to an identifiable spatial configuration over a more or less extensive area" (Forman and Godron, 1986). Second, Landscape Ecology focuses on spatial extensions that are more extensive than those traditionally studied in ecology. As known in the literature (Kimberly 2019), three attributes are characteristic of all landscapes and provide the basis for comparing and quantifying them:

1. Landscape structure concerns the diversity and spatial arrangement of landscape elements (e.g. habitat zones).
2. Landscape function refers to the interaction between these spatial elements

(e.g., the flow of energy, nutrients, species, or genes between portions of habitat).

3. Landscape change refers to the way in which the structure and function of the landscape varies over time.

The mosaic is composed of three spatial elements at each scale: patches, corridors and matrix (Forman, 1995).

From an ecological point of view, patches represent discrete areas with homogeneous environmental conditions. Patch boundaries are created by environmental discontinuities, and are variations that are perceived by the organism under examination (Wiens, 1976).

Corridors are linear elements of the landscape that can be defined according to the structure or function they perform in the landscape

Forman and Godron (1986) define corridors as narrow strips of territory that differ from the matrix that surrounds them. The corridors can be isolated strips, but they are usually attached to an area characterized by similar vegetation ".

There are 3 types of corridors: 1) Corridor habitat. A linear element that enables the survival, birth and movement of living things and can be either a temporary or permanent habitat. 2) Corridor that supports movement. It is a landscape element that supports movement, but not necessarily reproduction, between two habitat patches. 3) Corridor barrier or filter. A linear element that selectively blocks the flow of energy, nutrients and/or species. (Forman and Gordon, 1986).

Landscape ecology was born in response to the perceived need to manage resources more fully and on a wider landscape scale. Sustainability is a key concept of landscape ecology (Wu 2006) and is the basis for healthy management of ecosystems and natural resources (Liu & Taylor 2002; Bissonette & Storch 2003). Landscape ecology therefore makes it possible to integrate social and economic issues into models of territorial evolution and can therefore be of great practical

use for land use planning, biodiversity conservation or environmental risk management (van den Bergh et al. (2001).

## **1.2. Vegetation**

From the biological component of the ecosystem it is therefore possible to extract the bioindication, that is, information on the factors that regulate life in the ecosystem itself. Each plant species has a tolerance towards each ecological factor within which it can perform its vital functions.

The plant component must be analysed at three levels

- ✓ Flora: the set of species present in a given territory. Each species is considered separately from the others;
- ✓ Vegetation: for each species, the amount of organic matter present is measured and thus quantitative information is obtained on the individual components of the vegetation cover, which allows defining the type of vegetation (plant associations or communities);
- ✓ Vegetation complexes: characterized by several associations that regularly occur in close topographic relationship (chain) or succession (serial), and allow to define units of territory (biotopes).

Vegetation analysis is based on two major approaches: physiognomic-structural analysis, which detects the morphology, stratification and form of growth of species, and floristic analysis, based on the type and relative abundance of species present in a community (Giacanelli, 2005).

The study of vegetation in much of Europe has been studied and classified mainly with the phytosociological method. The plant association, a fundamental unit in the Braun-Blanquet vegetation classification system (1932), is a "grouping of plants more or less stable over time and in balance with the environment, characterized by a determined floristic composition, in which some exclusive

species (characteristics) reveal, with their presence, a particular and autonomous ecology". In accordance with the literature (Braun - Blanquet 1964, Westhoff & Van de Maarel 1978), vegetation maps are made on the basis of vegetative types through their floristic composition, and classified according to the criteria encoded by the phytosociological method. In agreement with Ercole et al., (2010) most of these maps follow a standard classification system of the types, adopted within the European project CORINE Land Cover (APAT, 2005). The creation of a vegetation map represents the last phase of a cognitive process that begins with the detection of vegetation on the ground and proceeds with the definition of vegetation types, the recognition of plant communities and their classification (Biondi and Blasi, 2004c; Pedrotti, 2004).

### **Habitat Fragmentation**

In Ecology, the meaning of habitat fragmentation was introduced in the 1970s (Haila, 2002), but the origin of the concept was introduced by McArthur and Wilson (1967), according to which the wealth of species on an oceanic island is due to: its area and distance from the mainland, and the occupation of new species followed by the extinction of those already present. Fragmentation and habitat loss, in the context of biodiversity conservation studies, are considered among the most important phenomena that threaten biodiversity itself (Saunders et al., 1991; Dobson, 1996).

Habitat fragmentation refers to the subdivision of a continuous habitat into small fragments (Saunders et al., 1991). The effects of fragmentation affect both the abiotic and biotic components of ecosystems (Reed et al., 1996; Saunders et al., 1991). Fragmentation can in fact involve negative processes, including the disappearance or reduction of a habitat, its progressive isolation and an increase in both the edge effect and trivial ecosystems (Forman, 1995; Laurance, 2002). The reduction in surface area and the increase in the distance between the various fragments can in fact affect the size of populations and the movements of

organisms at different scales (Celada, 1995; Davies et al., 2001). Fragmentation is a process that can be divided into two components: habitat loss, that is, the decrease in the amount of habitat available to the species. The division of a continuous habitat into two or more smaller fragments (Fahrig, 2003). Species-poor ecosystems are fragile ecosystems, exposed to change and inadequate to provide goods and services, especially in those areas where the intensification of agriculture has led to greater land consumption, and the transformation of ecosystems into much more simplified landscapes, posing a serious threat to biodiversity. The process of fragmentation on natural ecosystems can result in several aspects, including:

Margin effect: determines in the fragments a transformation of the vegetative structure, microclimate and soil cover, which cause direct and indirect effects on the abundance and distribution of plant and animal species (Henle et al., 2004; Battisti 2004; Kettunen et al., 2007).

Barrier effect: In particular, it is the biopermeability of the species in the face of landscape, localised, linear or "diffuse" elements that show little or no ecological suitability.

Corridor effect: The creation of new environments due to the presence of infrastructures, (such as along the roads), which increase the number of plant and animal species present, favouring the establishment of synanthropic and invasive species.

On a global scale, the degradation and fragmentation of habitats, caused by different natural and anthropogenic factors, are the main factors of loss of animal and plant biodiversity. Over the past few centuries, often uncontrolled urbanization has been associated with the erosion of global biodiversity (Mack et al., 2000; Sala et al., 2000, Penuelas & Boada, 2003; Hobbs et al., 2006).

### 1.3. Ecological Integrity

Ecological integrity has become a widely used approach to conservation planning (Westra et al., 2000, Borja et al., 2009). Ecological integrity can be defined as the ability to sustain and maintain the balanced and integrated ecosystem in a particular region (Karr, 1996, Parrish et al., 2000). Ecological integrity indices should take into account the various components and phenomena of interest of a given ecosystem in the ecosystem (Karr, 1993, Fore et al., 1996). Composition, structure and function are important elements of ecosystems (Franklin et al., 1981, Noss, 1990) and a list of indicators should include these three components.

#### Ecological Value

Knowledge of the ecological value of a habitat is fundamental to attributing greater interest to the conservation of biodiversity. (Margules and Usher, 1981; Goldsmith, 1983;). In ecological terms, indicators are used to assess the state of an ecosystem. Any biological variable capable of providing indications of other environmental variables is defined as a biological indicator (Blasi, 1987). The search for components that characterize environmental quality is widespread in the field of ecological disciplines, especially in the field of nature conservation,

The indicators used for the assessment of the ecological value are:

- ✓ Naturality
- ✓ ecological multiplicity ecosystem rarity
- ✓ rarity of landscape type (nationwide)
- ✓ presence of protected areas in the territory of the unit

Naturalness is defined as environmental development unconditioned by anthropogenic activity, closely associated with the concept of climate and, conversely, that of anthropization. Naturalness indicators can therefore be

identified on the basis of the degree of floristic or faunal pollution caused by the introduction of synanthropic or invasive species.

Rarity refers to the presence of environmental or biological entities in the territory where there is a condition of "poor availability" (rare species, endemisms, etc.). Protected areas play a vital role in conserving biodiversity.

#### **1.4. Biodiversity**

The concept of biodiversity defined in the 1992 Rio Convention as the variability between living organisms of all kinds, originating from terrestrial, marine and other aquatic ecosystems, as well as the ecological complexes of which they are part (CBD Convention on Biological Diversity 1992). Biodiversity can be interpreted at different scales by reproducing both the structure of organisms, but also the functional diversity and biological interactions present in natural systems (Colwell, 2009). Biodiversity is divided into different interspecific, intraspecific, ecosystem and landscape scales. Ecosystem diversity defines the number and abundance of habitats, living communities, and ecosystems within which different organisms live and evolve. Intraspecific diversity defines the difference of genes within a given species; it therefore corresponds to the totality of the genetic heritage to which all the organisms that inhabit the Earth contribute.

Interspecific biodiversity includes species diversity, measurable in terms of the number of the same species present in a given area, territory or habitat. Biodiversity plays a central role in the functioning of the biosphere and its sustainability (Walsh 1991, Young & Burton 1992). Italy, which is located in the center of the Mediterranean basin, has one of the richest biological diversity of European countries (Blasi et al. 2005). In some parts of our peninsula, in fact, endemic taxa reach values between 13 and 20% (Rossi et al., 2013). In the face of increasing pressures on biodiversity, conservation policies have been adopted at the European level and these include Directive 92/43/EEC ("Habitats Directive").

The Directive establishes the Natura 2000 Network, the main tool available for the conservation of biodiversity. It is an ecological network spread throughout Europe, consisting of Special Conservation Areas (SCAs), and Special Protection Areas (SPAs), in Italy these areas cover about 19% of the Earth's territory and 4% of that. The maintenance of biodiversity is important for ecosystems to maintain a sufficient degree of adaptation to environmental changes also induced by the anthropogenic use of resources (Bond, 1993; Forman, 1995; Farhing & Merriam, 1985; Sargolini, 2003). The implementation of the ecological network is to be interpreted as a fundamental strategy to guarantee the protection of naturalness and biodiversity but also to guarantee a better quality of life (APAT, 2003; Farina, 1993; Pignatti, 1994; Steine, 2004; Rodrigues et al., 2004).

### **1.5. Natura 2000 network**

In Italy, the term "network" used for ecological and conservation issues has been widespread since the early 1980s (Bullini et al., 1980; Contoli, 1981; see also Parisi, 1972). The Natura 2000 network is an ecological network spread throughout the territory of the Union, established pursuant to Directive 92/43/EEC "Habitats" to ensure the long-term maintenance of natural habitats and species of flora and fauna threatened or rare at Community level. It is an instrument of the European Union's policy for the conservation of biodiversity. Ecological network planning must be related to the articulated ecological and anthropic variables present at the territorial level (Soulé, 1986). In this regard, the IUCN (see website :<http://iucn.org>) designates the management and restoration of habitats and ecosystems, including the establishment of protected areas and ecological networks. Each site is characterized by a code and a name; the first 2 characters of the code refer to the state, IT for Italy, and are followed by three digits that identify the province.

The creation of this network of Special Areas of Conservation (SCAs) and Special Protection Areas (SPAs) fulfils a clear community obligation established under

the United Nations Convention on Biological Diversity.

The Calabria Region has extensive knowledge of the vegetation in the area (Brullo et al., 2001; Maiorca et al., 1999; Maiorca et al., 2002; Maiorca et al., 2003; Maiorca et al., 2005; Maiorca et al., 2006, Maiorca et al., 2007; Maiorca et al., 2013; Maiorca et al., 2008; Maiorca et al., 2020; Spampinato 2000a; 2000b; 2000c; Spampinato et al., 2007; ) which has made it possible to produce both phytosociological and habitat maps in a large part of the territory, defined using the Italian Habitat Interpretation Manual. (Biondi E., Blasi C., Burrascano S., S. Casavecchia, Copiz R., Del Vico E., Galdezi D., Gigante D., Lasen C., Spampinato G., Venanzoni R., 2009).

## **1.6. Cartography of Habitats**

ODUM (1971), at European level describes the habitat of a species as the "space characterized by a certain uniformity of physical, chemical and biotic factors, where an organism lives in equilibrium with those factors" the CORINE Habitat Classification system, created within the CORINE Biotopes project (Eur – 12587, 1991), identifies the habitat as "a set of spatial units in which organizations sufficiently similar in abiotic, physiognomic, phyto and zoo-cenotic terms play similar roles from the point of view of nature conservation. This definition has been maintained in the following European habitat classification initiatives, both in the project "A Classification of Palearctic Habitats" (Devillers et al., 1996), and in the EUNIS – Habitat of European Environmental Agency (EEA) programme, through the European Topic Centre on Nature Protection and Biodiversity (Davies C.E., Moss D., 1999, 2000, 2002). The creation of the Nature Map was established according to the Framework Law for Protected Natural Areas (Law no. 394/91) in art. 3 aimed at drawing up the layout lines of the territory. Nature Map was initially designed to define and identify Protected Areas, but today its products are also used in many other areas, such as: planning, environmental assessments,

identification and design of ecological networks, environmental reporting, analysis of territorial evolutionary scenarios and more. The conceptual and methodological basis taken as the initial reference for the creation of the Nature Map was tested, thanks to a 1995 study conducted by the University of Parma for the Ministry of the Environment on the Island of Salina. In this work, the methodological structure of the creation of the Nature Map was outlined for the first time, starting from the identification of homogeneous environmental units and then proceeding to an assessment of the environmental tiles on the basis of the contents of quality, anthropic pressure and vulnerability of the environments. The Nature Map, so far created (about six million hectares on a scale of 1: 50,000), has demonstrated the usefulness of this tool for the purpose of drawing up the planning lines of the territory, for environmental impact assessment studies, for the creation of ecological networks, for studies related to biodiversity and for further objectives that require knowledge of the territory. Carta della Natura is the result of two phases of activity, the cartographic production to know and represent at different scales the type and distribution of Italian terrestrial ecosystems and habitats throughout the national territory and the evaluation that focuses on the state of the ecosystems, highlighting the areas of greatest natural value and those most at risk of degradation. Environmental systems are organized in different levels of complexity depending on the scale of study (Allen & Starr 1982, O'Neill et alii 1986, O'Neill 1989, Wiens 1995) the two scales taken as a reference so far are the 1:250.000 scale and the 1:50.000 scale. On the 1:250,000 scale, suitable for defining landscapes at a regional and supra-regional level, a map of homogeneous environmental units was created from a physiographic point of view, thus using the physical aspects of the territory as discriminating elements. The studies on the 1:50,000 scale, the subject of this volume, provide for the mapping of ecologically homogeneous environmental units on a medium detail scale and the estimation of quality (value), sensitivity and ecological-environmental vulnerability of each of these units through the use of specific

indicators and algorithms.

The mapping of habitats constitutes the first piece of the entire process as it represents the mapping of the territorial areas homogeneous to this scale of analysis and responds to the first objective of the Nature Map, namely to represent the state of the environment. Today, information on the construction and advancement phases of Carta della Natura products is available for almost all Regions, except Piedmont, Lombardy, Trentino-Alto Adige, and Calabria where work is in progress. In the Abruzzo Region, the Habitats Map was created on the 1:50,000 scale (Bagnaia et al., 2011), as well as in other Regions, Basilicata (Papallo et al., 2012), Sicily (Papini et al., 2008), Umbria (Papallo et al., 2012) where an area of the Tiber River was initially studied; subsequently, at the end of 2007, in collaboration with Arpa Umbria, the Habitats Map was created on the 1:50,000 scale in an area including Lake Trasimeno and surrounding areas, in that of Puglia (Angelini et al., 2012) where the path that led to the creation of the Puglia Region Nature Map system was born with the signing of a Protocol of Intents in 2003 between ISPRA (former APAT) and the Regional Agencies for the Environmental Protection of Puglia, Calabria, Basilicata, Molise, Abruzzo and Campania. While in other Regions the Habitats Map was created on a scale of 1:250,000 as in Emilia – Romagna (Cardillo et al 2021) where the work for the creation of the Nature Map in Emilia-Romagna was organised on a provincial basis. Gradually, once the various maps of the provincial habitats have been completed, in recent years ISPRA has decided to deepen and modify the national legend of the habitats of the Nature Map project by creating the new National Legend for the mapping of habitats. The improvement of the thematic resolution, together with the methodological update for cartographic production, has allowed an increase in the return scale to 1: 25,000. The Molise territory has been affected by the works of Nature Map since the experimental phases of the project, thanks to the joint work between Arpa Molise and ISPRA that produced the Nature Map at a scale of 1:50.000, using integrated methodologies that involved

the guided interpretation of Landsat satellite images, field checks, the application of niche models and the use of aerial photographs. Subsequently, ISPRA started the production of a new Nature Map of the Molise region (Ceralli D. 2021) more in line with the new cartographic detail standards. The work for the realization of the new Molise map led to the publication of the Nature Map of the Molise region on the scale of 1:25,000. Finally, a Nature Map was also created in the Marche Region on the 1:25.000 scale (Papallo et al., 2022).

### **1.7. Nature Map of the Calabria region**

To map the habitats, we started from the Map of Land Use produced by the Calabria Region (Map of places scale 1:5.000). In particular, the 1:5000 sheets: were initially analysed using Google Earth Pro, each polygon was interpreted by inserting placeholders with the habitat code of Nature Map of the ISPRA 2019 legend, highlighting any mosaics or subdivisions of the polygon. Subsequently, on the shp file containing the polygons reinterpreted according to this legend, QGIS was used to correct any attribution errors of the orthophoto-mapped biotopes, and to highlight the types of habitats according to the preliminary phase or previously constructed maps (Bagnaia, et al., 2017). For each sheet, the shp file of the surveys carried out both by vegetational surveys with a phytosociological method and through georeferenced photos was produced, the shp file of the specific habitats, the shp of the surveys already present in previous studies and finally the shp file of the sheet where the final Nature Map file is produced.

For the coding of habitats, a Nature Map database was developed, also used in the organisation of the paper legend, starting from the ISPRA legend (2019) and adapting it to the reality of the territory of Calabria. The database has the following structure (Tabelle 1.1): habitat code and name; description adapted to the Calabria Region; habitat code and name; guide species present in Calabria; correspondences with other habitat classification systems (EUNIS Habitat, Habitat Directive CEE 43/92 Soil Use Map Land Cover Map Corine); syntax

(Prodrómo della vegetation d 'Italia); regional distribution; distribution in the Natura 2000 network (ZSC/ZPS) of the Calabria Region; Notes; bibliography.

**Table 1.7.1.** Nature Map database structure.

Presenza in Calabria	Macro-categoria	Gruppo di Habitat	Legenda Carta Natura 2019 Codice	Legenda Carta Natura 2019 Nome	EUNIS Codice	EUNIS Nome	Direttiva Habitat Codice	Direttiva Habitat Nome	CORINE Land Cover ISPRA Codice	CORINE Land Cover ISPRA Nome
C	4 - AMBIENTI BOSCHIVI E FORESTALI	Boschi di latifoglie decidue	41.18	Faggete dell'Italia meridionale	G1.67	Southern mediterranean European Fagus forests	9210* 9220*	Faggeti degli Appennini con Taxus e Ilex Faggeti degli Appennini con Abies alba	3115	Boschi a prevalenza di faggio

The creation of the Nature Map of the Calabria region (Figure 1.1) identified and mapped 130 habitats (Spampinato et al., 2023) divided into 7 macro categories:

- ✓ Coastal and halophilic communities (13 habitats);
- ✓ Non-sea waters (8);
- ✓ Bushes and Grasslands (40);
- ✓ Forests (33);
- ✓ Swamp formations (5);
- ✓ Rupees and gravel (6);
- ✓ 8. Crops and built-up areas (24).

The largest areas are occupied by the habitats of macrocategory 8 "Agricultural land and artificial landscapes" (43.7% of the regional area); among these, the habitat of the Olive groves in the regional territory has a larger area with 15.7%. 37.4% of the regional territory is characterized by the macrocategories of Forests that show a high diversity in terms of habitat types.

Among the most representative habitats we have beech trees that occupy 6.6% of the regional area, characterized by the various syntaxes: *Ranunculo brutii-Fagetum sylvaticae* Bonin 1967, *Anemone apenninae-Fagetum sylvaticae*, *Gallio hirsuti-Fagetum sylvaticae* Brullo, Scelsi & Spampinato 2001,

*Geranium versicoloris-Fagion sylvaticae* Gentile 1970. Other forest habitats that occupy greater areas are chestnut trees with 5.5% (*Crataego laevigatae-Quercion cerridis* Arrigoni 1997), and *Quercus Pubescens* oak tree (*Pino calabricae-Quercion congestae* Brullo, Scelsi, Syracuse & Spampinato 1999 em. Blasi, Di Pietro, Filesi 2004) with 4.9% of the regional area. The habitats of the macrocategories (bushes and grasslands) occupy an area of 16.4% of the Region, most influenced by anthropogenic activity. In the submontane and mountain ranges, the most frequent phytocenoses are represented by cytisis bushes (*Cytisus villosus*, *Cytisus sessilifolius* and *Cytisus scoparius*), tall arboreal heather patches (*Erica arborea*), finally also bushes dominated by shrubby Rosaceae of the genera *Prunus*, *Rosa*, *Crataegus* that prefer rich temperate soils on rich soils. The Calabria region as a whole is characterized by a high degree of naturalness, since the natural and siminatural habitats of the region occupy an area equal to 53% of the regional territory. Within the region there are also several habitats that occupy relatively low areas with high naturalistic value as they are defined as priorities according to the habitat directive (43/92), namely habitat 9510\* (Southern Apennine *Abies alba*) and habitat 2250\*(Coastal dunes with *Juniperus* spp.). All these data that allow us to understand the complexity of natural ecosystems are reported in the document of the Nature Charter of the Calabria region (geography of habitats) (Figure 1.2), which together with the recently published work "Biodiversity in Calabria" (Figure 1.3) represented valuable results for planning through land use choices and the related assessment paths of the environmental impacts of plans/programs/projects.

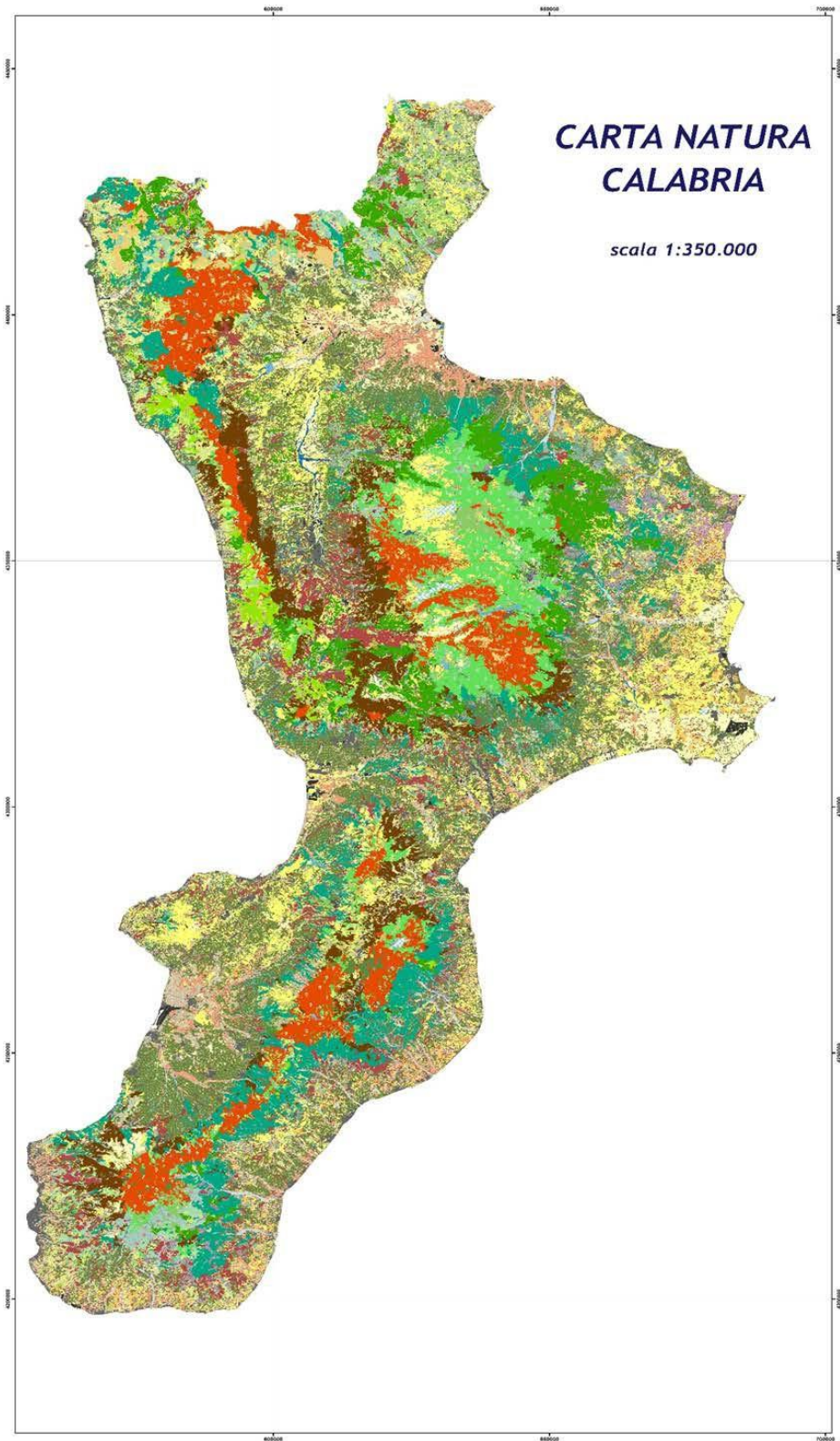


Figure 1.1 Nature Map of the Calabria Region

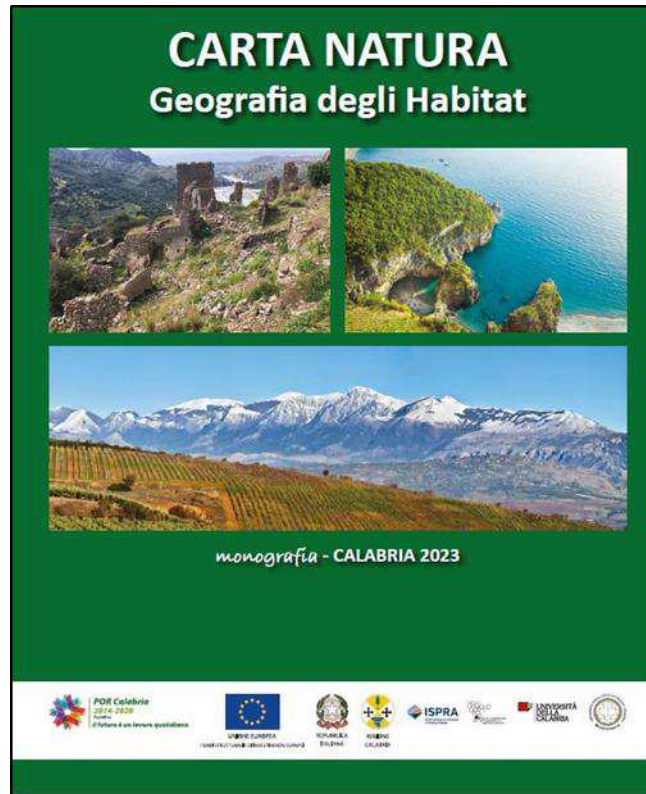


Figure 1.2. Nature Map monograph of Calabria Region



## **1.8. Objective**

The proposed research work aims, starting from the draft Nature Map established by ISPRA, according to the Framework Law for Protected Natural Areas (Law no. 394/91), at the recognition, interpretation and ecological assessment of natural and semi-natural habitats of EEC Directive 43/92. In addition, the study aims at the programming of an efficient and functional Ecological Network for the conservation of biodiversity using as a case study the natural map of the Nature Map of the Calabria Region. The comparison with the information layers of the GIS (Geographical Information System) and in particular the vegetation data was important. What emerged from this research is that, thanks to the application of the aforementioned methodology, it is possible to make useful comparisons between areas of greater ecological value and those of greater fragility in order to offer tools for reflection to implement actions aimed at territorial protection and planning.

The first part of the work is dedicated to bibliographic research data regarding the state of knowledge in the environmental assessment, the conservation status of Habitats and the Nature Map project coordinated in Italy by ISPRA.

The second part was dedicated to addressing the subject of my thesis, elaborating on the Nature Map of the Calabria Region, starting from the Nature Map project coordinated by ISPRA, carried out in Calabria thanks to the collaboration between the Environment Department of the Calabria Region, the Department of Agriculture of the Mediterranean University of Reggio Calabria and the DiBEST of the University of Calabria.

In detail, after delimiting using the interpretation by GIS of the uniform polygons for attributes of colour and density of the image, subsequent field checks made it possible to identify the various types of mapped habitats.

This activity has allowed the reporting of new national and regional Annex I

Habitat records for the Region of Calabria (Morabito et al., 2024; 2024; 2023; 2022).

The third part of the activity was dedicated to the ecological analysis and diversity of some habitat groups important for biodiversity conservation: grasslands (Morabito et al., 2024), oak woods (Morabito et al., 2022), coastal habitat (Morabito et al., 2024) and finally Aspromonte National Park forest habitats. The landscape assessment concerned the analysis of the fragmentation of the Nature Map habitats, and the assessment of connectivity through the identification of ecological corridors between the Natura 2000 Network sites aimed at defining a Regional Ecological Network.

## **CHAPTER 2. New national and regional Annex I**

### **Habitat records**

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**Abstract:**

The presence of habitats in an area is one of the indicators needed to assess their conservation status, allowing their expansion or loss to be estimated.

This study uses 'New National and Regional Annex I Habitats' for reporting, actual distribution, archiving and recovery of Annex I habitats. The analysis is based on 40 vegetation relevés carried out in the period 2018- 2021. The description of the newly registered habitats, species and sites was made according to the standard format of Gigante et al. (2019a; 2019b).

This contribution reports new Italian data on the distribution of Annex I habitats. In particular, 6 new occurrences in Natura 2000 sites and 27 new cells are added in the EEA 10 km × 10 km reference grid. The new data refer to the Calabria region. Our results show new cells useful for planning and overcoming challenges to biodiversity conservation.

Keywords: vegetation, 1430, 2110, 2250\*, 2270\*, 6420, 8210, 91AA, 91E0\*, 92A0, 9330.

## 2.1. Introduction

Today, the Natura 2000 network covers more than 18% of the EU's land area (European Commission, 2018), and is one of the largest conservation networks in the world. Natura 2000 sites represent a network for the in situ protection of species and habitats, identified as conservation objectives of "Community importance" according to Directive 92/43 EEC, Important regulatory instrument for the conservation of natural and semi-natural ecosystems in Europe (Evans 2012; Lengyel et al. 2008; Henle et al. 2013; Hoffmann et al. 2018).

The interpretation of habitats has taken on considerable importance since the legislative establishment of the Habitat Directive, (Rodwell et al., 2018). Today, many efforts have been made to clarify the interpretation of habitats at national level (Evans, 2010) or regional level (e.g., Brusa et al., 2017a).

Habitats are defined as important indicators for biodiversity, (Bunce et al., 2013a, 2013b) having a leading role in monitoring the conservation status of nature. In addition, over the last two decades, numerous studies have been carried out to represent and monitor biodiversity (Noss, 1996; Galdenzi et al., 2012; Rodríguez et al., 2012; Berg et al., 2014; Izco. 2015; Keith et al., 2015, Henle et al., 2013). Monitoring habitats is a complex task, given its large size. Great efforts have been made in this direction, on a European scale (Evans & Arvela, 2011, Mucina et al 2016, Chytrý et al.; 2020), in Italy (Stanisci et al. 2014: Del Vecchio et al., 2016, Biondi et al., 2012; Gigante et al., 2016; Angelini et al 2016).

Information on the distribution of habitat types and vegetation types is crucial for effective habitat conservation (Janssen et al., 2016). The extent and condition of habitats is also an important aspect for biodiversity, it appears to be a legal requirement in the EU to regularly monitor and report on the conservation status of Annex 1 habitats (Bunce et al., 2013). The various national projects use specific systems and methodologies to classify and map habitats (Ichter et al., 2014).

The conservation status of different habitat types is assessed on the basis of four quantitative ("range" and "area") and qualitative ("structure and functions")

parameters (EC 2016). Analysis of national mapping or selective recording in conservation areas, some of which are also supported by remote sensing methods, provides data for area and area parameters (e.g. Förster et al 2008, Vanden Borre et al. 2011, 2017).

The census of natural habitats in the same Directive has given new input to taxonomic and ecological research, involving different disciplines (Blondet et al. 2017).

For the support and implementation of habitats in Directive 92/43/EEC, the "New national and regional Annex I Habitat" as the reference vector for reporting, actual distribution, storage and retrieval of Annex I habitats

This research resulted in new national and regional records of Annex I habitats for the Calabria Region [30-32-33-34].

All the phytosociological surveys of this contribution, representative of the various Habitats of Annex I are archived and freely accessible in the national database "VegItaly" (Landucci et al., 2014), managed by the Italian Society for Vegetation Science.

## **2.2. Materials and Methods**

The analysis concerned the habitats present in the region of Calabria (Figure 2.1). The description of new recorded habitats, species and sites was done in the standard format by Gigante et al. (2019a; 2019b).

We have a summary in Table 1, which gives an overview of the new features. For the mapping, we used the open source geographic information QGIS system (QGIS.org 2021) with reference system WGS84 UTM Zone 33, (False\_East: 500000.00000 False\_North: 0.00000; Meridian\_Central: 15.00000; Scale\_Factor: 0.99960; Latitude\_Origin: 0.00000; Linear\_Unit: Kilometres).

The habitat analysis was based on the vegetation surveys carried out in 2018-2021, using the phytosociological method of the Zurich-Montpellier school

(Braun-Blanquet, 1964), which lists the taxa present in the different layers and their abundance/dominance within a homogeneous plant stand. Forty new georeferenced surveys were carried out (Table S1; Supplementary Material). Raw data were organised using Microsoft Excel 2010.

The nomenclature of species follows the "Portale della flora d'Italia" (Portal to the Flora of Italy 2023), while the syntaxonomic references of plant communities take into account the Prodrómo of vegetation (Biondi et al 2015). For the interpretation of Community habitats according to EEC Directive 43/92, the Manuals for the interpretation and monitoring of habitats of Community interest in Italy [Biondi et al 2009; Chytrý et al. 2020] were us

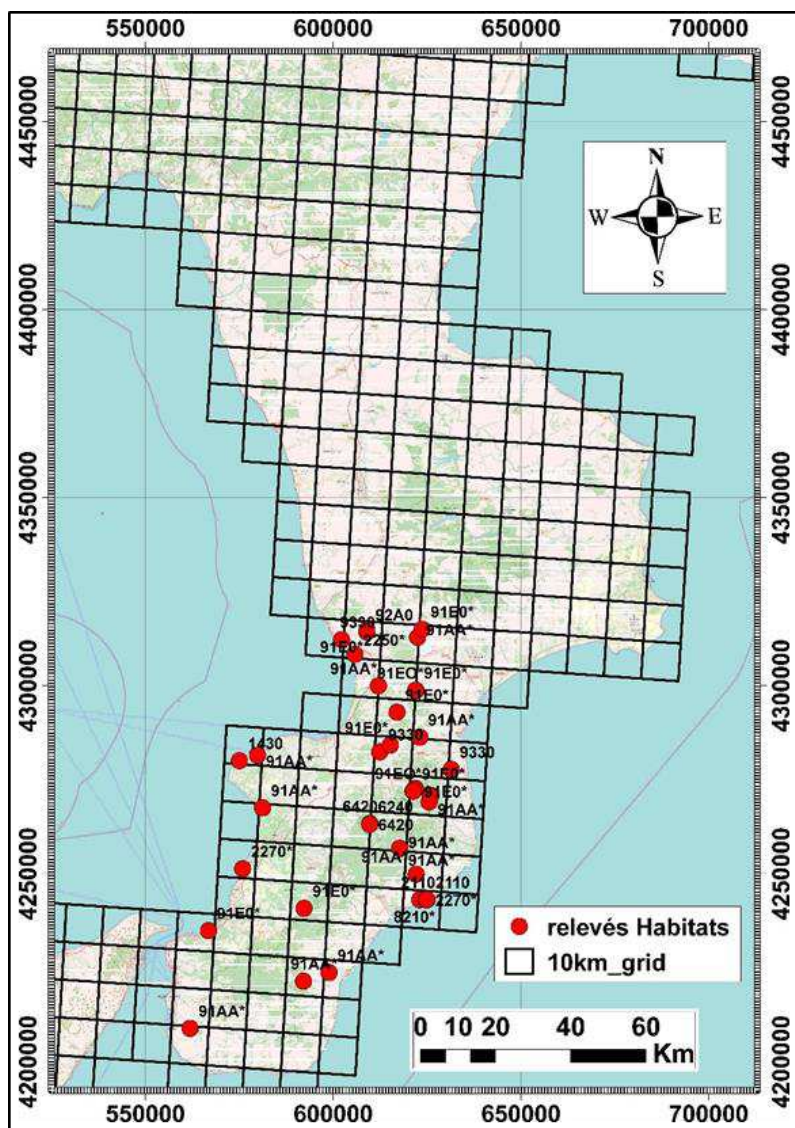


Figura 2.1. Study area. In red the relevance of the different habitats, in black the EEA 10 km × 10 km grid cells.

### 2.3. Results

This contribution contains the new Italian data on the distribution of habitats in Annex I 1430, 2250\*, 2270\*, 6410, 8210, 91AA\*, 91E0\*, 92A0, 9330. In particular, 3 new presences in Natura 2000 sites are presented and 23 new cells are added to the EEA reference grid 10 km 10 km. EEA reference grid. The new data refer to the regions of Calabria published in the journal Plant Sociology [30-32- 33-34].

2.3.1. #46. Annex I Habitat: 2270\* Wooded dunes with *Pinus pinea* and/or *Pinus pinaster*

(Morabito A, Musarella CM, Spampinato G)

**EUNIS Classification system:** N1G (formerly B1.7): Mediterranean coniferous coastal dune forest (Chytrý et al. 2020)

Biogeographical Region: Mediterranean

**National Habitat Checklist of reference:** Italian Interpretation Manual of the Directive 92/43/EEC Habitats (Biondi et al. 2009).

**Phytosociological reference:** *Pistacio lentisci-Rhamnetalia alaterni* Rivas Martínez 1975, *Quercetea ilicis* Br.-Bl. In Br.-Bl., Roussine et Nègre 1952 (Biondi and Blasi 2015; Biondi et al. 2009).

**Geographic information:** Italy, Calabria, Reggio Calabria, Palmi, 7 m a.s.l. Coordinates: 38.406858 N, 15.869278 E (Rel. 1); Roccella Ionica, Via Marina Porto delle Grazie, 9 m a.s.l. Coordinates 38.327940 N, 16.429254 E (, Rel. 2). (Table 2.1)

**Cells ID in the EEA reference grid:** 10kmE483N172, 10kmE488N171 (Tab. 3,) (Figure 2.2).

**Natura 2000 Site Code:** currently not included in any Natura 2000 Site.

**Phytosociological table:** Nomenclature and taxa delimitation according to Portal to the Flora of Italy (2022) (Supplementary Materials File S1)

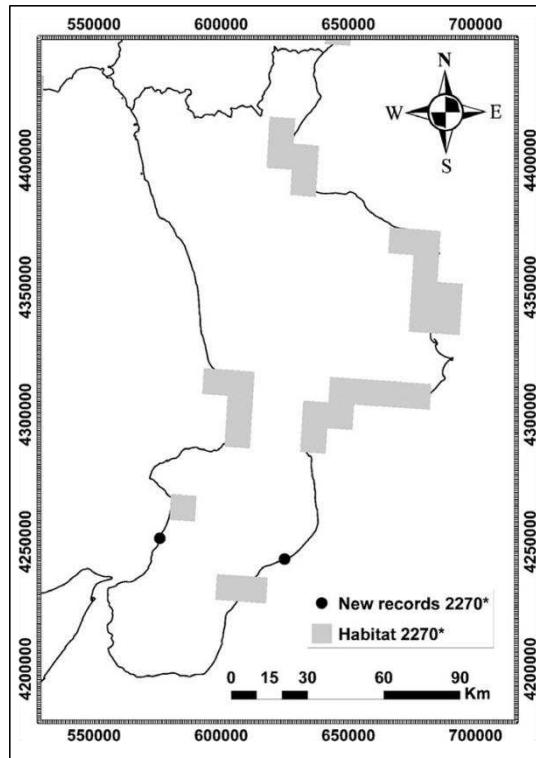


Figura 2.2. Distribution of Habitat 2270\* in Calabria: in black the new cells, in grey the cells officially reported in the 4th Habitat Report ex-Art. 17 (period 2013–2018; Eionet 2019).

The habitat has been identified on the Tyrrhenian coast of Calabria near Palmi and on the Ionian coast near Roccella Ionica (RC). In both locations, the habitat extends a long stretch of the shoreline. These are communities planted on the inland dune system about seventy years ago. They consist exclusively of *Pinus halepensis* and *Pinus pinea*, currently in a precarious state of conservation due to the high density of the planting. This prevents the regeneration of pine trees and the establishment of woody species typical of the Mediterranean maquis.

2.3.2 #53. Annex I Habitat: 6420 Mediterranean tall humid herb grasslands of the *Molinio-Holoschoenion*

(Morabito A, Musarella CM, Spampinato G)

**EUNIS Classification system:** R31 (formerly E3.1) Mediterranean tall humid inland grassland (Chytrý et al. 2020)

**Biogeographical Region:** Mediterraneana

**National Habitat Checklist of reference:** Italian Interpretation Manual of the Directive 92/43/EEC Habitats (Biondi et al. 2009).

**Phytosociological reference:** *Dactylorhizo-Juncetum effusi* Brullo et Grillo 1978, *Dactylorhizo- Juncion striati* Brullo et Grillo 1978, *Holoschoenetalia vulgaris* Br.-Bl. ex Tchou1948, *Molinio- Arrhenatheretea* Tüxen 1937 (Brullo and Spampinato 1999, Biondi and Blasi 2015).

**Geographic information:** Italy, Calabria, Vibo Valentia, Arena, Arruggiato, 1148 m a.s.l., Coordinates: 38.510383 N, 16.258294 E (Rel. 1); 1142 m a.s.l., Coordinates: 38.511694 N, 16.258992 E (Rel. 2); 1146 m a.s.l., Coordinates: 38.510861 N, 16.258442 E (Rel. 3). (Table 2.1).

**Cells ID in the EEA reference grid:** 10kmE486N173 (Figure 2.3).

**Natura 2000 Site Code:** ZSC IT9340119 "Marchesale"

**Phytosociological table:** Table 2.3 Nomenclature and taxa delimitation according to Portal to the Flora of Italy (2022) (Supplementary Materials File S2).

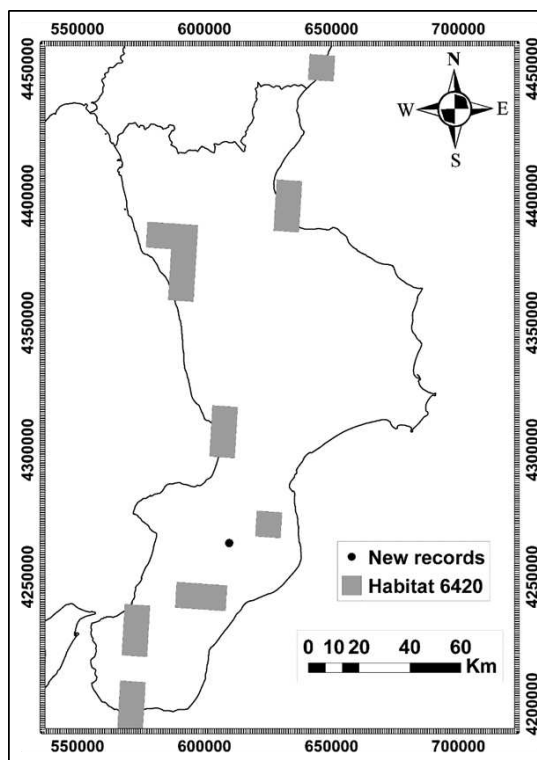


Figura 2.3 Distribution of Habitat 6420 in Calabria: in black the new cells, in grey the cells officially reported in the 4th Habitat Report ex-Art. 17 (period 2013–2018; Eionet 2019).

The habitat was identified on the Serre (southern part of Calabrian Apennines) above Arena (VV), located in humid depressions within *Fagus sylvatica L.* forest formations. The association *Dactylorhizo-Juncetum effusi*, to which the habitat aspects detected refer, frames hygrophilous grasslands, characterised by thermophilous hygrophilous species and the dominance of *Juncus effusus*, mainly localised on silty-clayey soils of the mountain belt, periodically subjected to submersion (Brullo et al. 2001). The presence of marsh habitats within beech forests contributes to increase the mountain range's biodiversity levels, which is densely covered by woodland.

Table 2.1. Synthetic overview of the newly reported data.

Hab ID	Hab name	Cell ID	Coun try	BR	N2000 Site	Authors
2270*	Wooded dunes with Pinus pinea and/or Pinus pinaster	10kmE483N1 72	Italy	MED	-	Morabito A., Musarella C.M., Spampinato G.
6420	Mediterranean tall humid herb grasslands	10kmE486N1 73	Italy	MED	IT9340119	MorabitoA., MusarellaC. M. Spampinato G.

2.3.3. #64. Annex I Habitat: 2250\* Coastal dunes with Juniperus spp.

(Morabito A, Musarella CM, Spampinato G)

**EUNIS Classification system:** N1B21 (formerly, B1.631) - Dune prickly juniper thickets (Chytrý et al. 2020).

**Biogeographical Region:** Mediterranean

**National Habitat Checklist of reference:** Italian Interpretation Manual of the Directive 92/43/EEC Habitats (Biondi et al. 2009).

**Phytosociological reference:** *Pistacio lentisci-Juniperetum macrocarpae* Caneva, De Marco and Mossa 1981, *Juniperion turbinatae* Rivas-Martínez 1975 corr. 1987, *Pistacio lentisci-Rhamnetalia alaterni* Riv.-Mart. 1974, *Quercetea ilicis* Br.-Bl. 1947 in Br.-Bl., Roussine and Nègre 1952

**Geographic information:** Italy, Calabria, Catanzaro, Lamezia Terme, Contrada Maricello, 5 ma.s.l. Coordinates: 38.917158 N, 16.220564 E (Rel. 1). (Table 2.2)

**Cells ID in the EEA reference grid:** 10kmE486N178 (, Figure 2.4).

**Natura 2000 Site Code:** currently not included in any Natura 2000 Site.

**Phytosociological table:** Nomenclature and taxa delimitation according to Portal to the Flora of Italy (2023). (Supplementary Materials File S3)

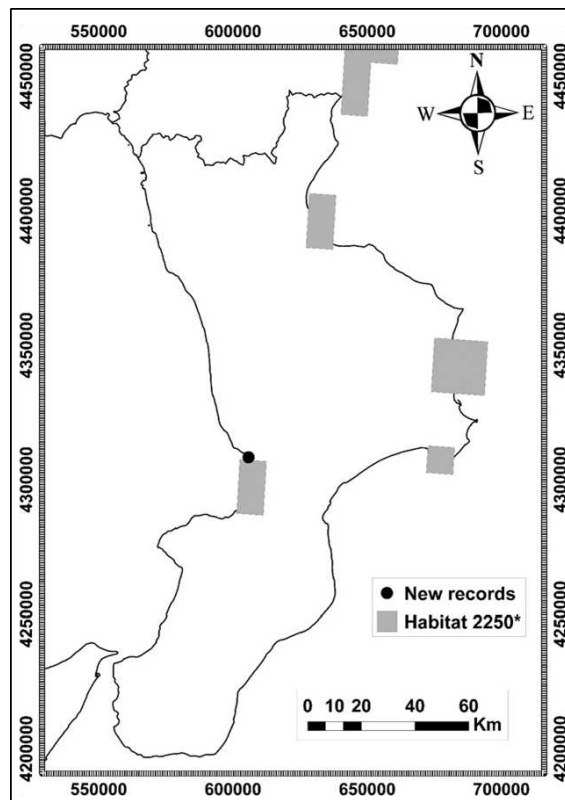


Figura 2. 4. Distribution of Habitat 2250\* in Calabria: in black the new cells, in grey the cells officially reported in the 4th Habitat Report ex-Art. 17 (period 2013–2018; Eionet 2019)

The association *Pistacio lentisci-Juniperetum macrocarpae* Caneva, De Marco and Mossa 1981, is a type of dense and intricate psammophilous scrub that constitutes the first woody vegetation colonizing sandy dune. This vegetation has been described for Sardinia region (Caneva et al. 1981) and brought back to Tuscany (Arrigoni et al. 1985; De Dominicis et al. 1988), currently limited in a few coastal stretches not exploited for tourist or residential purposes (Acosta and Ercole 2015). The scrub with *Juniperus macrocarpa* Sm. is important for the conservation of coastal dunes, as it contributes significantly to the consolidation of coastal sand dunes. In the survey carried out there are invasive alien species including *Acacia saligna* (Labill.) H.L. Wendl, which compromises the structure and conservation of the habitat (Spampinato et al. 2022). These new records report for the first time the *Pistacio lentisci-Juniperetum macrocarpae* association for the Calabria Region, expanding the distribution area of the 2250\* habitat in the region.

2.3.4. #75. Annex I Habitat: 91AA\* Eastern white oak woods

(Morabito A, Musarella CM, Spampinato G)

**EUNIS Classification system:** T1932 (formerly, G1.732) - Italo-Sicilian *Quercus pubescens* woods (Chytrý et al. 2020).

**Biogeographical Region:** Mediterranean

**National Habitat Checklist of reference:** Italian Interpretation Manual of the Directive 92/43/EEC Habitats (Biondi et al. 2009).

**Phytosociological reference:** *Erico arboreae-Quercion ilicis* Brullo, Di Martino and Marcenò 1977; *Quercetalia ilicis* Br.-Bl. ex Molinier 1934; *Quercetea ilicis* Br.-Bl. in Br.-Bl., Roussine and Nègre 1952 (Biondi and Blasi 2015).

**Geographic information:** Italy, Calabria, Catanzaro, Gizzeria, Contrada Jacona, 75 m a.s.l., Coordinates: 38.841122 N, 16.290958 E (Rel. 1); Italy, Calabria, Catanzaro, Serrastretta Timpone Chianta, 393 m a.s.l., Coordinates: 38.956261 N, 16.413381 E (Rel. 2); Italy, Calabria, Vibo Valentia, Parghelia, S. Antonio, 89 m a.s.l., Coordinates: 38.678453 N, 15.917989 E (Rel. 3); Italy, Calabria, Catanzaro, Cenadi, Contrada Griffi, 485 m a.s.l. Coordinates: 38.716733 N, 16.415092 E (Rel.

4); Italy, Calabria, Vibo Valentia, Nicotera, S. Francesco, 116 m a.s.l., Coordinates: 38.552583 N, 15.931750 E (Rel. 5); Italy, Calabria, Catanzaro, Santa Caterina dello Ionio, Monte Cervaro, 1176 m a.s.l., Coordinates: 38.561517 N, 16.440864 E (Rel. 6); Italy, Calabria, Catanzaro, Isca sullo Ionio, Le Baracche , 1007 m a.s.l., Coordinates: 38.576092 N, 16.446147 E (Rel. 7); ); Italy, Calabria, Catanzaro, Isca sullo Ionio, Le Baracche , 1021 m a.s.l., Coordinates: 38.577169 N, 16.445275 E (Rel. 8); Italy, Calabria, Vibo Valentia, Nardodipace, Albani , 672 m a.s.l., Coordinates: 38.451739 N, 16.348911 E (Rel. 9); Italy, Calabria, Vibo Valentia, Nardodipace, Albani , 662 m a.s.l., Coordinates: 38.451222 N, 16.349028 E (Rel. 10); Italy, Calabria, Reggio Calabria, Caulonia, Roversa, 65 m a.s.l., Coordinates: 38.389144 N, 16.397900 E (Rel. 11); Italy, Calabria, Reggio Calabria, Benestare, Fiumara Careri, 45 m a.s.l., Coordinates: 38.156086 N, 16.128778 E (Suppl. Material 1, Table S12, Rel. 12); Italy, Calabria, Reggio Calabria, San Luca, Brancato, 205 m a.s.l., Coordinates: 38.135914 N, 16.050669 E (Rel. 13); Italy, Calabria, Reggio Calabria, Motta San Giovanni, Castello di S. Aniceto (rud.i), 591 m a.s.l. Coordinates: 38.025456 N, 15.705636 E (Table 2.2).

**Cells ID in the EEA reference grid:** 10kmE486N177 (Rel. 1), 10kmE487N178 (Rel. 2), 10kmE483N175 (Rel. 3), 10kmE488N176 (Rel. 4), 10kmE484N173 (, Rel. 5), 10kmE488N174 (Rels. 6, 7, 8), 10kmE487N173 (Rels 9, 10), 10kmE488N172 (, Rel. 11), 10kmE486N169 (SRel.12), 10kmE485N169 (Rel.13), 10kmE485N179 (Rel.14), 10kmE482N167 (Rel. 15) (Figure 2.5).

**Natura 2000 Site Code:** currently not included in any Natura 2000 Site.

**Phytosociological table:** Nomenclature and taxa delimitation according to Portal to the Flora of Italy (2023). (Supplementary Materials File S4).

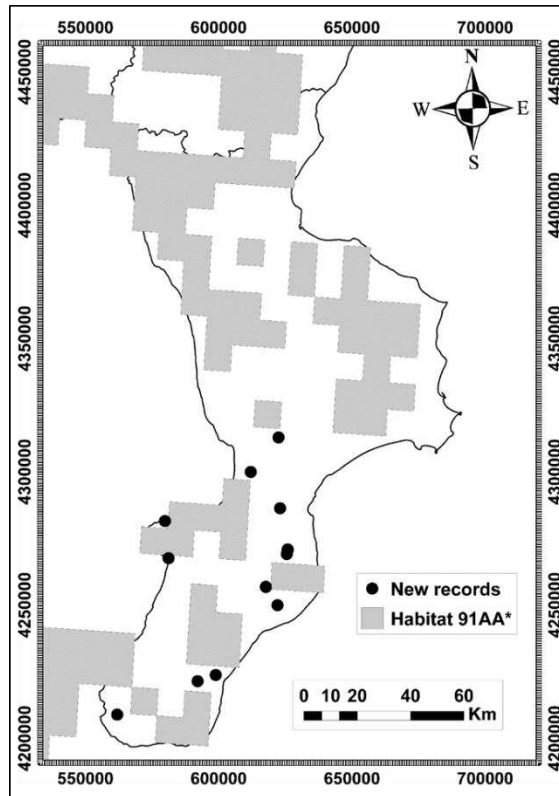


Figura 2. 5. Distribution of Habitat 91AA\* in Calabria: in black the new cells, in grey the cells officially reported in the 4th Habitat Report ex-Art. 17 (period 2013–2018; Eionet 2019).

In the Calabria Region, the group of *Quercus pubescens* Willd. subsp. *pubescens*. has remarkable forestry importance and has been interpreted differently by various authors who have dealt with the taxonomy of this species (Musarella et al. 2018; Di Pietro et al. 2020, 2021). Brullo et al. (2001) attributed the acidophilous thermo-xerophilous oaks woods of Calabria to the *Erico arboreae-Quercetum virgiliana* (Brullo and Marcenò 1985), an association located in the thermo and meso Mediterranean belt. Several authors claim that the forest coenoses with *Quercus pubescens* s.l. of southern Italy and islands, due to the relevance of the evergreen sclerophyllous species in the floristic assemblage, fall in the class *Quercetea ilicis* Br.-Bl. in Br.-Bl., Roussine et Nègre 1952 (Brullo et al. 2001; Bacchetta et al. 2004; Brullo et al. 2008).

2.3.5. #78. Annex I Habitat: g1Eo\* Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion*, *Alnion incanae*, *Salicion albae*)

(Morabito A, Musarella CM, Spampinato G)

**EUNIS Classification system:** T14B13 (formerly, G1.1313): Western Mediterranean alder and ash- alder galleries (Chytrý et al. 2020).

**Biogeographical Region:** Mediterranean

**National Habitat Checklist of reference:** Italian Interpretation Manual of the Directive 92/43/EEC Habitats (Biondi et al. 2009).

**Phytosociological reference:** *Ligustro vulgaris-Alnion glutinosae* Poldini, Sbrulino and Venanzoni 2015 in Biondi et al. 2015, *Populetales albae* Br.-Bl. ex Tchou 1948, *Salici purpureae-Populetea nigrae* (Rivas-Mart. et Cantó ex Rivas Mart. et al. 1991) Rivas-Mart. et Cantó 2002 (Biondi and Blasi 2015).

**Geographic information:** Italy, Calabria, Catanzaro, Lamezia Terme, Caronte, 248 m a.s.l., Coordinates: 38.975917 N, 16.258431 E (Rel.1); Italy, Calabria, Vibo Valentia, Brognaturo, Lacina, 1004 m a.s.l., Coordinates: 38.588022 N, 16.393328 E (Rel.2); 1014 m a.s.l., Coordinates: 38.588147 N, 16.392011 E (Rel.3); Italy, Calabria, Catanzaro, Serrastretta, Valle Apite, 607 m a.s.l., Coordinates: 38.975397 N, 16.427989 E (Rel. 4); Calabria, Catanzaro, Girifalco, C. Pellegrini, 358 m a.s.l., Coordinates: 38.829164 N, 16.404547 E (Suppl. Material 1, Table S14, Rel. 5); Coordinates: 38.829097 N, 16.405750 E (Rel. 6); Calabria, Vibo Valentia, Capistrano, Spicchiali, 666 m a.s.l., Coordinates: 38.699014 N, 16.324903 E (Rel. 7); Calabria, Vibo Valentia, Filadelfia, Masone, 731 m a.s.l., Coordinates: 38.777242 N, 16.346686 E (Rel. 8); Calabria, Vibo Valentia, Brognaturo, Lacina, 997 m a.s.l., Coordinates: 38.594142 N, 16.399900 E (Rel. 9); 1001 m a.s.l., Coordinates: 38.594478 N, 16.399725 E (Rel. 10); Calabria, Reggio Calabria, Scilla, F.ra di Favazzina, 41 m a.s.l., Coordinates: 38.259411 N, 15.763797 E (Rel. 11); Calabria, Reggio Calabria, Molochio, T. Palata, 317 m a.s.l., Coordinates: 38.310544 N, 16.054958 E (Rel. 12). (Table 2.2)

**Cells ID in the EEA reference grid:** 10kmE486N178 (Suppl. Material 1, Table S14, Rel. 1), 10kmE488N174 (Rels 2–3 and 9–10), 10kmE488N178 (Rel. 4), 10kmE487N177 (Rels 5–6), 10kmE487N175 (Table S14, Rel. 7), 10kmE487N176

(Rel. 8), 10kmE482N170, 10kmE485N171 (Rel. 12) (Figure 2.6).

**Natura 2000 Site Code:** currently not included in any Natura 2000 Site (Rels 1, 4, 5, 6, 7, 8, 10, 12 in Suppl. Material 1, Table S14), IT9340120 - "Lacina" (Rels 2, 3, 9 in Suppl. Material 1, Table S14). IT9350300 – "Costa Viola" (Rel. 11, in Suppl. Material 1, Table S14).

**Phytosociological table:** Nomenclature and taxa delimitation according to Portal to the Flora of Italy (2023). (Supplementary Materials File S5)

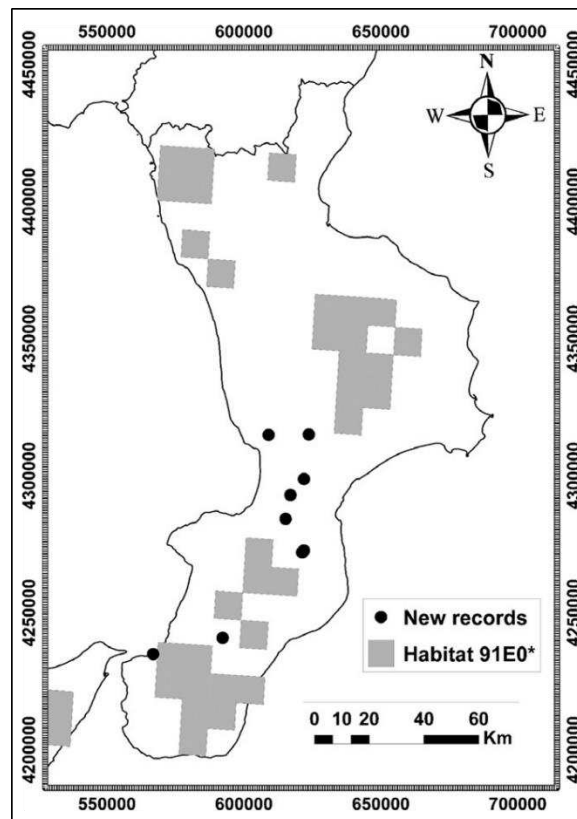


Figura 2. 6. Distribution of Habitat 91E0\* in Calabria: in black the new cells, in grey the cells officially reported in the 4th Habitat Report Ex-Art. 17 (period 2013–2018; Eionet 2019).

In accordance with Biondi et al. (2015) and Sciandrello et al. (2022) the riparian woodland with *Alnus glutinosa* of Calabria are referred to the Ligustro vulgaris–*Alnion glutinosae* Poldini, Sburlino and Venanzoni in Biondi et al. 2015, alliance that brings together the riparian meso-thermophilous forests dominated by *Alnus glutinosa* (L.) Gaertn. of *Populetalia albae* growing in the sub- mediterranean

regions of the Apennine Peninsula. The alder woods found occupy a wide altitude range and in some reliefs present invasive alien species such as *Robinia pseudoacacia* L., *Ailanthus altissima* (Mill.) Swingle and *Catalpa bignonioides* Walter, expanding species that compromise habitat conservation (Spampinato et al. 2022).

2.3.6. #80. Annex I Habitat: 92A0 *Salix alba* and *Populus alba* galleries

(Morabito A, Musarella CM, Spampinato G)

**EUNIS Classification system:** G1.314; T1424 (formerly) - Italic poplar galleries (Chytrý et al. 2020).

**Biogeographical Region:** Mediterranean

**National Habitat Checklist of reference:** Italian Interpretation Manual of the Directive 92/43/EEC Habitats (Biondi et al. 2009).

**Phytosociological reference:** *Populion albae* Br.-Bl. ex Tchou 1948, *Populetales albae* Br.-Bl. ex Tchou 1948, *Salici purpureae-Populetea nigrae* Rivas-Martínez & Cantó ex Rivas-Martínez, Báscones, T.E. Díaz, Fernández-González & Loidi 2001 (Biondi and Blasi 2015).

**Geographic information:** Italy, Calabria, Catanzaro, Lamezia Terme, Caronte, 210 m a.s.l., Coordinates: 38.970150 N, 16.258033 E Rel. 1) (Table 2.2)

**Cells ID in the EEA reference grid:** 10kmE486N178 (, Figure 2.7).

**Natura 2000 Site Code:** currently not included in any Natura 2000 Site.

**Phytosociological table:** Nomenclature and taxa delimitation according to Portal to the Flora of Italy (2023) (Suppl. Material File S6).

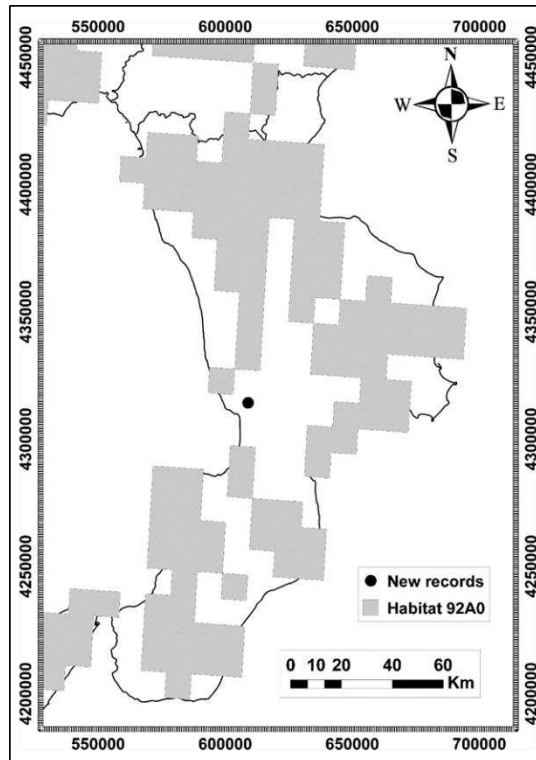


Figura 2. 7. Distribution of Habitat 92A0 in Calabria: in black the new cells, in grey the cells officially reported in the 4th Habitat Report ex-Art. 17 (period 2013–2018; Eionet 2019).

The riparian vegetation with white willow is a particular azonal formation growing along the Calabrian water courses with silty sandy floods, variable flow and high level of the aquifer (Brullo and Spampinato 1997). These riparian forests, which belong to the *Populion albae* alliance, are composed by deciduous softwood species such as willows, poplars, and alders, and are widespread mainly in the hilly and submontane belt of the region, being linked by a macrobioclimate between thermo- and meso- mediterranean (Brullo et al. 2001).

2.3.7. #82. Annex I Habitat: 9330 *Quercus suber* forests  
(Morabito A, Musarella CM, Spampinato G)

**EUNIS Classification system:** T211 (formerly G2.11) - *Quercus suber* forest  
(Chytrý et al. 2020).

**Biogeographical Region:** Mediterranean

**National Habitat Checklist of reference:** Italian Interpretation Manual of the Directive 92/43/EEC Habitats (Biondi et al. 2009).

**Phytosociological reference:** *Helleboro-Quercetum suberis* Signorello 1984; variante a *Myrtus communis* L. (Mercurio and Spampinato 2003), *Erico arboreae-Quercion ilicis* Brullo, Di Martino et Marcenò 1977; *Quercetalia ilicis* Br.-Bl. ex Molinier 1934; *Quercetea ilicis* Br.-Bl. in Br.-Bl., Roussine et Nègre 1952 (Biondi and Blasi 2015).

**Geographic information:** Italy, Calabria, Catanzaro, Gizzeria, Contrada Jacona, 75 m a.s.l., Coordinates: 38.953347 N, 16.179847 E (Rel. 1); Italy, Calabria, Vibo Valentia, Capistrano, Contrada Bufalo, 579 m a.s.l., Coordinates: 38.683064 N, 16.292239 E (Rel. 2); Italy, Calabria, Catanzaro, San Sostene, Contrada Bufalo, 580 m a.s.l., Coordinates: 38.638206 N, 16.510347 E (Rel. 3). (Table 2.2)

**Cells ID in the EEA reference grid:** 10kmE485N178 (Rel. 1), 10kmE487N175 (Rel. 2), 10kmE489N175 (Rel. 3) (Figure 2.8).

**Natura 2000 Site Code:** currently not included in any Natura 2000 Site.

**Phytosociological table:** Nomenclature and taxa delimitation according to Portal to the Flora of Italy (2023) (Suppl. Material S7).

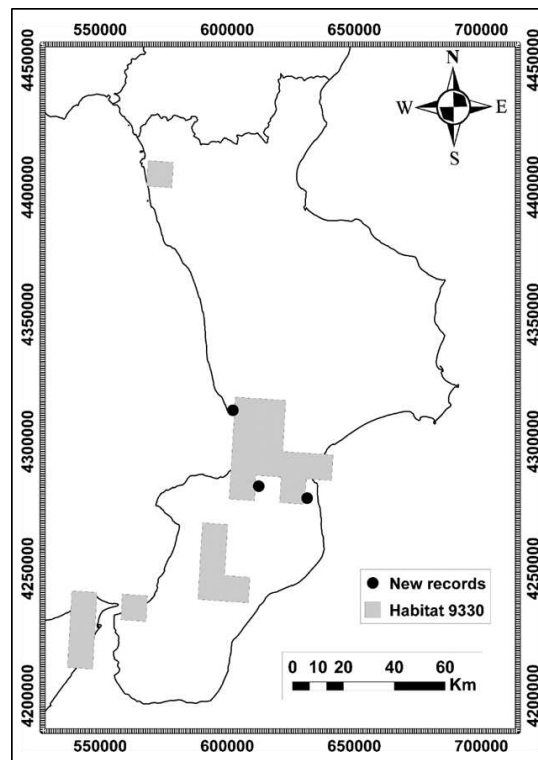


Figura 2.8. Distribution of Habitat 92Ao in Calabria: in black the new cells, in grey the cells officially reported in the 4th Habitat Report ex-Art. 17 (period 2013–2018; Eionet 2019)

Italian cork oaks for their acidophilic species assemblage have been referred by Brullo and Marcenò (1984) to the *Erico-Quercion ilicis*. This alliance groups forest associations dominated by evergreen sclerophyllous species with a high presence of calcifugous species, which develop on siliceous or strongly leached soils, in subhumid to humid Mediterranean macrobioclimates (Biondi and Blasi 2015). At the association level, the communities detected (Suppl. Material 1, Table S18, Rels 1-3) are to be ascribed to the *Helleboro-Quercetum suberis* Signorello 1984, community spread in Calabria region (Signorello 1984; Brullo et al. 2001) and in particular to the variant of *Myrtus communis* (Mercurio and Spampinato 2003) that group to the thermo-xerophilous cork oaks, located in the thermo-Mediterranean settled in more xeric environmental conditions than those typical of the association which instead is characterized by an assemblage of mesophilous species and bioclimatic conditions of meso-Mediterranean type. These new records expand the distribution area of the habitat 9330 in the Calabria Region.

Table 2.2 Synthetic overview of the newly reported data

Hab ID	Hab name	Cell ID	Country	BR	N2000 Site	Authors
2250*	Coastal dunes with <i>Juniperus</i> spp.	10kmE486N178	Italy	MED	-	Morabito A., Musarella C.M., Spampinato G.
		10kmE486N177, 10kmE487N178, 10kmE483N175, 10kmE488N176,				
91AA*	Eastern white oak woods	10kmE484N173, 10kmE488N174,	Italy	MED	-	Morabito A., Musarella C.M., Spampinato G.

		10kmE487N173, 10kmE488N172, 10kmE486N169, 10kmE485N169, 10kmE485N179, 10kmE482N167				
91E0*	Alluvial forests with <i>Alnus glutinosa</i> and <i>Fraxinus excelsior</i> ( <i>Alno-Padi-on</i> , <i>Alnion incanae</i> , <i>Salicion albae</i> )	10kmE482N170, 10kmE485N171 10kmE487N175, 10kmE487N176, 10kmE488N178, 10kmE487N177, 10kmE486N178, 10kmE488N174, 10kmE443N224	Italy	MED	IT9340120, IT9350300	Morabito A., Musarella C.M., Spampinato G.
92A0	<i>Salix alba</i> and <i>Populus alba</i> gallerie	10kmE486N178	Italy	MED	-	Morabito A., Musarella C.M., Spampinato G.
9330	<i>Quercus suber</i> forests	10kmE485N178, 10kmE487N175, 10kmE489N175	Italy	MED	-	Morabito A., Musarella C.M., Spampinato G.

### 2.3.8. #85. Annex I Habitat: 2110 Embryonic shifting dunes

(Morabito A, Musarella CM, Spampinato G)

**EUNIS Classification system:** N14 - Mediterranean, Macaronesian and Black Sea shifting coastal dune (formerly B1.3 - Shifting coastal dunes) (EEA 2021)

Biogeographical Region: Mediterranean

**National Habitat Checklist of reference:** Italian Interpretation Manual of the Directive 92/43/EEC Habitats (Biondi et al. 2009).

**Phytosociological reference:** *Cypero mucronati-Elytrigietum juncae* Br.-Bl. 1933, *Ammophilion* Br.-Bl. 1921, *Ammophiletalia* Br.-Bl. and Tx. ex Westhoff et al. 1946, *Ammophiletea* Br.-Bl. and Tx. ex Westhoff et al. 1946 (Biondi and Blasi 2015, Mucina et al. 2016)

**Geographic information:** Italy, Calabria, Reggio Calabria, Roccella Ionica, 6 m a.s.l., Coordinates: 38.327411 N, 16.430000 E (Rel. 1); 4 m a.s.l., Coordinates: 38.327245 N, 16.427569 E (Rel. 2); (Table 2.3)

**Cell ID in the EEA reference grid:** 10kmE488N171 (Figure 2.9).

**Natura 2000 Site Code:** currently not included in any Natura 2000 Site.

**Phytosociological table:** Nomenclature and taxa delimitation according to Portal to the Flora of Italy (2023). (Suppl. Material File S8).

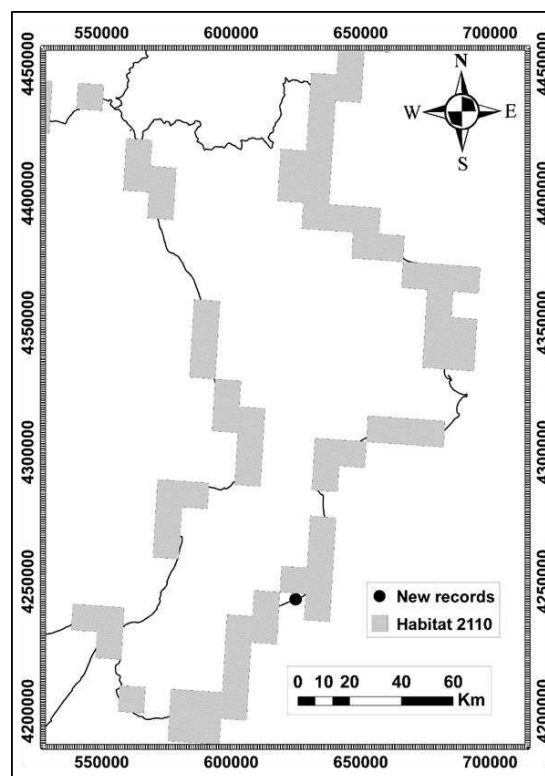


Figura 2.9. Distribution of Habitat 2210 in Calabria: in black the new cells, in grey the cells officially reported in the 4th Habitat Report ex-Art. 17 (period 2013–2018; Eionet 2019).

The habitat occurs on a stretch of sandy coast with natural conditions. The plant community found is related to *Cypero mucronati-Elytrigietum juncae* Br.-Bl. 1933,

a widespread association on the sandy coasts of Italy.

2.3.9. #98. Annex I Habitat: 8210 Calcareous rocky slopes with chasmophytic vegetation

(Morabito A, Musarella CM, Spampinato G)

**EUNIS Classification system:** H3.2 - Basic and ultra-basic inland cliffs (Chytrý et al. 2020).

**Biogeographical Region:** Mediterranean

**National Habitat Checklist of reference:** Italian Interpretation Manual of the Directive 92/43/EEC Habitats (Biondi et al. 2009).

**Phytosociological reference:** *Erucastretum virgati* Brullo and Marcenò 1979, *Dianthion rupicolae* Brullo and Marcenò 1979, *Asplenietalia glandulosi* Br. - Bl. and Meier in Meier and Br. - Bl. 1934, *Asplenietea trichomanis* (Br. - Bl. in Meier and Br. - Bl. 1934) Oberdorfer 1977 (Biondi and Blasi 2015; Brullo and Marcenò 1979).

**Geographic information:** Italy, Calabria, Reggio Calabria, Roccella Ionica, Castello, 65 m a.s.l. Coordinates: 38.327394 N, 16.407747 E (Rel. 1); (Table 2.3)

**Cell ID in the EEA reference grid:** 10kmE488N171 (Figure 2.10).

**Natura 2000 Site Code:** currently not included in any Natura 2000 Site.

**Phytosociological table:** Nomenclature and taxa delimitation according to Portal to the Flora of Italy (2023). (Suppl. Material File S9).

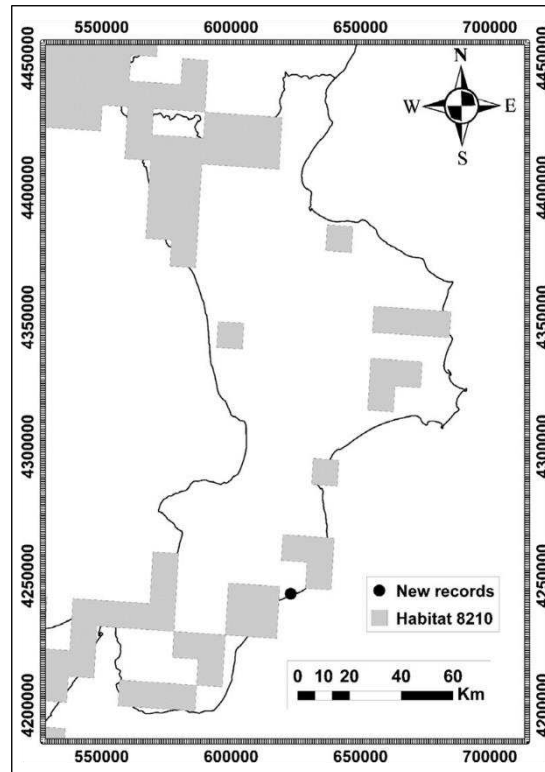


Figura 2.o. Distribution of Habitat 8210 in Calabria: in black the new cells, in grey the cells officially reported in the 4th Habitat Report Ex-Art. 17 (period 2013–2018; Eionet 2019)

The habitat hosts a population of *Ptilostemon gnaphaloides*, an eastern Mediterranean species that grows spontaneously in Italy only on the cliffs of eastern Calabria, which is assessed, according to IUCN criteria, as vulnerable (Conti et al. 1997). The phytocenosis found is related to *Erucastretum virgatae* Brullo and Marcenò 1979, an association of *Dianthion rupicolae* Brullo and Marcenò 1979 distributed in southern Calabria and North-Eastern Sicily. The presence of *Ptilostemon gnaphaloides* also allows the community to be assigned to the subassociation *Erucastretum virgati centaureetosum ionicae* Brullo and Marcenò 1979, exclusive to the Ionian slopes of Central-Southern Calabria (Brullo et al. 2001a; Brullo and Spampinato 2003; Spampinato et al. 2009).

Table 2.3 Synthetic overview of the newly reported data

Hab ID	Hab name	Cell ID	Count	BR	N2000	Authors
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			ry		Site	
2110	Embryonic shifting	10kmE488 N171	Italy	MED	-	Morabito A., Musarella C.M., Spampinato
8210	Calcareous rocky slopes with chasmo-	10kmE488 N171	Italy	MED	-	Morabito A., Musarella C.M., Spampinato G.

2.3.10. #102. Annex I Habitat: 1430 Halo-nitrophilous scrubs (*Pegano-Salsoletea*)

(Morabito A, Musarella CM, Spampinato G)

**EUNIS Classification system:** S6625 – Sicilian halo-nitrophilous scrub (EEA 2021).

**Biogeographical Region:** Mediterranean

**National Habitat Checklist of reference:** Italian Interpretation Manual of the Directive 92/43/EEC Habitats (Biondi et al. 2009).

**Phytosociological reference:** *Atriplici halimi-Artemisietum arborescentis* Biondi 1988 (1–19) *Artemision arborescentis* Géhu et al. 1986, *Salsolo-Peganetalia* Br.-Bl. and O. de Bolòs 1954, *Pegano-Salsoletea* Br.-Bl. and O. de Bolòs 1954 (Biondi and Blasi 2015)

**Geographic information:** Italy, Calabria, Vibo Valentia, Ricadi, S. Domenica, 33 m a.s.l., Coordinates: 38.665712°N, 15.862635°E (Rel. 1). (Table 2.4)

**Cells ID in the EEA reference grid:** 10kmE483N175 (Figure 2.11)

**Natura 2000 Site Code:** SAC IT9340091 “Zona costiera fra Briatico and Nicotera”

**Phytosociological table:** Nomenclature and taxa delimitation according to Portal to the Flora of Italy (2024). (Suppl. Material File S10).

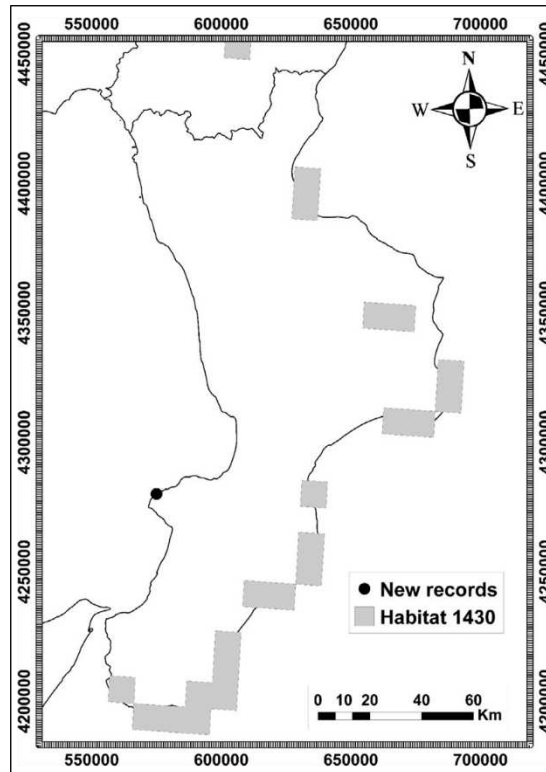


Figura 2.11. Distribution of Habitat 1430 in Calabria: in black the new cells, in grey the cells officially reported in the 4<sup>th</sup> Habitat Report ex-Art. 17 (period 2013–2018; Eionet 2019).

This habitat is characterized by nanophanerophyte shrub vegetation and often by succulent halonirophilous chamaephytes, typically found on arid soils, generally salty, in areas with a particularly hot and arid Mediterranean bioclimate of a dry or semi-arid Mediterranean thermal type. This is the first record of 1430 habitat on the Tyrrhenian coast of the Calabria region (Suppl. material 2: fig. S1).

Unfortunately, in the Mediterranean region, urbanization and coastalization have had a great impact on this vegetation (Brullo et al. 2013).

2.3.11. #120. Annex I Habitat: g1Eo\* Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion*, *Alnion incanae*, *Salicion albae*)

(Morabito A, Musarella CM, Spampinato G)

**EUNIS Classification system:** T14B13 (formerly, G1.1313) – Western Mediterranean alder and ash- alder galleries (EEA 2021)

**Biogeographical Region:** Mediterranean

**National Habitat Checklist of reference:** Italian Interpretation Manual of the Directive 92/43/EEC Habitats (Biondi et al. 2009)

**Phytosociological reference:** *Ligustro vulgaris-Alnion glutinosae* Poldini, Sbrulino and Venanzoni 2015 in Biondi et al. 2015, *Populetalia albae* Br.-Bl. ex Tchou 1948, *Salici purpureae-Populetea nigrae* (Rivas-Mart. and Cantó ex Rivas-Mart. et al. 1991) Rivas-Mart. and Cantó 2002 (Biondi and Blasi 2015).

**Geographic information:** Italy, Calabria, Catanzaro, Girifalco, C. Pellegrini, 358 m a.s.l., Coordinates: 38.829096°N, 16.405749°E (, Rel. 1) (Table 2.4)

**Cells ID in the EEA reference grid:** 10kmE488N177 (Figure 2.12)

**Natura 2000 Site Code:** currently not included in any Natura 2000 Site.

**Phytosociological table:** Nomenclature and taxa delimitation according to Portal to the Flora of Italy (2024) (Suppl. Material File S11).

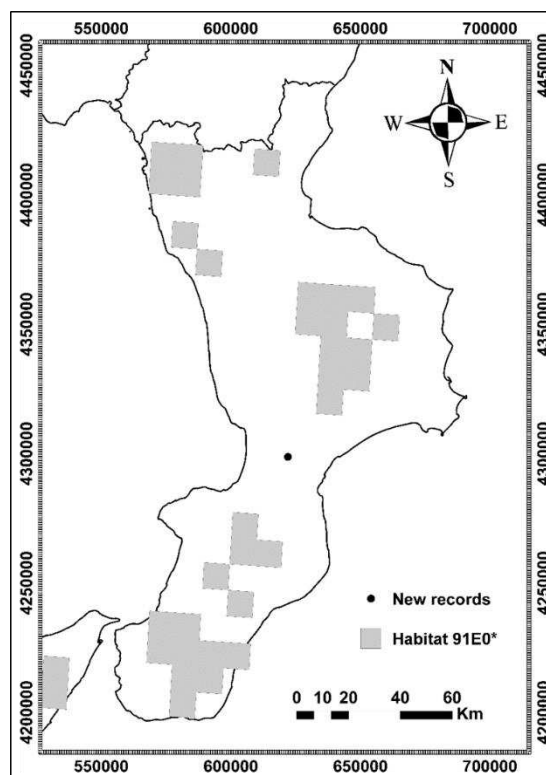


Figura 2.12. Distribution of Habitat 1430 in Calabria: in black the new cells, in grey the cells officially reported in the 4th Habitat Report ex-Art. 17 (period 2013–2018; Eionet 2019).

In Calabria, this habitat refers to *Ligustro vulgaris-Alnion glutinosae* Poldini,

Sburlino and Venanzoni in Biondi et al. 2015, in accordance with Biondi et al. (2015) and Sciandrello et al. (2023).

Table 2.4. Synthetic overview of the newly reported data.

Hab ID	Hab name	Cell ID	Coun try	BR	N200 o Site	Authors
1430	Halo-nitrophilous scrubs (Pegano-Salsoletea)	10kmE48 3N175	Italy	MED	IT934 0091	Morabito A, Musarella CM, Spampinato G
91Eo *	Alluvial forests with <i>Alnus glutinosa</i> and <i>Fraxinus excelsior</i> ( <i>Alno-Padion</i> , <i>Alnion incanae</i> , <i>Salicion albae</i> )	10kmE48 8N177	Italy	MED	-	Morabito A, Musarella CM, Spampinato G

## 2.4 Conclusions

This study aimed to identify new distributions of habitats of Directive 93/42 present in the Region of Calabria, taking into account also the areas of the Natura 2000 network. Our results show new cells useful for planning and overcoming challenges to biodiversity conservation. The presence of new habitat distributions of directive is also important for the implementation of the regional ecological network and ensure the conservation of species as provided by EU Directive.

## CHAPTER 3. Biodiversity as a Tool in the Assessment of the Conservation Status of Coastal Habitats: A Case Study from Calabria (Southern Italy)

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Article

## Biodiversity as a Tool in the Assessment of the Conservation Status of Coastal Habitats: A Case Study from Calabria (Southern Italy)

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### Abstract:

The Mediterranean coasts are threatened by human activities that alter habitats structure and functionality, modifying vegetation and causing the loss of typical species. The definition of the conservation status of coastal habitats is essential to preserve these fragile environments through planned policies. This study aims to assess the conservation status of the habitats of community interest (sensu EEC Directive 43/92) through the analysis of biodiversity and correlating it with urbanisation. A total of 73 vegetation relevés were carried out, so allowing 13 revealing different habitats to be identified. The total plant species diversity per habitat was measured by means of the H-index, also used to assess naturalness (N), differently considering native, alien, and disturbance species. To correlate the N index with distance from urban centres, a statistical analysis was performed. The analysis showed the highest values of H+ were found in habitats 2240, 2110, 2260, and 2230, while lowest values were observed in habitats 2270\* and 2240. The habitats 2270\* and 2240, the closest to urban centres, have a lower naturalness score than habitats 1420, 2120, 2250\*, and 2270\*, where higher naturalness scores have been found and therefore lower levels of disturbance. The criteria and methods discussed in this study can be used in coastal management in



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order to identify the most sensitive habitats and implement an effective conservation strategy.

**Keywords:** diversity; naturalness; Directive Habitat; alien and disturbing species

### 3.1. Introduction

Coastal ecosystems are typical transition ecosystems, linked to the interface between marine and terrestrial environments, usually with linear development, along the coastline, where environmental factors profoundly influence their dimensions, shape, and boundaries (McLachlan, et al., 2006; Glemarec et al., 2023). They are very dynamic ecosystems affected by strong environmental gradients, mainly related to the coherence of the substrate, salinity, wind, and salt spray, which vary with distance from the coastline and host a series of distinctive habitats of high conservation value, characterised by plant communities with relatively few but highly specialised and exclusive species (Acosta et al., 2007; Marcenò et al., 2018).

In recent decades, habitats have been recognized to play an important role in biodiversity conservation and ecosystems functionality, so to deserve specific protection measures (Bonari et al., 2021). In the European Union, coastal habitats are of “Community interest” for the protection of European biodiversity and included in Annex I EU Habitats Directive (92/43/EEC), a fundamental legal tool in the European nature conservation policy. Furthermore, some of the habitats are “priority” in EU biodiversity conservation strategy (Feola et al., 2011).

Anthropogenic pressures on coastal ecosystems make them particularly vulnerable and highly endangered, as they are considered among the habitats most threatened by extinction [Cardinale et al., 2012; van Rooijen et al., 2015]. From the 1950s to 1980s, coasts, especially across the Mediterranean basin, have been deeply anthropized, becoming very attractive tourist destinations (Malavasi, et al., 2014) and useful areas for agriculture [Sciandrello et al., 2019]. This has drastically changed the vegetation and ecological diversity formerly

characterising these habitats [Sciandrello et al., 2019, Prisco et al., 2020], which have recently been included among those at the greatest risk of extinction (Janssen et al., 2016).

The exploitation of the coastal zone for urbanisation and tourism has led to the decline and even extinction of typical coastal habitat species, at the same time promoting the rapid spread of synanthropic species, such as weedy and ruderal species adapted to urban environments (Carranza et al., 2020), and the establishment of invasive species (Musarella et al., 2014). This has resulted in significant alterations of the structure and functionality of plant communities characterising coastal habitats, potentially threatening the extinction of the highly specialised and typical species (Vitti et al., 2020; Lami et al., 2021; Simberloff et al., 2013). The spread of invasive alien species is one of the most serious pressures on ecosystems, and one of the main threats to biodiversity conservation (Musarella et al., 2014; Buffa et al., 2012) especially for coastal ecosystems (Tordoni et al., 2019). The establishment of synanthropic and invasive alien species in coastal ecosystems also causes serious changes in physical processes, and the loss of native species diversity reduces the ability of ecosystems to maintain their functioning in an environment increasingly affected by climate change (Carboni et al., 2010, Genovesi et al., 2014).

From this perspective, habitat monitoring has considerable importance both in the assessment of the conservation status of the environment and to identify priorities and critical issues in coastal ecosystem management (Ostermann 2000). According to Carboni et al. (2009), vegetation survey could help performing the assessment of biodiversity and conservation status of coastal habitats.

Mediterranean coastal ecosystems high ecological value is mainly due to both species diversity and environmental heterogeneity (Biondi et al., 2007). This implies that active management is always needed in areas globally considered crucial for biodiversity conservation, such as the Natura 2000 Network of the

European Union (Lazzaro et al., 2020). Indicator species can be used to assess the conservation status of vegetation and habitats (Siddig et al., 2016)

Several scientific approaches quantified habitat and vegetation human-induced change by applying indices such as species richness and diversity, in order to assess the conservation status of coastal habitats (Pretto et al., 2012; Van der Hagen et al., 2023; Pinna et al., 2019). These can include habitat-specific specialist species and species associated with habitat degradation, such as synanthropic species.

At the habitat scale, alpha diversity can be estimated by considering species richness and species importance, and also used to evaluate the conservation status of a habitat and its naturalness;  $H^*$  is a plant diversity index to assess human impact on coastal dunes derived from the Shannon index of entropy (Grünwald et al., 2007). The Shannon–Wiener diversity index ( $H^*$ ) (Shannon 1949) is often used in ecological studies, and vegetation analysis (Kent et al., 1992) can be applied to assess habitat conservation status and naturalness (Del Vecchio et al., 2016) distinguishing the contribution of typical and synanthropic/alien species to biodiversity.

The aim of this research, which takes as a case study the coastal habitats of Calabria (Southern Italy) is to propose a useful method for assessing the conservation status of coastal environments. The proposed methodology is biodiversity-based through the analysis of vegetation and landscape, also considering the impact of urbanisation on coastal habitats. The coastal habitats of Calabria are well suited for this study because they are quite well known thanks to many studies, mainly performed by various authors applying the phytosociological method (Brullo et al., 2001; Maiorca et al., 2007; Caruso 2015; Maiorca et al., 2020;). Our study has three main objectives: (1) to evaluate the conservation status of coastal habitats by applying diversity indices to the plant assemblage; (2) to verify how the impact of urban centres affects the

conservation of characteristic habitats and typical species; and (3) to test the effectiveness of this methodology based on landscape analysis using a Geographic Information System (GIS), and analysis of the habitat diversity through the study of vegetation.

### **3.2. Materials and Methods**

This study was conducted on the coastal habitats of Calabria, a region in the centre of the Mediterranean basin, located in the southern Italian peninsula between the Ionian Sea to the east and the Tyrrhenian Sea to the west. The region has more than 700 km of coastline, most of which is sandy, partly affected by coastal erosion (Foti et al., 2022).

The analysis of coastal habitats was based on vegetation relevés carried out in the period 2018–2021, applying the phytosociological method of the Zurich–Montpellier school which consist in a list of plants in each homogeneous area, including the degree of coverage for each species expressed using the scale provided by Braun-Blanquet (1964).

Seventy-three unpublished relevés with 261 species were carried out along the Calabrian coasts (Supplementary Materials File S12).

A multivariate analysis was performed on the matrix of phytosociological relevés for the definition of statistical-based coenological groups. To this end, the abundance–dominance value of each species reported with the Braun-Blanquet scale was converted to the numerical value scale proposed by Van der Mareel (1979). The softwares used for the organization of the raw data and the subsequent statistical analysis have been Microsoft Excel 2010; PASSED version 4.13; and R 4.1.1 R Core Team 2021.

The cluster analysis of the relevé matrix used the average linkage criterion (UPGMA) and the Chord distance algorithm to identify homogeneous floristic

compositions. The interpretation of habitats was performed according to the literature (Biondi et al., 2009; Angelini et al., 2016; Chytrý et al., 2020).

From the Nature Map of the Calabria Region (Aramini et al.; 2023), all the polygons between 0 and 200 m a.s.l. (Figure 3.1) were extrapolated using the QGIS software (2023).

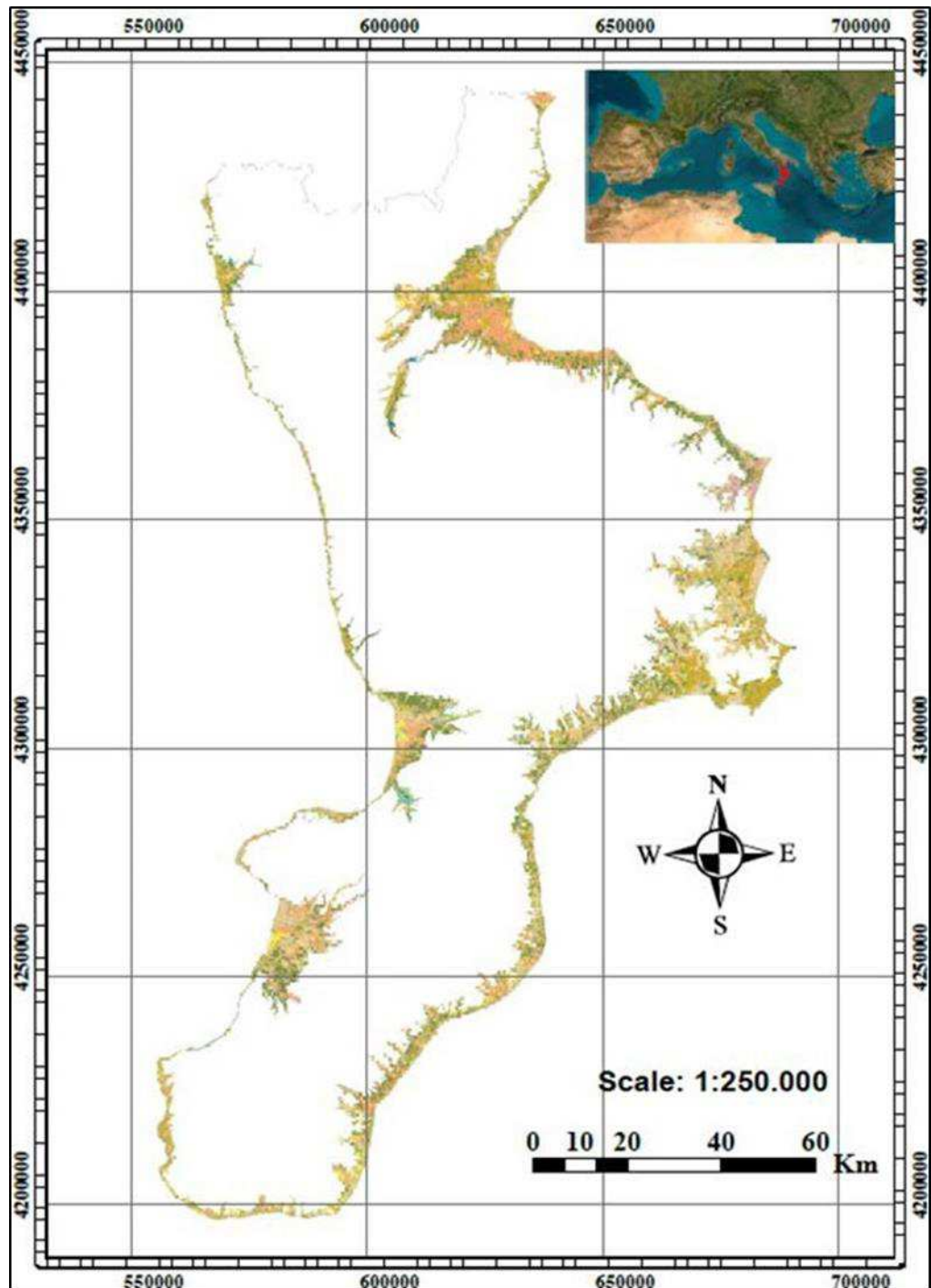


Figura 3.1. Study area with highlighted Nature Map habitats of the Calabria region extrapolated in the altitudinal range 0-200 m a.s.l.

The distance in meters between the points of the relevés and the centre of the polygons coded as urban were calculated by QGIS.

According to the literature (Acosta et al., 2003), the spatial model of dune plant communities was compared with quality and disturbance by plant community analyses.

Indicator species can be used to assess the conservation status of vegetation (Silva et al., 2019). These can include habitat-specialised species and species associated with habitat degradation (e.g., synanthropic). Synanthropic species structure two main vegetation types: weedy vegetation and ruderal vegetation (Biodi et al., 2015). Weedy vegetation grows on crop land for agricultural purposes, while ruderal vegetation can be found in urban areas, and more generally in different human infrastructures, such as roads, railways, walls, industrial or commercial settlements, etc.

The total plant species diversity by habitat was measured with the Shannon–Wiener  $H^+$  index, one of the most used indices to estimate the species diversity of a biological community, combining species richness (the number of species in the community) and species evenness (how equal are the numbers of individuals of each species) [Shannon 1949].

$$H^+ = - \sum_{j=1}^s p_i \ln p_i$$

where  $p_i$  = coverage of the  $i$ -th species compared to the entire community;  $S$  = number of species.

The total diversity does not provide information on the species types that make up the plant assemblage of the various habitats; typical or alien species can equally contribute. Different indices can be calculated to give a better indication of the flora. As highlighted by Grunewald and Schubert (2007), Pinna et al. [2019], and Caldaresi et al. [2023], the Shannon–Wiener index ( $H^+$ ) allows the evaluation of levels of naturalness ( $N$ ) of a habitat by distinguishing the biodiversity linked to autochthonous species and that due to alien species; we, on the other hand, also

considered species linked to anthropic disturbance (Morabito et al., 2024), i.e., species typical of synanthropic habitats (e.g., uncultivated land, ruderal environments, species infesting crops, etc.), reshaping the naturalness index as follows:

$$N = H + (\text{without alien and disturbing plant species}) / H +$$

The naturalness index assumes values ranging 0 to 1, where 0 indicates that plant diversity consists entirely of alien and disturbance species, while 1 indicates the absence of the latter in the plant communities. Alien species were identified in accordance with the Portal to the Flora of Italy (2023), while plant communities and disturbance species were verified considering the “Prodrómo della Vegetazione d’Italia” (Biondi et al., 2015) as well as the contributions of other authors (Lami et al., 2021; Simberloff et al., 2013; Buffa et al., 2012; Tordoni et al., 2019, Carboni., 2010, Genovesi et al., 2014; Ostermann 2000; Carboni et al., 2009; Biondi et al.; 2007; Lazzaro et al., 2020; Siddig, et al.; 2016; Pretto et al., 2012; Van der Hagen et al., 2023; Pinna et al.; 2019; Grünewald et al., 2007; Shannon 1949; Kent, 2016; Brullo et al., 2001; Maiorca et al., 2002; Caridi et al 2006; Maiorca et al., 2007; Caruso 2015; Maiorca et al., 2020; Foti et al., 2022; Braun-Blanquet 1964). In particular, the disturbance species were identified considering the characteristics of plant communities belonging to the anthropogenic vegetation of the phytosociological classes Stellarietea mediae Tüxen, Lohmeyer & Preising ex Von Rochow 1951 and Galio aparine-Urticetea dioicae Passarge ex Kopecký 1969 according to Biondi and Blasi (2015).

To correlate the habitat naturalness index (N) with the average distances from urban centres (Ds), a statistical analysis was performed using PAST version 4.13, a linear regression model with Pearson’s correlation coefficients, and the Durbin–Watson and Breusch–Pagan tests. [Farebrother 1980; Rousseeuw et al., 2006; Warton et al., 2006; Wooldridge 2013).

### 3.3. Results

Cluster analysis of the vegetation matrix produced the dendrogram in Figure 3.2, where the abscissa represents the distinguishing number of each survey, and the ordinate represents the similarity scale. The first subdivision is at a similarity level of 1.4 and separates the typically halophilic habitats of brackish depressions from the others. The subsequent subdivisions (similarity coefficient 1.2) shows a total of 13 groups of relevés, each corresponding to a specific habitat type according to Annex 1 of European Directive 43/92.

Table 1 shows the EEC 92/43 habitats identified by means of the cluster analysis. For each habitat, indicated by the code and the name of Annex I of the EEC Directive 92/43, the following information is provided: a brief description, the typical species present in the analysed relevés (Supplementary Material File S1) with the scientific names updated according to the "Portal to the Flora of Italy" (2023), and the reference phytosociological syntaxa according to Biondi et al. (2009). In File S2 (Supplementary Material) the syntaxonomic scheme of the cited syntaxa is reported, updated according to the 'Prodromo della Vegetazione d'Italia' (Biondi et al., 2023).

Table 3.1. Main characteristics of identified habitat types of community interest by the cluster analysis. (\* priority habitat type in accordance with Directive 92/43/EEC).

Habitat Directive	Description	Typical Species	Syntaxa
1210 - Annual vegetation of drift lines	Sandy or shingle beaches with little or no vegetation	<i>Cakile maritima</i> subsp. <i>maritima</i> , <i>Euphorbia peplis</i> , <i>Glaucium flavum</i> , <i>Polygonum maritimum</i> , <i>Salsola squarrosa</i> .	<i>Salsolo kali-Cakiletum maritimae</i> Costa & Manzanet 1981 nom. mut. propos. in Rivas-Martínez et al. 2002

1240	-	Rocky shores with discontinuous and sparse vegetation, characterised by stenoendemic species of the genus <i>Limonium</i> and <i>Crithmum maritimum</i>	<i>Limonium calabrum</i> , <i>Limonium remotispiculum</i> , <i>Crithmum maritimum</i> , <i>Limbarida crithmoides</i> <i>subsp. longifolia</i> , <i>Allium commutatum</i> , <i>Hyoseris lucida</i> L. <i>subsp. taurina</i> .	<i>Crithmo-Limonietum remotispiculi</i> Bartolo, Brullo & Signorello 1989, Limonietum calabri Bartolo, Brullo & Signorello 198
1410	-	Halophilous rushes with <i>Juncus maritimus</i> , <i>J. acutus</i> , <i>J. subulatus</i> , located in coastal depressions behind dunes, periodically flooded by saline or sub-saline water in winter and dried out in summer.	<i>Juncus acutus</i> , <i>Juncus maritimus</i> , <i>Limonium narbonense</i> , <i>Puccinellia festuciformis</i> <i>lagascana</i> .	<i>Juncetum maritimo-acuti</i> Horvati'c 1934.
1420	-	Purely halophilous low shrub formations dominated by woody Chenopodiaceae and other salt-tolerant species	<i>Sarcocornia perennis</i> , <i>Suaeda vera</i>	<i>Puccinellio festuciformis</i> — <i>Sarcocornietum perennis</i> (Braun-Blanquet 1931) Géhu 1976
1430	-	Halo-nitrophilous scrubs ( <i>Pegano-Salsoletea</i> ) succulent, chamaephytes found on dry, usually salty, soils in the coastal strip with a hot, dry Mediterranean bioclimate	<i>Salsola oppositifolia</i> , <i>Moricandia arvensis</i>	<i>Asparago albi-Salsoletum oppositifoliae</i> Brullo, Giusso del Galdo, Guarino, Minissale, Sciandrello, Spampinato 2012

2110-	Embryonic shifting dunes	Mobile coastal sands with sparse herbaceous perennial vegetation. The dunes are first colonised by <i>Agropyron junceum</i> ( <i>Elymus farctus</i> ) and then consolidated by <i>Ammophila arenaria</i> , which is rare on the Calabrian coast.	<i>Thinopyrum junceum</i> , <i>Echinophora Achillea maritima</i> , <i>spinosae-Echinophora spinosa</i> , <i>Elymetum farcti Eryngium maritimum</i> , Géhu 1987, <i>Medicago marina</i> , <i>Pancratium maritimum</i> , <i>Cyperus capitatus</i> , <i>Lotus creticus</i> .
2120-	Shifting dunes along the shoreline with <i>Ammophila arenaria</i> (white dunes)	Mobile coastal sands with sparse herbaceous perennial vegetation. The dunes are first colonised by <i>Agropyron junceum</i> ( <i>Elymus farctus</i> ) and then consolidated by <i>Ammophila arenaria</i> , which is rare on the Calabrian coast.	<i>Calamagrostis arenaria</i> , <i>Echinophora Achillea maritima</i> , <i>spinosae-Echinophora spinosa</i> , <i>Ammophiletum australe</i> (Br.-Bl. 1933) Géhu, Rivas-Martinez & R. Tx. 1972 in Géhu et al. 1984 <i>Lotus creticus</i> , <i>Polygonum maritimum</i> , <i>Matthiola incana</i> , <i>Seseli tortuosum</i>
2210-	Crucianellion <i>maritima</i> e fixed beach dunes	This is a chamaephytic and suffruticose vegetation represented by the primary garrigues that develop on the inner slopes of the shifting dunes with more stable and compact sands	<i>Ephedra distachya</i> , <i>Helichryso italici-Pancratium maritimum</i> , <i>Ephedretum Anthemis peregrina</i> , <i>distachyae</i> Géhu et al. 1987 <i>Artemisia campestris subsp. variabilis</i>
2230-	Malcolmietalia dune grasslands	Annual vegetation on sandy substrates, and often abundant ephemeral spring bloom, located in clearings of perennial vegetation belonging to the	<i>Marcus-kochia ramosissima</i> , <i>Medicago Ononidetum littoralis</i> , <i>Lagurus ovatus</i> , <i>variegatae</i> Géhu et al. 1986 <i>Ononis variegata</i> , <i>Polycarpon tetraphyllum</i> , <i>Silene niceensis</i> .

Ammophiletea and HelichrysoCrucianelletea classes.

2240- Brachypodietali a dune grasslands with annuals	Ephemeral annual plant communities of stabilized dunes that develop in spring on sandy oligotrophic soils that are base-rich, often calcareous, located in the clearings of scrub and perennial herbaceous vegetation	<i>Andryala integrifolia</i> , <i>Lagurus ovatus</i> , <i>Anchusa hybrida</i> .	Community of <i>Andryala integrifolia</i> and <i>Anchusa hybrida</i> .
2250*-Coastal dunes with <i>Juniperus</i> spp.	Stable inland brown dunes colonised by psammophilous scrub, dominated by tall shrubby junipers, generally associated with other evergreen sclerophyllous species	<i>Juniperus turbinata</i> , <i>Phillyrea latifolia</i> , <i>Pistacia lentiscus</i> , <i>Smilax aspera</i> , <i>Stachys major</i>	<i>Oleo sylvestris-Juniperetum turbinatae</i> Arrigoni, Bruno, De Marco & Veri 1985 in De Marco, Dinelli & Caneva 1985 corr. 1992
2260-Cisto- Lavanduletalia dune sclerophyllous shrubs	Inland brown dunes colonised by the evergreen sclerophylls of the Mediterranean scrub	<i>Pistacia lentiscus</i> , <i>Myrtus communis</i> , <i>Stachys major</i> , <i>Rhamnus alaternus</i> , <i>Cistus salviiifolius</i> , <i>Clematiflammula</i> , <i>Lonicera implexa</i> , <i>Osyris alb</i>	<i>Myrto communis-Pistacietum lentisci</i> Rivas-Martínez 1974
2270* - Wooded dunes with <i>Pinus</i> <i>pinus</i> and/or <i>Pinus pinaster</i>	Thermophilous Mediterranean pine forest located on the most inland and stable coastal dunes. They tend to have naturalisation	<i>Pinus pinea</i> , <i>Asparagus acutifolius</i> , <i>Phillyrea latifolia</i> , <i>Smilax aspera</i> , <i>Pistacia lentiscus</i> , <i>Rubia peregrina</i>	Community of <i>Pinus pinea</i>

processes of considerable  
landscape value.

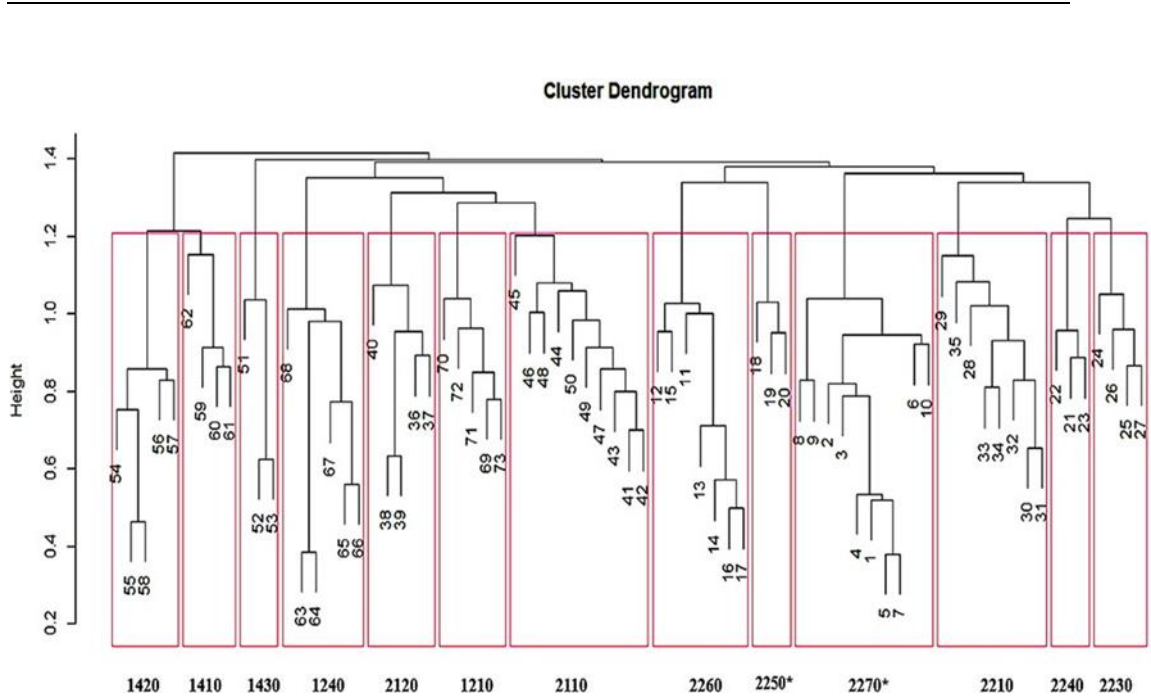


Figura 3.2. Dendrogram derived from cluster analysis on matrix relevés (Chord as distance coefficient and UPGMA as clustering algorithm) showing 13 habitat types (see Table 1).

The biodiversity values of the coastal habitats compared (Table 2, Figure 3.3) show that the Shannon–Wiener index ( $H^+$ ) is higher for habitats 2240, 2110, 2260, and 2230. Lower values were found in habitats 1420, 2120, 2250\*, and 2270\*.

Table 3.2. Indicators of naturalness and biodiversity of different habitat types. **N** = naturalness index; **H<sup>+</sup>**= Shannon- Wiener diversity index; **Ds**= average distances from urban centres in metres; **H<sup>+</sup>sp. typ.**= percentages of Shannon- Wiener diversity index due to typical species, **H<sup>+</sup> dist./alien** = percentages of Shannon–Wiener diversity index due to alien and disturbance species. (\* priority habitat type in accordance with EEC Directive 92/43/EEC).

Habitat Type	N	H <sup>+</sup>	Ds	H <sup>+</sup> sp. typ.	H <sup>+</sup> sp. dist./alien
1210	0.87	1.00	724.0	0.64	0.55
1240	0.99	0.92	867.6	0.66	0.24
1420	1.00	0.46	844,5	0.50	0.30

1410	0.99	1.02	844.0	0.63	0.44
1430	0.97	0.98	780.3	0.46	0.5
2110	0.97	1.22	818.1	0.70	0.44
2120	0.97	0.78	874.8	0.57	0.34
2210	0.80	0.96	537.7	0.36	0.92
2230	0.96	1.18	751.1	0.46	0.47
2240	0.87	1.28	649.3	0.53	0.47
2250*	0.78	0.84	485.6	0.43	0.63
2260	0.85	1.10	695.5	0.50	0.51
2270*	0.77	0.80	403.3	0.30	1.05

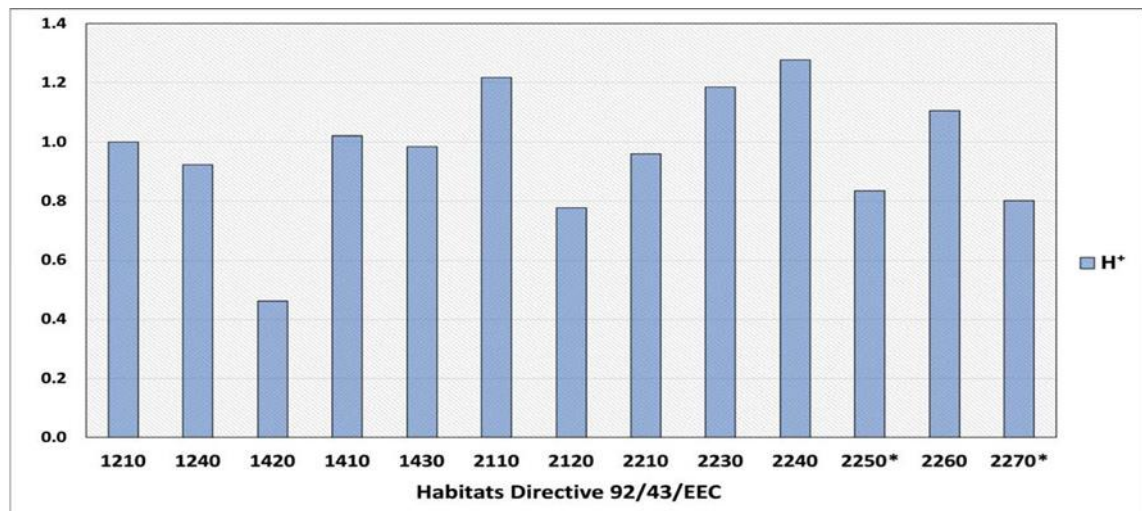


Figura 3.3. Biodiversity values of Shannon–Wiener index ( $H^+$ ) in the coastal habitat types. (\* priority habitat type in accordance with Directive 92/43/EEC).

The highest values of the naturalness index (N), equal to 1, were found in habitats 1240, 1420, 1410, 2110, and 2230 (Figure 3.4), while the lowest values, around 0.8, were observed for habitats 2270\*, 2250\*, and 2210, which were found to be more susceptible to disturbance as they host a high number of synanthropic species such as *Cynodon dactylon* (L.) Pers., *Galactites tomentosus* Moench, *Reichardia picroides* (L.) Roth, *Pallenis spinosa* (L.) Cass., and alien species such as *Acacia saligna*

(Labill.) H.L. Wendl., *Carpobrotus acinaciformis* (L.) L. Bolus, *Erigeron canadensis* L., *Oxalis pes-caprae* L., and *Pittosporum tobira* (Thunb.) W.T. Aiton.

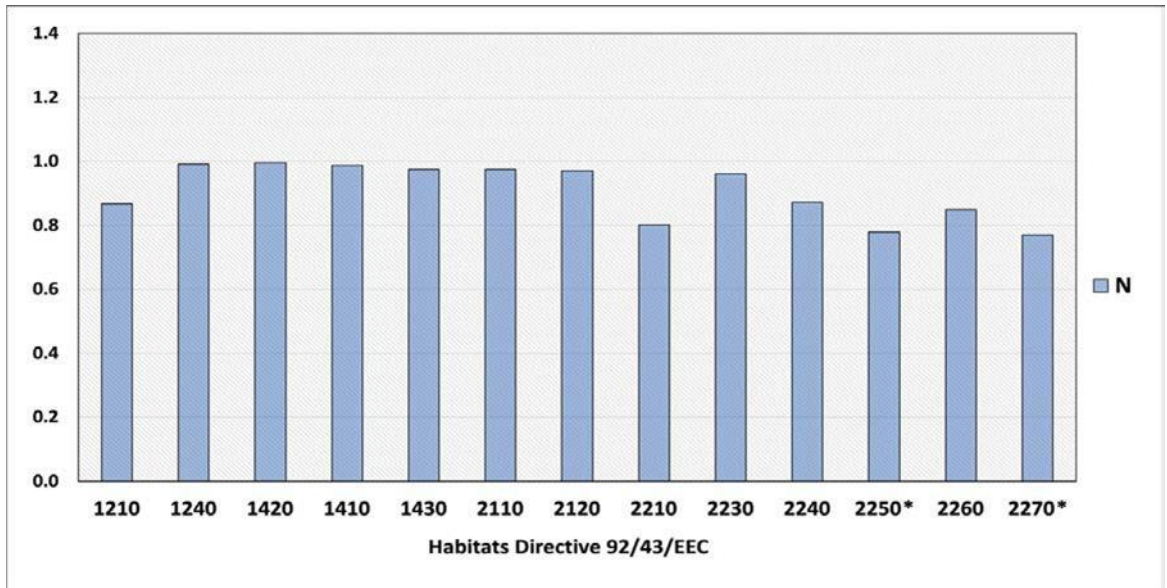


Figura 3.4. Values of the naturalness index (N) in the coastal habitat types. (\* priority habitat type accordance with Directive 92/43/EEC).

Figure 3.5 shows that in habitats 2270\*, 2250\*, 2230, and 2210 the H<sup>+</sup> values of disturbance species (H<sup>+</sup> dist./alien) are higher than the H<sup>+</sup> values of typical species (H<sup>+</sup> typical), unlike habitats 2110, 2120, 1210, 1240, 1410, and 1420, where the greatest diversity (H<sup>+</sup>) is represented by typical species.

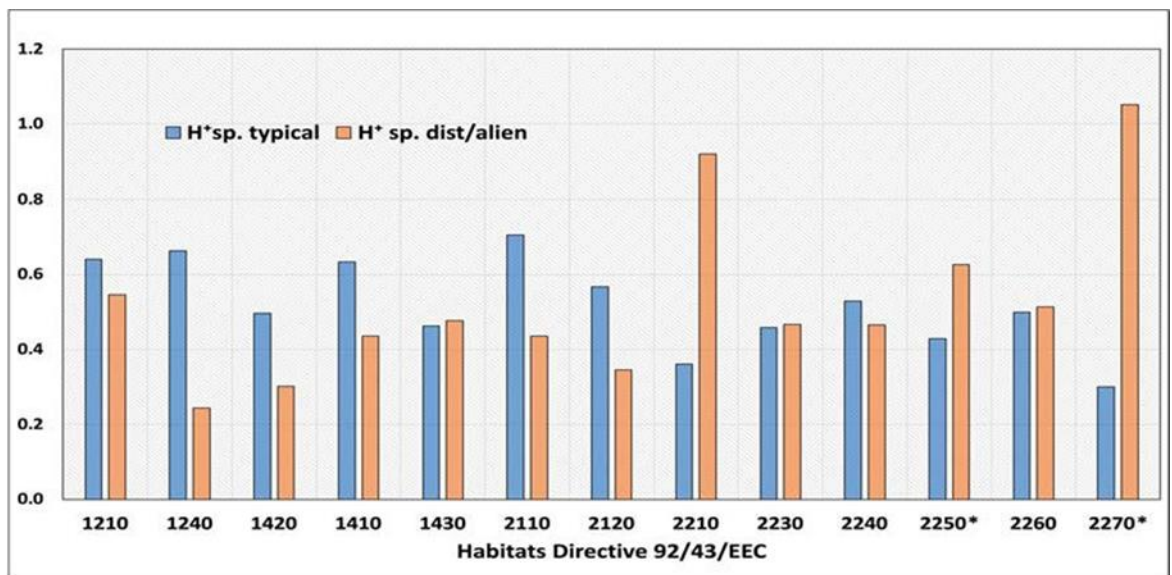


Figura 3.5. H<sup>+</sup> index values of typical species (H<sup>+</sup> sp. typical) and of disturbance and alien species (H<sup>+</sup> sp. dist/alien) in the coastal habitat types. (\* priority habitat type in accordance with Directive 92/43/EEC).

The linear correlation analysis  $r$  (Pearson) between the naturalness index values (N) and the average distances (Ds) between the relevés carried out and the polygons coded as urban centres shows a strong significance for the two variables with  $p$ -value  $< 0.05$  ( $1.03 \times 10^{-7}$ ).

For the statistical analysis, a linear regression model (Figure 3.6) was applied between the mean distances and the naturalness index (N). Although the number of cases is not very high, the model shows a significant slope  $p$ -value  $< 0.05$  ( $0.00000048404$ ), and a correlation of 0.96.

This analysis shows that the naturalness of habitats increases with increasing distance from polygons coded as urban, confirming that the closest habitats to urban areas are those most impacted by human activity.

To verify the autocorrelation analyses, the Durbin–Walson statistical test was applied with a value of 1.83 and a probability of autocorrelation of 0.45 ( $p > 0.05$ ), while the variance of the residuals and therefore the homoscedasticity was calculated with the Breusch–Pagan test, with a value of 0.01 and a probability of homoscedasticity of 0.91 ( $p > 0.05$ ). (Table 3.3).

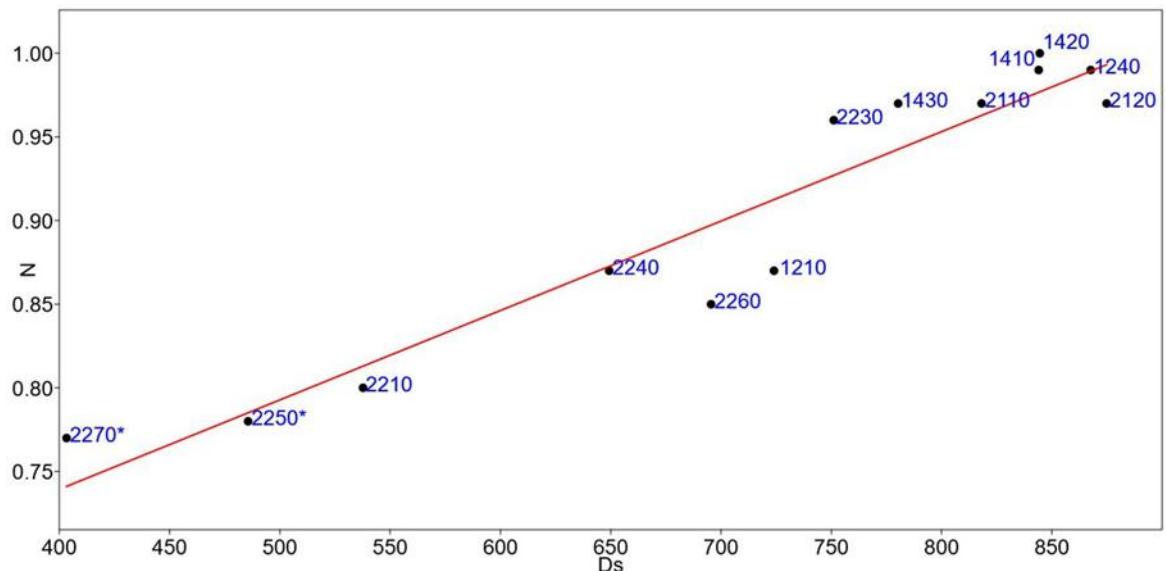


Figura 3.6. Linear regression model between naturalness index (N) versus average distances from urban centres in metres (Ds) between habitat types and polygons

coded as urban (\* priority habitat type in accordance with Directive 92/43/EEC).

Table 3.3 Linear regression model between naturalness index (N) and mean distances (Ds) between habitats and polygons coded as urban.

Ordinary Least Squares Regression: Ds-N			
Slope a:	0,00053454	Std. error a:	5,12E-05
t:	10,431	p (slope):	4,84E-07
Intercept b:	0,52552	Std. error b:	0,037341
95% bootstrapped confidence intervals (N=1999):			
Slope a:	(0.00040974, 0.00059747)		
Intercept b:	(0.48078, 0.62091)		
Correlation:			
r:	0,95299		
r <sup>2</sup> :	0,90819		
t:	10,431		
p (uncorr.):	4,84E-07		
Permutation p:	0,0001		
Durbin - Watson		Breusch Pagan	
1,83		0,01	
p (no pos. autocorr.)		p (omeskedastic)	
0,45		0,91	

Figure 3.7, a linear regression model is applied between the average distances (Ds), and the percentage of Shannon–Wiener index (H+) values obtained only by considering the disturbance species including aliens. Although the number of cases is not very high, the model shows a significant slope p-value < 0.05 (0.02), and a 0.6 correlation. This analysis agrees with the previous one showing that the presence of ruderal and alien species decreases with increasing distance from urban centres.

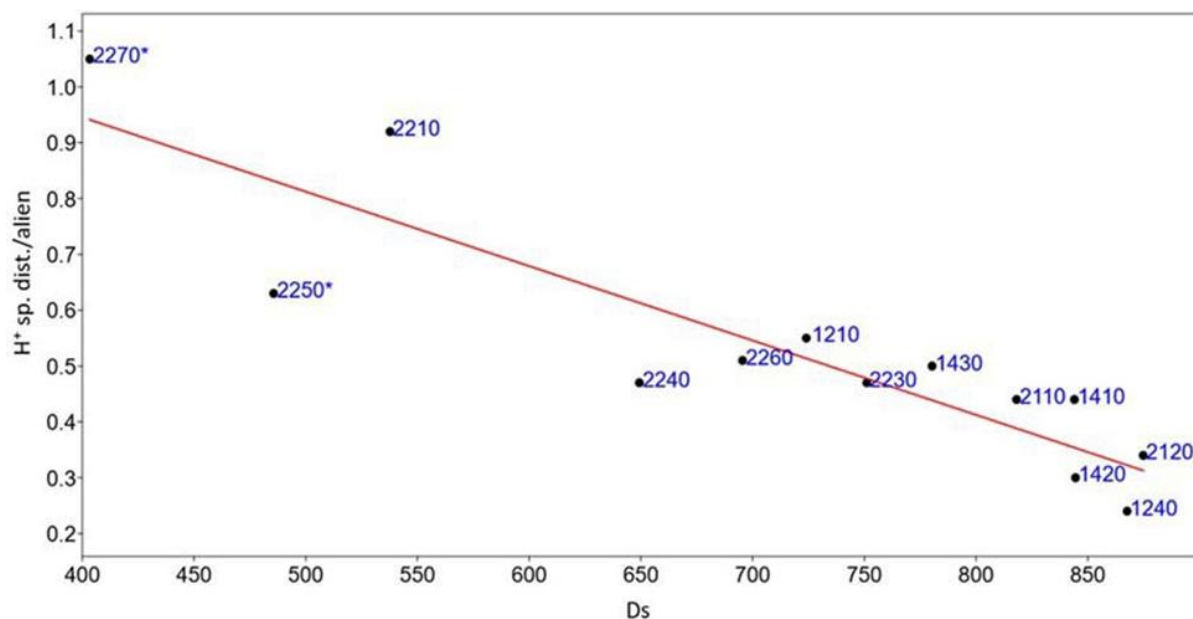


Figura 3.7. Linear regression model between average distances from urban centres ( $D_s$ ) and percentages of Shannon–Wiener diversity index due to alien and disturbance species ( $H^+$  sp. dist./alien) for each habitat types. (\* priority habitat type in accordance with Directive 92/43/EEC).

In order to verify the autocorrelation analysis, the Durbin–Walson statistical test was applied with a value of 1.19 and a probability of autocorrelation of 0.04% ( $p > 0.05$ ), while the variance of the residuals and therefore the homoscedasticity was calculated with the Breusch–Pagan test, with a value of 6.32. (Table 3.4)

Table 3.4. Linear regression model between average distances from urban centres (Dist.) and %  $H^+$  values of typical species ( $H^+$  sp. Tip.) including aliens for each habitat.

Ordinary Least Squares Regression: $D_s$ - $H^+$ sp. dist./alien			
	-0,00133	Std.	
Slope a:		error a:	0,0002000 9
t:	6,6624	p(slope):	3,55E-05
		Std. error	
Intercept b:	1,4789	b:	0,1458

95% bootstrapped confidence intervals (N=1999):	
Slope a:	(-0.0019762, -0.00090962)
Intercept b:	(1.149, 1.9924)
Correlation:	
r:	-0,89521
r <sup>2</sup> :	0,8014
t:	-6,6624
p (uncorr.):	3,55E-05
Permutation p:	0,0001
Durbin - Watson	Breusch Pagan
1,19	6,32
p (no pos. autocorr.)	po (omeskedastic)
0,08	0,01

A linear regression model (Figure 3.8) is applied between the average distances (Ds), and the percentage of the Shannon–Wiener index taking into account typical species (H<sup>+</sup> sp. Typ.). The model shows a significant slope p-value < 0.05 (0.01), and a correlation of 0.8 (Table 3.5). This analysis is consistent with previous ones, showing that typical habitat reference species increase with increasing distance from urban centres and are therefore less impacted by human activity.

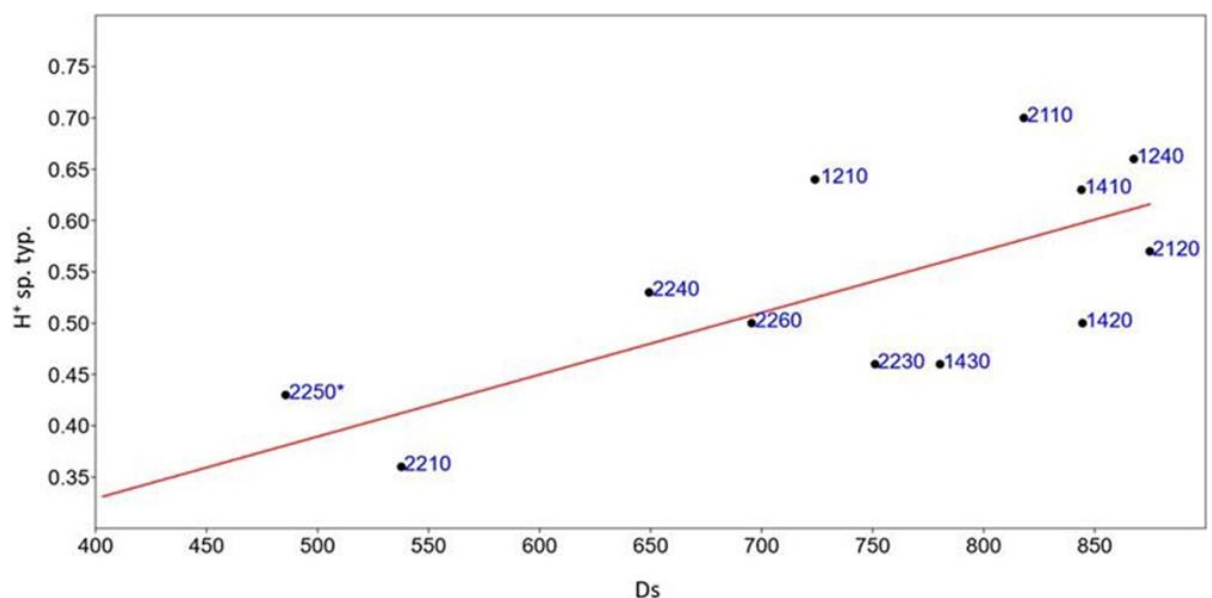


Figura 3.8. Linear regression model between average distances from urban centres (Ds)

versus % H+ values of typical species (H+ sp. typical) including aliens for each habitat types.  
 (\* priority habitat type in accordance with Directive 92/43/EEC).

Ordinary Least Squares Regression: Ds-H+ typical			
		Std. error	
Slope a:	0,0006041	a:	0,0001467
			7
t:	4,1159	p(slope):	0,0017126
		Std. error b:	
Intercept b:	0,087434		0,10695
95% bootstrapped confidence intervals (N=1999):			
		(0.00038744,	
Slope a:	0.00089314)		
Intercept b:	(-0.124, 0.2293)		
Correlation:			
r:	0,77866		
r2:	0,60631		
t:	4,1159		
p (uncorr.):	0,0017126		
Permutation p:	0,0016		
	Durbin - Watson		Breusch Pagan
	2,31		1,54
	p (no pos. autocorr.)		po (omeskedastic)
	0,78		0,21

### 3.4. Discussion

Coastal habitats are particularly fragile and highly threatened environments, which implies the need for active monitoring and management of these habitats.

In this study, vegetation analysis proved to be an excellent tool in the identification and assessment of the conservation status of coastal habitats. The occurrence of different plant communities, characteristic of different habitat

types, was found along the Calabrian coasts. The distribution of these communities generally follows the succession typical of other Mediterranean coasts: on sandy coasts, the succession of habitats begins with annual vegetation near the coastline (habitat 1210) and continues inland with psammophilous herbaceous communities of embryonic and mobile dunes (habitat 2110; 2120), then fixed dunes (habitat 2210), interspersed with annual herbaceous phytocoenoses (habitats 2230; 2240) up to shrub or forest communities on stabilised dunes (2250\*; 2260 and 2270\*). The analysis of plant community diversity using the naturalness index (N) proved to be very interesting in assessing the impact of anthropisation on coastal habitats, conversely to what has been shown in other studies (Ciccarelli et al., 2024). In fact, the low values of the naturalness index (N) are not only due to the presence of alien taxa in the study area, but also to the presence of synanthropic species, which are indicators of disturbance.

The analysis shows that coastal habitats closer to urban centres show low naturalness values and a higher contribution to total diversity from exotic and disturbance species, highlighting that, in agreement with other studies (Ciccarelli et al., 2024), urbanisation and invasive non-native species constitute the most important threats to coastal habitats not only in open environments but also in more stabilised ecosystems, such as grey dunes and forests. Among these, we can observe habitat 2270\*, 2250\*, and 2210, the latter in agreement with other studies (Šilc et al., 2020), are considered the most sensitive to anthropogenic disturbance.

Several studies (European Commission 2008) (Janssen, et al.; 2016) have shown that habitat 2210—*Crucianellion maritimae* fixed beach dunes—is considered at risk in all Mediterranean coasts. Meanwhile, habitat 2250\*, in accordance with Acosta et al. (2015), in Calabria is also currently limited to the few coastal stretches not exploited for tourist or residential purposes.

The results obtained show that in habitat 2270\* synanthropic species are particularly widespread and this agrees with what has been observed in other territories by Bonari et al. (2017) and Sarmati et al. (2019). Probably one of the main vectors in the establishment of these weeds and ruderal communities is trampling resulting from tourist exploitation. Habitat 2250\* also has a bad conservation status, in agreement with other studies (Prisco et al., 2020), and shows a marked reduction in area due to human activity.

According to Acosta et al. (2009), the species richness of coastal dune habitats is maximum in the intermediate dune, and the diversity in the inland area is more characterized by synanthropic species such as therophytes or chamaephytes.

The presence and spread of alien species within wooded dunes is another critical issue for the protection of coastal habitats, altering their diversity in different ecosystems (Calabrese et al., 2017), including *Acacia saligna*, which is used for reforestation and produces litter that takes a long time to decompose, negatively affecting soil availability.

### **3.5. Conclusions**

Coastal ecosystems are dynamic systems influenced by both natural and anthropogenic pressures, which have increasingly intensified in recent decades, resulting in changes in plant communities and landscapes. This relationship can be used as a monitoring tool in coastal habitats. Plant communities, which represent a well-identifiable component of habitats with relatively stable composition, structure, and interrelationships, all of which are linked to specific environmental conditions, can provide a reliable basis for monitoring activities. Habitat vegetation analysis and environmental analysis through a GIS can provide a complete picture of the naturalness, allowing us to recognise the conservation status of coastal habitats.

Our results show that priority should be given to, and monitoring activities should focus primarily on wooded dune habitats and stable dunes near urban centres, due to the presence of alien and disturbance species that affect these

habitats, causing a reduction in biodiversity and posing a threat to the conservation of these habitats. The application of diversity indices linked to landscape analysis is therefore suitable for identifying the causes of alteration due to invasive and disturbance species and can also be used to monitor and assess the conservation status of habitats of community interest. This methodology summarises the conservation status of coastal vegetation in a standardised, objective, and repeatable way over the years to assess the effects of management changes, through the analysis of plant community and the use of different diversity indicators. Overall, it can be a valuable support for the implementation of a conservation strategy compatible with the integrated management of Mediterranean coastal ecosystems.

**Supplementary Materials:** The following supporting information can be downloaded at: [https:// www.mdpi.com/article/10.3390/d16090535/s1](https://www.mdpi.com/article/10.3390/d16090535/s1), File S1—Phytosociological relevés; File S2— Syntaxonomic scheme; File S3—Linear regression model between naturalness index (N) and mean distances (Ds) between habitat types and polygons coded as urban; File S4—Linear regression model between average distances from urban centres (Ds) and % H+ values of typical species (H+ sp. typ.) including aliens for each habitat types; File S5—Linear regression model between average distances from urban centres (Dist.) and % H+ values of typical species (H+ sp. dist./alien) including aliens for each habitat types.

**Author Contributions:** Conceptualization, A.M., G.S. and C.M.M.; methodology, A.M. and G.S.; software, A.M.; analysis, A.M.; data curation, A.M.; writing—original draft preparation, A.M.; writing—review and editing, C.M.M., G.C. and G.S.; supervision, G.S.; funding acquisition, G.S. All authors have read and agreed to the published version of the manuscript.

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## **CHAPTER 4. Diversity and Ecological Assessment of Grasslands Habitat Types: A Case Study in the Calabria Region (Southern Italy)**

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Article

# Diversity and Ecological Assessment of Grasslands Habitat Types: A Case Study in the Calabria Region (Southern Italy)

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## Abstract:

Grasslands differ in many types depending on the diversity of climatic conditions and substrates. Due to the great wealth of species found in semi-natural grasslands, they conserve an essential part of the biodiversity of the European Union (EEC 43/92), defined as habitats of community interest. Using the region of Calabria (southern Italy) as a case study, this study aims to evaluate how species assemblages and a set of indicators applied to them can be used to analyse and characterize the diversity, ecological features and conservation status of grassland habitats. Vegetation analysis was carried out using the phytosociological method, and habitat ecological characteristics were defined by Ellenberg's ecological indicator adapted to the Italian flora. Multivariate analysis of the surveys by means of cluster analysis and Principal Components Analysis (PCA) made it possible to define eight habitat groups according to EEC Directive 43/92: 6110 Rocky or basophilous calcareous grasslands of the *Alyso-Sedion albi*, 6170 Alpine and subalpine calcareous grasslands, 6220\*a Pseudo-steppe with grasses and annuals of the *Thero-Brachypodietea* dominated by a *Lygeum spartum*, 6220\*b Pseudo-steppe with grasses and annuals of the *Thero-Brachypodietea* dominated by *Hyparrhenia hirta*, 6210\* Semi-natural dry grasslands and scrub facies on calcareous substrates (*Festuco-Bromometalia*) (\*important orchid sites), 6230\* Species-rich *Nardus* grasslands, on siliceous substrates in mountain areas (and submountain areas, in Continental Europe), 6410 *Molinia* meadows on calcareous, peaty or clayey-siltladen soils (*Molinio-caeruleae*), 6420 Mediterranean tall humid herb grasslands of the *Molinio-Holoschoenion*, 6430 Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels. Temperature (T) and oisture (U) are the most statistically significant ecological factors in differentiating different habitat types. Analysis of diversity, assessed through Shannon and Evenness indices, showed that it is strongly correlated with habitat diversity as soil moisture increases. The study of ecological characteristics, correlated with biodiversity indices, helps to characterize grassland habitats, providing guidance for the implementation of active conservation policies for these habitats.



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**Keywords:** biodiversity; naturalness; Calabria region; grassland

#### 4.1. Introduction

Grasslands contain a high percentage of the world's biodiversity, despite only a part of the continents being covered by natural or semi-natural grasslands (Bohn et al., 2004; Musarella et al., 2020; Cano Ortiz et al., 2022). These ecosystems account for 28% of natural and semi-natural habitats, ranking after forests in terms of importance (Mücher et al., 2000). In the Italian territory, grasslands cover about 6.2% of the surface, and about 3.6% is mapped as open grasslands by APAT (2005).

Generally, seminatural grassland habitats embedded in agricultural landscapes support floristic diversity and a variety of plant communities (Oppermann et al., 2012; Van Elsen 2000; Cano et al.; 2024), being characterized by a high number of species, many of which are endemics, and are important ecosystems for maintaining biodiversity [Söderström et al., 2001; Pärtel et al., 2005; Gibson 2009]. These habitats, therefore, have a high conservation value, particularly due to their high biodiversity and related ecosystem services (Wilson et al., 2012, Bengtsson et al., 2019). The maintenance of grassland habitats and their associated species has been an important issue in nature conservation for decades (Schrautze et al., 2009). Today, numerous studies analyse the ecological and floristic features of natural and semi-natural Palearctic grasslands (accessed on 6 November 2023). Understanding and analysing the ecological factors that influence biodiversity is essential for designing biodiversity management and conservation plans that are consistent with the floristic and ecological characteristics of habitats (Cano Carmona et al., 2022, Dengler, et al., 2014; Valkó et al., 2014).

The remarkable species richness of grasslands is threatened across Europe due to global changes, fire and biological invasions (Veen et al., 2009; Reitalu et al., 2010; Reitalu et al., 2014; Turtureanu et al., 2014; Mendes et al., 2014; Roleček et al., 2014; Musarella et al., 2024). The decline in the diversity and connectivity of

grasslands in Europe has increasingly become a major issue for their conservation. Changes in land use have the greatest impact on the degradation and loss of different habitat types (Hansen et al., 2004; Spampinato, et al., 2022; Spampinato, et al., 2017). Over the last century, a continuous loss of species-rich grassland habitats, influenced by humans with conversion to intensive arable or grassland, or abandonment to evolve into forests, has been recognized in Europe (Kuemmerle et al., 2016, Watson et al., 2016). In this perspective, beta-diversity, defined as the amount of turnover in species composition (Whittaker 1972) is important as a measure of species diversity on a regional scale, to be used as a basis for conservation (Margules 2000). The conservation and sustainable use of a given territory must take into account models that consider biodiversity as a factor in ecosystem stability and functioning (Whittaker, et al., 2015; Tilman et al., 1994; Hooper et al., 2005).

Some studies show that the species composition of grasslands varies to a different extent depending on environmental characteristics (Auestad et al., 2008; De Knegt et al., 2010; Maccherini et al., 2011). Various ecological factors affect the species diversity of grasslands habitats (Boch et al., 2010); among them, the most important are climate (Chytrý et al., 2007; Palpurina et al., 2015), altitude and, above all, soil moisture conditions (Garcia 2015; Bratli et al., 1999). In particular, the humidity is one of the most important ecological factors that influence plant species, the diversity and the floristic composition of grasslands habitats, as highlighted by Zelnik et al. (2013); there have also been numerous research studies carried out in the last decade in Europe on wetlands and the role of ecological factors (Hölzel et al., 2004; Grootjans et al., 2005; Zelnik, 2015; Havlová, 2006; Janišová et al., 2007; Hájek et al., 2008; Stančić 2008; Zelnik et al., 2008; Spampinato et al., 2019; Perrino et al., 2021). Some studies state that nutrient availability within the soil influences species richness in various plant communities (Borer et al., 2014; Klaus et al., 2013).

Grazing management is another factor that influences the structure and function

of these ecosystems [Roman et al., 2019; Li et al., 2021; Zhang et al., 2021], changing their plant diversity. Lozano et al. (2021) suggest that grazing pressure has a negative effect on the presence of endemic species, whereas in alpine environments, grasslands with higher floristic diversity are generally associated with environments with forms of management that involve the removal biomass, such as mowing and grazing (Grime et al., 2012; Zanzottera et al., 2020).

The use of ecological indices can point out anthropogenic impact and thus allow the degree of naturalness or degradation of a habitat to be assessed based on species composition (Erdős et al., 2022).

This study aims to assess the conservation status of grassland habitats by analysing the diversity, naturalness, and ecological characteristics of the plant communities. The grassland spread in the Calabria region was used as a case study. In particular, the study aims to (1) identify the different habitat types through the species assemblage; (2) define the main ecological factors responsible for variation in the floristic composition of grassland habitats vegetation; (3) assess the biodiversity and naturalness of the different habitat types; (4) evaluate the relationship between species diversity and ecological factors. The results of this study can be useful and applied in the management of grassland habitats for biodiversity conservation purposes.

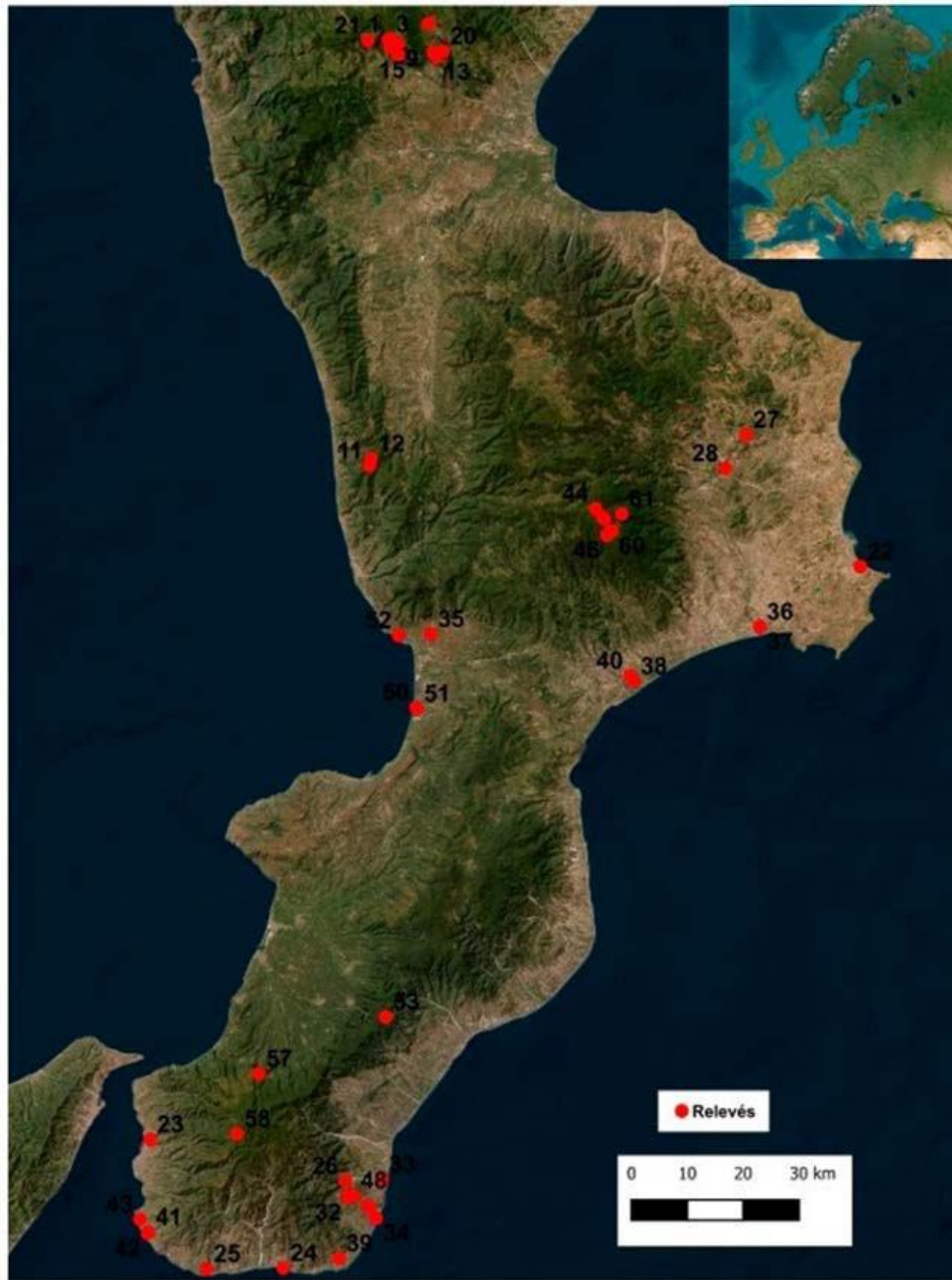
#### **4.1. Materials and Methods**

The study area was the Calabria region, which, as indicated in the Carta Natura (Spampinato., 2023), occupies 24,375 ha, or 2.4% of the regional territory. For the photointerpretation of the habitats, arc map 10.7 was used, with reference system WGS84 UTM Zone 33, (False\_Easting: 500000,00000 False\_Northing: 0.00000; Central\_Meridian: 15.00000; Scale\_Factor: 0.99960; Latitude\_Of\_Origin: 0.00000; Linear Unit: Kilometres). The analysis has affected all grass-land habitats depicted on the nature map.

These habitats are distributed throughout the Calabrian territory, from sea level to

the mountain range, affecting different environmental contexts characterized by different ecological conditions (Spampinato et al., 2017).

The analysis of grassland habitats was based on the vegetation relevés carried out in the period 2018– 2021, using the phytosociological method of the Zurich-Montpellier school, considered to date the most suitable method for analysing vegetation [Cano Carmona, et al., 2022, Rivas-Martinez, 2005; Blasi et al., 2011]. A total of 61 unpublished relevés with 490 species were carried out (Figure 4.1) (Supplementary Materials Table S13). The matrix of phytosociological relevés was subjected to multivariate analysis to define coenological groups on an actual statistical basis. To this end, the abundance-dominance data of the individual species reported with the Braun-Blanquet scale were converted with the scale of numerical values proposed by Van der Mareel. The software used for the organization of raw data and subsequent statistical analyses was Microsoft Excel 2010; PAST version 4.13; R 4.1.1 R Core Team 2021.



*Figura 4.1. Study area: Calabria region. The red dots and numbers indicate the location of the vegetation relevés.*

The cluster analysis of the relief matrix used the average bond criterion (UPGMA) and the Chord distance algorithm to identify homogeneous floristic compositions.

To highlight the ecological characteristics of plant species, the Pignatti–Ellenberg

indicator value was used in the version modified by Pignatti (2017a; 2017b; 2018) for the Italian territory. The values of the ecological indicator of continentality (C), substrate reaction (R), temperature (T), humidity/water availability (U), light (L) and nutrients (N) were taken into account.

The PCA was performed taking into account the Ellenberg ecological indicator attributed to each species in the survey matrix to show the distribution of values for ecological characteristics.

The nomenclature of the species follows the "Portal to the flora of Italia" (2023), while syntaxonomic references of plant communities take into account several studies (Biondi et al., 2015). Manuals for the interpretation and monitoring of habitats of community interest in Italy were used for the interpretation of community habitats according to EEC Directive 43/92 (Biondi et al., 2009; Gigante et al., 2016).

Grassland biodiversity was assessed using the Shannon–Wiener  $H^+$  (Shannon 1949) and Evenness (J) indices.

$$H^+ = - \sum_{j=1}^s p_i \ln p_i$$

where  $p_i$  is the relative presence value of the  $i$ th species.

$$J = H/H_{max}$$

$$H_{max} = \ln S$$

where  $H_{max} = \ln S$  and  $S$  = species richness.

This index depends on the abundance and uniform distribution of species (Pielou, 1966).  $J'$  varies between 1 when the species of the community are equally distributed and 0 when only one species is present.

The Shannon index ( $H^+$ ) has also made it possible to evaluate Naturality ( $N_a$ ) by taking into account not only the presence of alien species (Pielou 1966; Grunewald

et al., 2007; Pinna et al., 2015; Pinna et al., 2019; Calderisi, et al., 2023) but also the indicators of disturbance, which emphasise the anthropic impact on the community.

$$N = H + (\text{without alien and disturbing plant species}) / H +$$

The Na index varies from 0 to 1, where 0 indicates that plant diversity consists entirely of alien and disturbance species, while 1 indicates the absence of the latter in phytocoenosis (Pielou 1966; Grunewald et al., 2007; Pinna et al., 2015; Pinna et al., 2019; Calderisi, et al., 2023). The alien species were extrapolated from the "Portal of the flora of Italy" (2023), while for the disturbance species the syntaxonomic references of the plant communities (Biondi et al., 2015) belonging to the anthropic vegetation classes *Stellarietea mediae* Tüxen, Lohmeyer & Preisling ex Von Rochow 1951 and *Galio aparines-Urticetea dioicae* Passarge ex Kopecký 1969 were taken. Most disturbance species characterize various alliances: *Securigero securidacae- Dasypyrrion villosi*, Biondi & Canoex Cano-ortiz, Biondi & Canoin Biondi et al., 2015 [*Bromopsis erecta* (Huds.), *Dasypyrrum villosum* (L.) P. Candargy), *Fedio graciliflorae- Convolvulion cupaniani* Brullo & Spampinato 1986 [*Avena barbata* Pott ex Link, *Galactites tomentosus* Moench, *Sonchus oleraceus* L., *Geranium dissectum* L.]; *Fumarion wirtgenii-agrariae* Brullo in Brullo & Marcenò 1985 [*Calendula arvensis* L. (Raf.) Nyman, *Rumex bucephalophorus* L., *Fumaria agraria* Lag]; *Trifolio medii-Geranietea sanguinei* Müller 1962 [*Senecio scopoli* Hoppe & Hornsch; *Asphodelus ramosus* L.]; *Scleranthion annui* (Kruseman & Vlieger 1939) Sissingh in Westhoff, Dijk, Passchier & Sissingh 1946 [*Anthemis arvensis* L., *Agrostis castellana* Boiss. & Reut., *Muscari comosum* (L.) Mill.]; *Convolvulo arvensis- Agropyrrion repenti* Görs 1966 [*Picris hieracioides* L., *Dactylis glomerata* L., *Bunium bulbocastanum* L.]; *Inulo viscosae-Agropyrrion repentis* Biondi & Allegrezza 1996 [*Reichardia picroides* (L.) Roth, *Pallenis spinosa* (L.) Cass., *Daucus carota* L., *Verbena officinalis* L.]; *Cerastio arvensis- Cynosurenion cristati* Blasi, Tilia, Rosati, Del Vico, Copiz, Ciaschetti, Burrascano 2012 [*Anthoxanthum odoratum* L., *Lotus corniculatus* L., *Plantago lanceolata* L.]; *Resedo albae-*

*chrysanthemenion coronarii* Cano-Ortiz, Biondi & Cano In Biondi, Allegrezza, Casavecchia, Galdenzi, Gasparri, Pesaresi, Poldini, Sburlino, Vagge & Venanzoni 2015 [*Reseda alba* L.]; *Echio plantaginei-Galactition tomentosae*, O. Bolòs & Molinier 1969 [*Sherardia arvensis* L., *Plantago lagopus* L., *Lotus ornithopodioides* L.]; *Digitario ischaemi-Setarion viridis* Sissingh in Westhoff, Dijk, Passchier & Sissingh 1946 (*Digitaria sanguinalis* (L.) Scop.; *Hordeion leporini* Br.-Bl. in Br.-Bl., Gajewski, Wraber & Walas 1936 corr. O. Bolòs 1962 [*Carduus pycnocephalus* L., *Anacyclus clavatus* (Desf.) Pers., *Rostraria cristata* (L.) Tzvelev, *Glebionis coronaria* (L.) Spach]; *Hypochoeridion achyrophori* Biondi & Guerra 2008 [*Linum strictum* L., *Euphorbia exigua* L.]; *Taeniathero-Aegilopion geniculatae* Rivas- Martínez & Izco 1977 [*Trifolium stellatum* L., *Trifolium scabrum* L.]; *Holco mollis-Pteridion aquilini* Passarge (1994) 2002 [*Pteridium aquilinum* (L.); *Holcus lanatus* L.]; *Ridolfion segeti* Negre ex Rivas-Martinez, Fernandez-Gonzalez & Loidi 1999 [*Phalaris paradoxa* L., *Trigonella sulcata* (Desf.) Coulot & Rabaute]; *Caucalidion platycarpi* Tüxen ex Von Rochow 1950 nom. mut. Rivas-martinez, T.E. Diaz, Fernandez-Gonzalez, Izco, Loidi, Lousã & Penas 2002 [*Lysimachia arvensis* (L.) U. Manns & Anderb.]; *Veronico agrestis-Euphorbion peplus* Sissingh ex Passaggio 1964 [*Sonchus asper* (L.) Hill].

To verify the significance of the differences observed between the different habitat groups and the average values of the ecological indicator, the Mann–Whitney test was used. Finally, a correlation analysis (PAST version 4.13 (Zar 1996; Farebrother 1980) was applied between the value of Naturalness (Na) and the values of the ecological indicator of temperature (T) and humidity (U) of the identified habitat types. Person statistics were used, and, finally, the linear regression model by Durbin–Watson and Breusch–Pagan tests were applied (Rousseeuw et al., 1999; Warton et al., 2006; Wooldridge 2012).

## **4.2. Results**

### **4.2.1. Cluster Analysis to Define Habitat Types**

Cluster analysis of the grassland vegetation relevés matrix produced the dendrogram in Figure 4.2, where the abscissa shows the distinctive number of each relevés, while the ordinate shows the scale of similarity. The first subdivision is at a similarity level of 1.4; the subsequent subdivisions (similarity coefficient 1.3-1.2-1.1) show us eight groups of different grassland habitats.

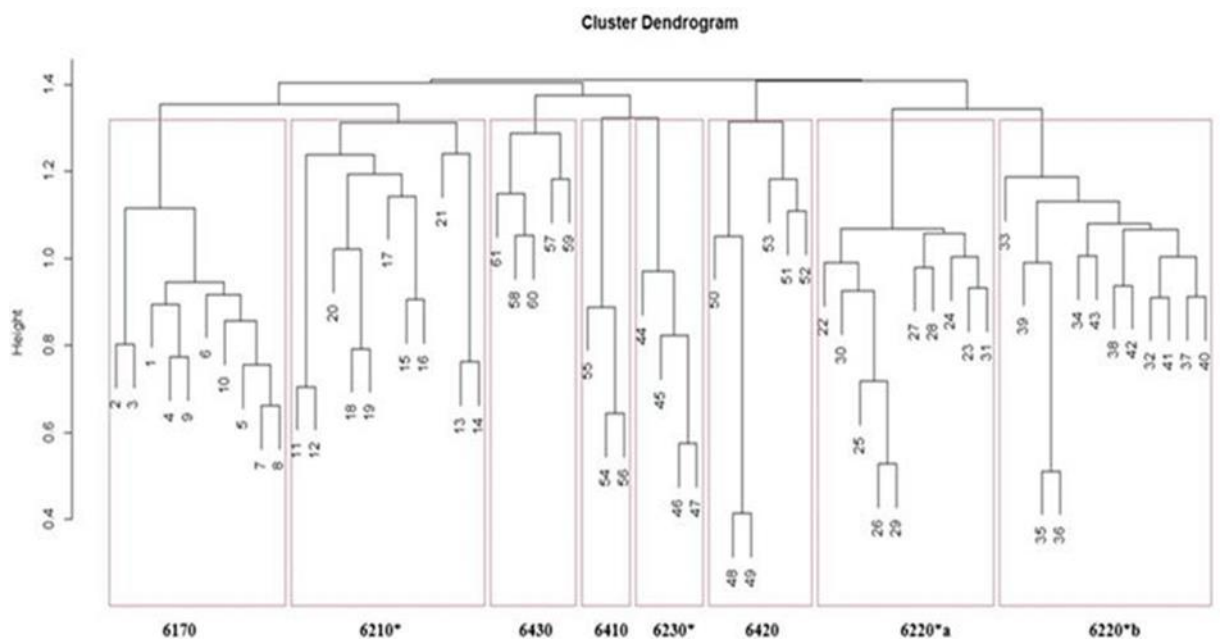


Figura 4.2. Dendrogram derived from cluster analysis on grassland relevés (Chord as distance coefficient and UPGMA as clustering algorithm) showing 8 habitat groups: 6220\*a: Pseudo-steppe with grasses and annuals of the Thero-Brachypodietea dominated by *Lygeum spartum* L., 6220\*b: Pseudo-steppe with grasses and annuals of the Thero-Brachypodietea dominated a *Hyparrhenia hirta* (L.) Stapf, 6230\*: *Nardus* grasslands rich in species, on siliceous substrates in mountain areas; 6210\*: Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*) (\*important orchid sites).

The first group (Rel. 1–10), according to "Italian interpretation manual of the 92/43/EEC Habitats Directive" [71], belongs to the habitat 6170: Alpine and subalpine calcareous grasslands, the second group (Rel 11–21) belongs to habitat 6210\*: Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*) (\*important orchid sites), the third group (Rel. 22–31) to the habitat 6220\*a: Pseudo-steppe with grasses and annuals of the *Thero-*

*Brachypodietea* dominated by *Lygeum spartum* L., the fourth group (Rel. 32–43) to habitat 6220\*b: Pseudo-steppe with grasses and annuals of the *Thero-Brachypodietea* dominated by *Hyparrhenia hirta*, the fifth group (Rel. 44– 47) fits to the habitat 6230\*: *Nardus* grasslands rich in species, on siliceous substrates in mountain areas (and submountain areas, in Continental Europe), the sixth group (Rel. 48–53) belongs to habitat 6420: Mediterranean tall humid herb grass- lands of the *Molinio-Holoschoenion*, the seventh group (Rel. 54–56) belongs to habitat 6410: *Molinia* meadows on calcareous, peaty or clayey-siltladen soils (*Molinion caeruleae*), and the eighth group (Rel. 57–61) belongs to habitat 6430: Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels.

Habitat 6220\* is characterized as grassland of small grasses rich in therophytes, pre- dominantly open, thermo- and meso-Mediterranean bioclimate, xerophilous; oligotrophic soil communities are located on base-rich substrates, often calcareous. In loose soil, we find the habitat dominated by *Hyparrhenia hirta* (Brullo et al., 1997), while on clayey soils, we find the habitat dominated by *Lygeum spartum* (Brullo et al., 1990); in both, it is possible to find some interesting species (Spampinato et al., 2018). Habitat 6230\* (Viciani et al., 2000; Di Pietro et al., 2005) includes grasslands dominated by *Nardus stricta* which develop on acid soils in rather flat areas from the hills to the mountain range; in acidic soils, they can derive from siliceous or carbonate rocks through leaching. The grasslands of habitat 6210\* (Biondi et al., 2009; Venanzoni et al., 1999; Brullo et al., 2005) are predominantly of secondary origin and characterized by a high density of species. Hemicryptophytes dominate these communities and can develop on different types of substrate. In Italy, these grasslands, excluding the North, show their greatest presence along the Apennine chain. Habitat 6170 is located on limestone sub- strates (Passalacqua et al., 1998; Di Pietro 2004) and frames the grasslands present in the Alps and the Apennines above the forest limit. Habitat 6410 includes wet semi-natural grasslands characterized by *Molinia caerulea*

(Venanzoni 1988; Buffa et al., 1997) and is located from the plain to the upper limit of the forest. Habitat 6420 includes high size grasslands characterised by Mediterranean reeds and other hygrophilous species (Acosta et al., 2000, Maiorca et al., 2005) and is present in retrodunal systems but also in indoor wetlands. Habitat 6430 is characterized by hygrophilous and nitrophilous species (megaforbes), which settle mainly along the edge of waterways (Brullo et al., 1990; ganguxxi et al., 2004).

#### 4.2.2. Ecological Factors Analysis

The PCA was carried out taking into account the Ellenberg ecological indicator value, which showed the distribution of relevés on the basis of ecological characteristics and explained 81.3% of total dataset variation with the first two components, with PC1: 60.9% and PC2: 20.4% (Figure 4.3).

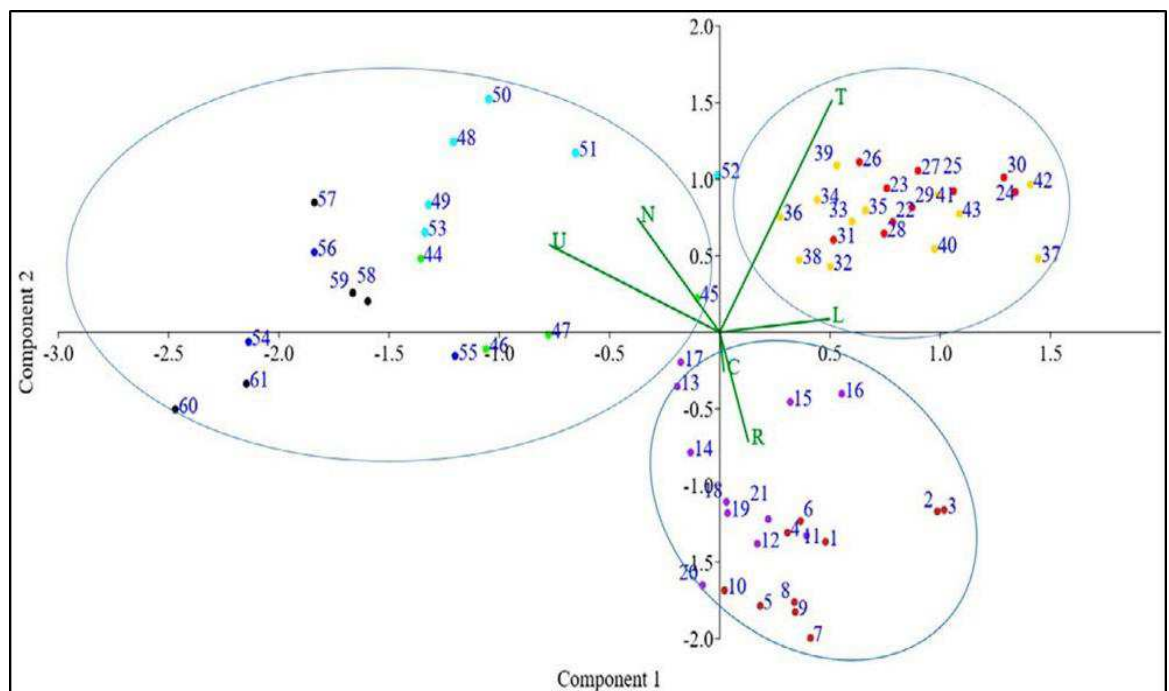


Figura 4.3. Biplot of relevés dispersion on PCA related to Ellenberg ecological indicator. The numbered points are the relevés of the various habitat types: in purple is the habitat 6210\*, brown is the habitat 6170, light green is the habitat 6230\*, red is the habitat 6220\*a, yellow

is the habitat 6220\*b, sky blue is the habitat 6410, black is the habitat 6430, blue is the habitat 6420. The green lines indicate the direction of maximum correlation of the Ellenberg indicator values. (U = humidity; C = continentality; R = substrate reaction; T = temperature; L = light; N = nutrients).

The PCA highlights three habitat groups. The habitats 6230\*, 6410, 6420, and 6430 are related to the ecological factors of moisture (U) and nutrients (N); these are in fact habitat types located in the mountainous belt, where there is a climate with greater water availability. The habitats 6220a\* and 6220\*b are arranged along ecological gradients of temperature (T) and light (L), confirming that these habitats are characterised by herbaceous, perennial, thermophilous vegetation that settles in the driest areas of the Mediterranean [70]. Habitats 6170 and 6210\* are distributed on the basis of the ecological indicator of continentality (C) and substrate reaction (R); they are in fact habitats located in the mountainous belt on highly permeable basic pH limestone substrates. (Table 4.1).

Table 4.1. Total change in the dataset with principal components.

Principal component	Eigenvalue	% variance
1	4.83798	60.949
2	1.62452	20.466
3	0.815708	10.276
4	0.501369	6.3162
5	0.111929	1.4101
6	0.0462611	0.5828

The ecological features of the eight identified habitats are shown in Figure 4.4 by boxplots with the values of the ecological indicator of humidity (U), temperature (T), light (L), nutrient (N), continentality (C) and substrate reaction (R). To quantify the separability of the various habitat groups considering the mean values of the ecological index, the Mann–Whitney test was applied.

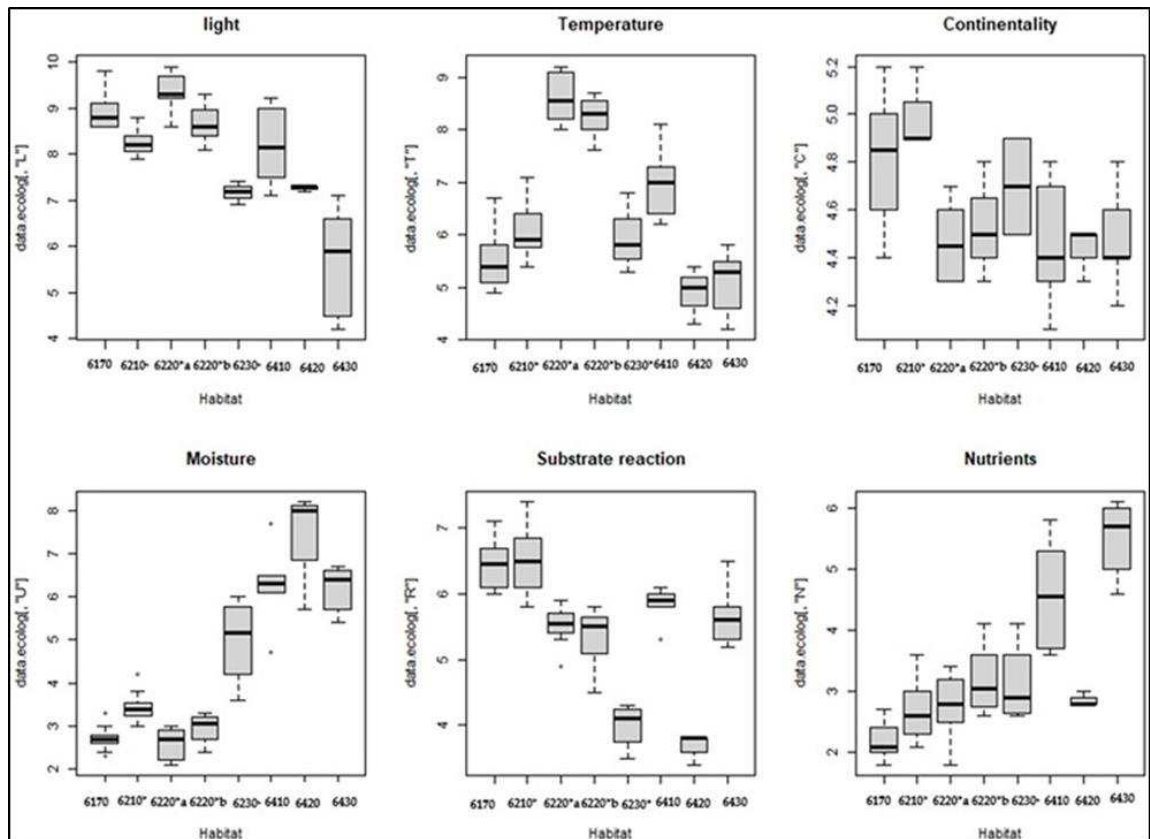


Figura 4.4. Box plot representing the Ellenberg indicator values of each habitat: 6170 Alpine and subalpine calcareous grasslands; 6210\* Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*) (\*important orchid sites); 6220\*a Pseudo-steppe with grasses and annuals of the Thero-Brachypodietea dominated a *Lygeum spartum* L., 6220\*b Pseudo- steppe with grasses and annuals of the Thero-Brachypodietea dominated by *Hyparrhenia hirta*; 6230\* *Nardus* grasslands rich in species, on siliceous substrates in mountain areas; 6420 Mediterranean tall wet grass grasslands of the *Molinio-Holoschoenion*; 6410 *Molinia* meadows on calcareous, peaty clayey-siltladen soils (*Molinion caeruleae*); 6430 *Hydrophilous* tall grass fringe communities of plains and of the mountain to alpine levels.

The ecological factor light (L) is greatest regarding 6220\*a and 6220b\*, while lower values are observed in the habitat 6420; significant differences occur for this ecological indicator between habitat 6220\*a and habitats 6170 (p-value = 0.000) and with habitat 6210\* (p-value = 0.000); other significant differences are observed between habitat 6220\*b and habitat 6430 (p-value = 0.04).

The ecological indicator temperature (T) is higher in habitats 6220a\* and 6220\*b and lower in habitats 6170, 6420 and 6430, as shown by the dissimilarity between habitat 6170 and habitats 6220\*a (p-value = 0.00) and 6220\*b (p-value = 0.00); other statistically significant differences are shown between habitat 6220\*a and habitats 6210\* (p-value = 0.00); 6420 (p-value = 0.05); and 6430 (p-value = 0.05). Finally, habitat 6220\*b also shows differences with habitat 6210\* (p-value = 0.00) and 6430 (p-value = 0.04).

The Ellenberg indicator values of continentality (C) are highest in habitat 6210\* and 6170, while they are lower in habitats 6220\*a, 6220\*b, 6410 and 6430. These differences are significant because habitat 6210\* differs from habitats 6220\*a (p-value = 0.00), 6220\*b (p-value = 0.00), 6410 (p-value = 0.01) and 6430 (p-value = 0.03).

The indicator values of moisture (U) are higher in habitats 6430, 6420 and 6410, while they are lower in habitats 6220\*a, 6220\*b, 6170 and 6210\*. Statistically significant differences are observed between habitat 6170 and 6210\* (p-value = 0.0097), 6410 (p-value = 0.0314;) and 6430 (p-value = 0.0490;). Other significant differences are found between habitat 6210\* and habitats 6220\*a (p-value = 0.00), 6220\*b (p-value = 0.03), 6410 (p-value = 0.02) and 6430 (p-value = 0.04). Finally, the humidity factor differentiates habitat 6220\*a with 6410 (p-value = 0.03), 6220\*a with 6430 (p-value = 0.04), habitat 6220\*b with 6410 (p-value = 0.03), and 6220\*b with 6430 (p-value = 0.03).

The indicator values of substrate reaction (R) show other significant differences between habitat 6170 and habitats 6220\*a (p-value = 0.00); 6220\*b (p-value = 0.00). Analysis shows that habitat 6210\* differs from habitats 6220\*a (p-value = 0.00) and 6220\*b (p-value = 0.00), confirming that the grasslands of this habitat develop on calcareous and basic or sub-acid substrates (Biondi et al., 2015).

The nutrient ecological indicator (N) in wet grasslands 6430 and 6410 differs significantly from other habitats. In particular, habitat 6170 differs from habitat

6220\*b (p-value = 0.00) and habitats 6410 (p-value = 0.03) and 6430 (p-value = 0.05), and also habitat 6220\*a has significant differences to habitats 6410 (p-value = 0.03) and 6430 (p-value = 0.05), and habitat 6220\*b differs from habitat 6430 (p-value = 0.04).

Overall, this analysis showed that the ecological indicator humidity (U) and nutrients (N) are the most important that influence the composition of the species in the analysed dataset, while the factors of light (L) and substrate reaction (R) are less important. This confirms the clear difference between dry and wet grasslands (Table 4.2).

Table 4.2. The mean values of the ecological index, the Mann-Whitney test.

Ecological Temperature (T) index							
	1	2	3	4	5	6	7
2	0.4813	-	-	-	-	-	-
3	0.0045	0.0032					
4	0.0023	0.0015	0.8673				
5	0.8946	1.0000	0.1009	0.0846			
6	0.1009	0.2477	0.0541	0.0644	0.4819		
7	0.8726	0.2025	0.1976	0.1710	0.8673	0.2619	
8	1.0000	0.1710	0.0588	0.0438	0.8673	0.0846	1.0000
Ecological Moisture(U) index							
	1	2	3	4	5	6	7
2	0.0097	-	-	-	-	-	-
3	0.1624	0.0044					
4	0.7778	0.0345	0.3059				
5	0.0889	0.1617	0.0889	0.0710			
6	0.0314	0.0265	0.0314	0.0219	0.5529		
7	0.1617	0.1617	0.1617	0.1544	0.7778	1.0000	
8	0.0490	0.0435	0.0490	0.0376	0.7778	1.0000	1.0000
Ecological Light (L) index							
	1	2	3	4	5	6	7
2	0.0198	-	-	-	-	-	-
3	0.4132	0.0051					

4	0.6041	0.1467	0.0498				
5	0.0987	0.0954	0.1009	0.0848			
6	0.6041	1.0000	0.1300	0.6615	0.4837		
7	0.1579	0.1579	0.1579	0.1562	1.0000	0.6154	
8	0.0561	0.0514	0.0582	0.0453	0.3577	0.1562	0.3577
Ecological Nutrients (N) index							
	1	2	3	4	5	6	7
2	0.1575	-	-	-	-	-	-
3	0.1186	1.0000					
4	0.0039	0.3630	0.9019				
5	0.1752	1.0000	1.0000	1.0000			
6	0.0346	0.0346	0.0346	0.0926	0.4292		
7	0.2133	1.0000	1.0000	1.0000	1.0000	0.3630	
8	0.0562	0.0507	0.0562	0.0424	0.2381	1.0000	0.4292
Ecological Light (C) index							
	1	2	3	4	5	6	7
2	1.0000	-	-	-	-	-	-
3	0.1624	0.0024					
4	0.3563	0.0011	1.0000				
5	1.0000	0.6462	1.0000	1.0000			
6	0.6110	0.0182	1.0000	1.0000	1.0000		
7	0.9082	0.1760	1.0000	1.0000	1.0000	1.0000	
8	0.9082	0.0346	1.0000	1.0000	1.0000	1.0000	1.0000
Ecological Substrate reaction (R) index							
	1	2	3	4	5	6	7
2	1.0000	-	-	-	-	-	-
3	0.0046	0.0053					
4	0.0023	0.0019	1.0000				
5	0.1245	0.1115	0.1245	0.1016			
6	0.1245	0.2204	0.2862	0.2204	0.2204		
7	0.2204	0.2204	0.2204	0.2109	1.0000	0.2362	
8	0.2204	0.2245	1.0000	1.0000	0.2204	1.0000	0.2862

#### 4.2.3. Plant Diversity and Naturalness

The biodiversity values of the grassland habitats compared (Figure 4.5) show that the total Shannon index ( $H^+$ ) is higher in grassland habitats characterized by species with higher humidity values (U), including 6230\*, 6430, 6420 and 6210\*, while the Shannon index ( $H^+$ ) calculated on disturbance and alien species has higher values for the driest grassland habitats, such as 6220\*a and 6220\*b, characterized by species with higher Ellemberg indicator value of temperature (T) and light (L). Equipartition (J) is higher in habitats with higher humidity index (U) (Table 4.3).

The naturalness values (Na) for the different habitat types (Figure 4.6), which take into account the ratio between the values of total  $H^+$  and  $H^+$  without disturbance and alien species, are found to be at a maximum level in habitats 6230\*, 6410, 6430 and 6420, while habitats 6220\*b, 6220\* and 6170 show lower values of naturalness (Table 4.3).

Figure 4.7 shows the contribution to the biodiversity of alien and disturbance species in the different habitat types, taking into account the relationship between the total  $H^+$  value and the  $H^+$  value of the alien and disturbance species. The graph shows that maximum values are found in habitats 6220\*b, 6220\* and 6170, confirming that in these habitats disturbance and alien species contribute more to the value of biodiversity than habitats 6230\*, 6410, 6430 and 6420, which show lower values and are therefore characterised by greater biodiversity (Table 4.3).

Table. 4.3. Values of biodiversity indices for each habitat type ( $H^+$ = Shannon total species, J= Evenness,  $H^+$ sp. dist/alien= Shannon alien species and disturbance, Rs= richness specific), Na= naturalness index

Habitat	$H^+$ sp.tot	$H^+$ sp.dist/alien	J	Rs	Naturalness (Na)
6170	2,30	1,846701803	1,279473	63	0,814911573
6210*	3,47	2,452900912	1,710765	106	0,949365837

6220*b	1,14	1,123209051	0,562131	107	0,805802701
6220*a	1,98	1,725861095	0,891077	168	0,764506818
6230*	2,23	1,052277279	1,265485	58	0,95865655
6420	1,14	0,572814106	0,662192	53	0,890365919
6410	0,55	0,276434591	0,407601	22	0,981513823
6430	1,32	0,629378682	0,717311	69	0,935407052

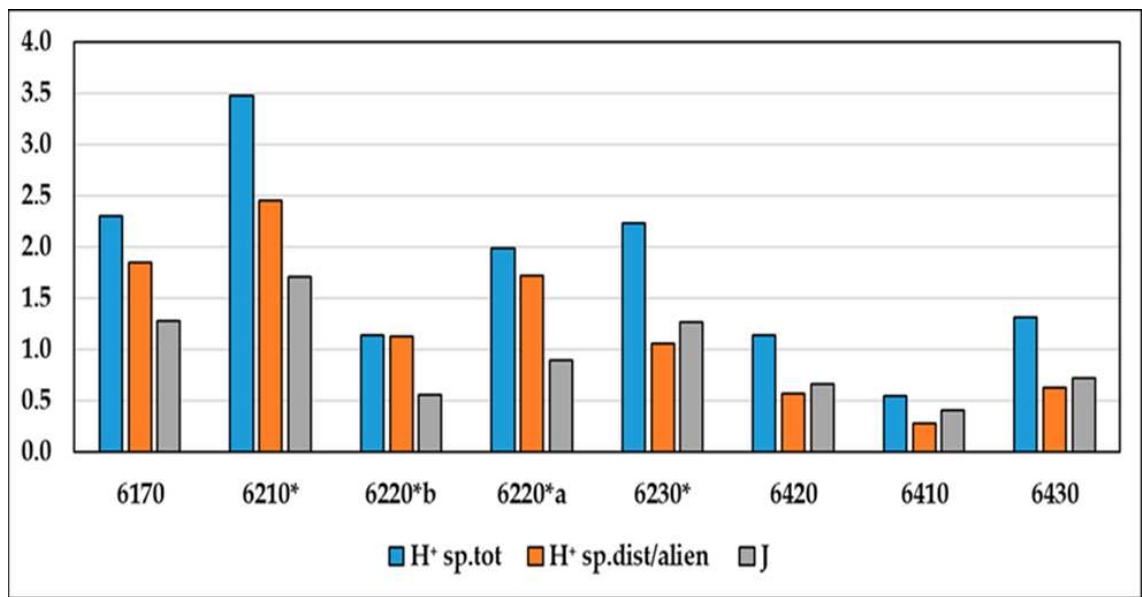


Figura 4.5. Values of biodiversity indices for each habitat type ( $H^+$  = Shannon total species,  $J$  = Evenness,  $H^+$  sp. dist/alien = Shannon alien and disturbance species).

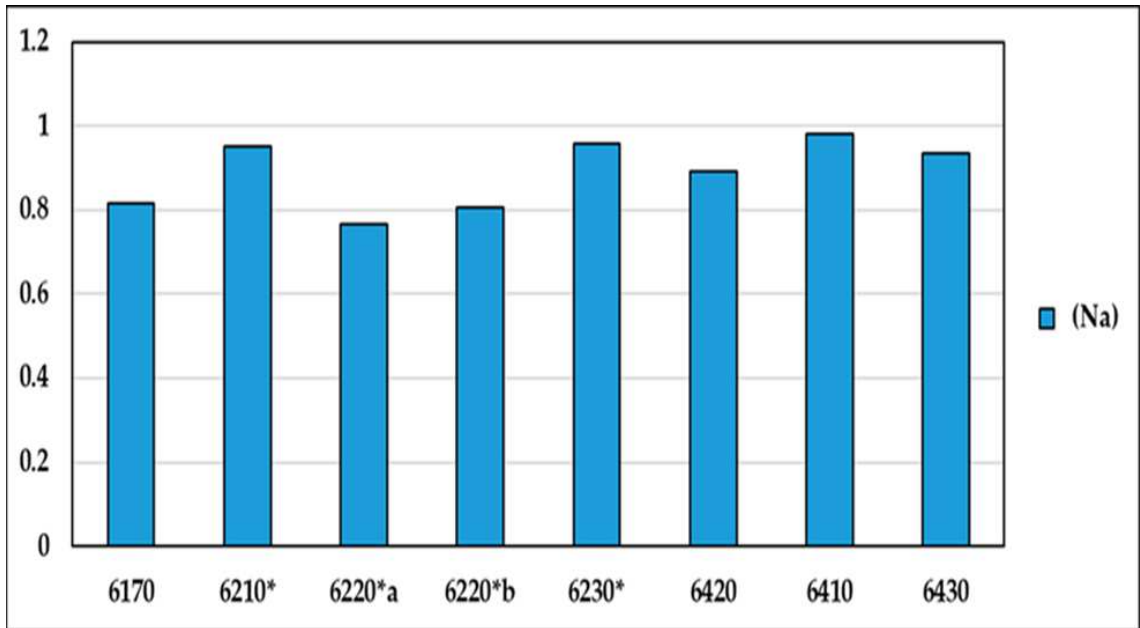


Figura 4.6. Values of the naturalness index (Na) for the various habitat types.

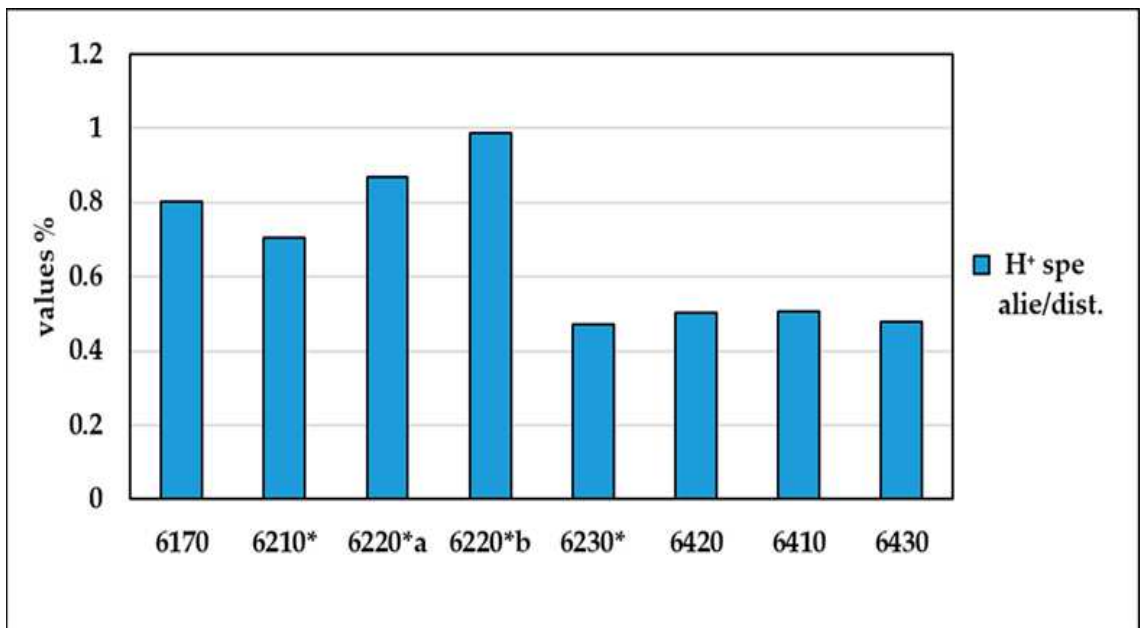


Figura 4.7. Percentage values of the H+ of alien and disturbance species on total biodiversity in the various types of habitat.

#### 4.2.4. Relationship between Diversity and Ellenberg Indicator Values

The linear regression model (Figure 4.8) between the naturalness index (Na) and the ecological temperature indicator (T) shows a significant slope value  $< 0.05$  (0.000046817), correlation index  $r = -0.84$  and regression index  $r^2 = 0.71$

(Table 4.4).

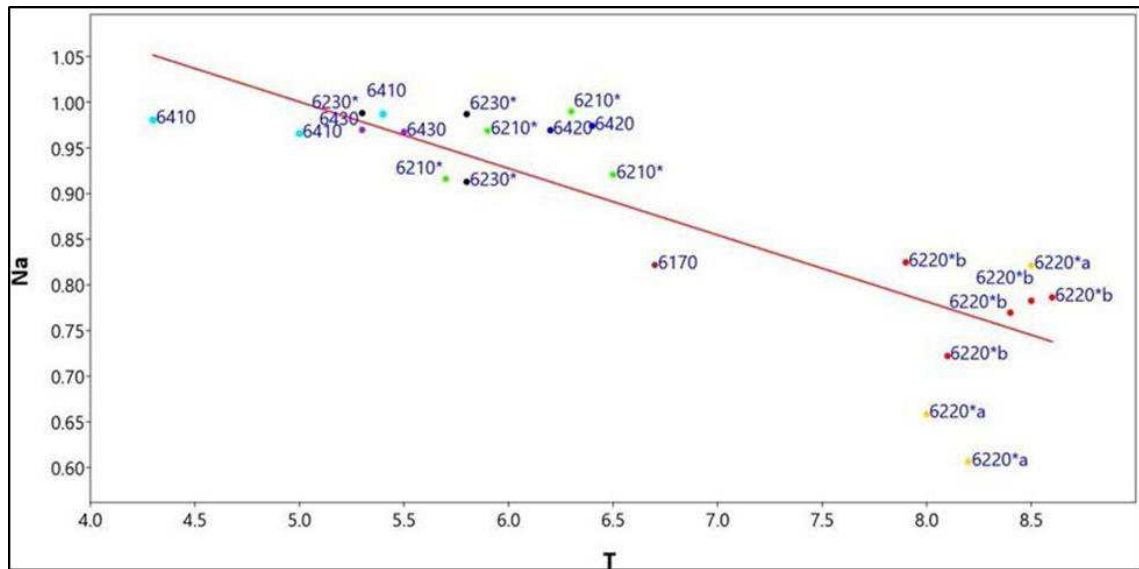


Figura 4.8. Linear regression model between the naturalness index (Na) and the Ellenberg indicator values of temperature (T) of the representative relevés for each habitat type: in yellow 6220\*a, in red 6220\*b, in black 6230\*, in green 6210\*, in brown 6170, in dark blue 6420, in blue 6410, in violet 6230\*.

To check the autocorrelation analyses, the Durbin-Walson statistical test was applied, which assumes a value of 1.82 and a probability of autocorrelation of 32%, while the variance of the residuals and thus the homoscedasticity was calculated using the Breusch–Pagan test, with a value of 3.01 and a probability of homoscedasticity of 0.08%. This analysis shows that habitats' naturalness decreases with increasing temperature, as low-lying habitats are most impacted by anthropogenic activity and are often close to urbanized areas.

Table. 4.4. Linear regression model between the naturalness index (Na) and the values of the ecological temperature factor (T).

Ordinary Least Squares Regression: T-NA			
Slope a:	-0,07293	Std. error a:	0,01019
t:	7,1566	p (slope):	4,68E-07
	1,365	Std. error b:	0,068791
Intercept b:			

95% bootstrapped confidence intervals (N=1999):	
Slope a:	(-0,091163, -0,046703)
Intercept b:	(1,2005, 1,4735)
Correlation:	
r:	-0,84215
r2:	0,70921
t:	-7,1566
p (uncorr.):	4,68E-07
Permutation p:	0,0001
Durbin-Watson Statistic	Breusch-Pagan statistic
1,82	3,01
p (no pos. Autocorr.)	p (homeskedastic)
0,32	0,08

The linear regression model between the naturalness index (Na) and the Ellenberg indicator values of moisture (U) (Figure 4.9) shows a significant slope value  $< 0.05$  ( $0.000000010994$ ), correlation index  $r = -0.87$  and regression index  $r^2 = 0.75$  (Table 4.5). In order to verify the autocorrelation analyses, the Durbin–Watson statistical test was applied, which assumes a value of 1.51 and a probability of autocorrelation of 0.09%, while the variance of the residuals and thus the homeschedasticity was calculated using the Breusch–Pagan test, with a value of 1.40 and a probability of homeschedasticity of 23%. This analysis agrees with the previous one; in fact, it shows that the naturalness of habitats increases with increasing humidity, an ecological indicator that characterizes habitats at higher altitudes with low values of the temperature index, located in the mountain belt where most of the protected areas of the region are located and where the anthropic pressure is lower.

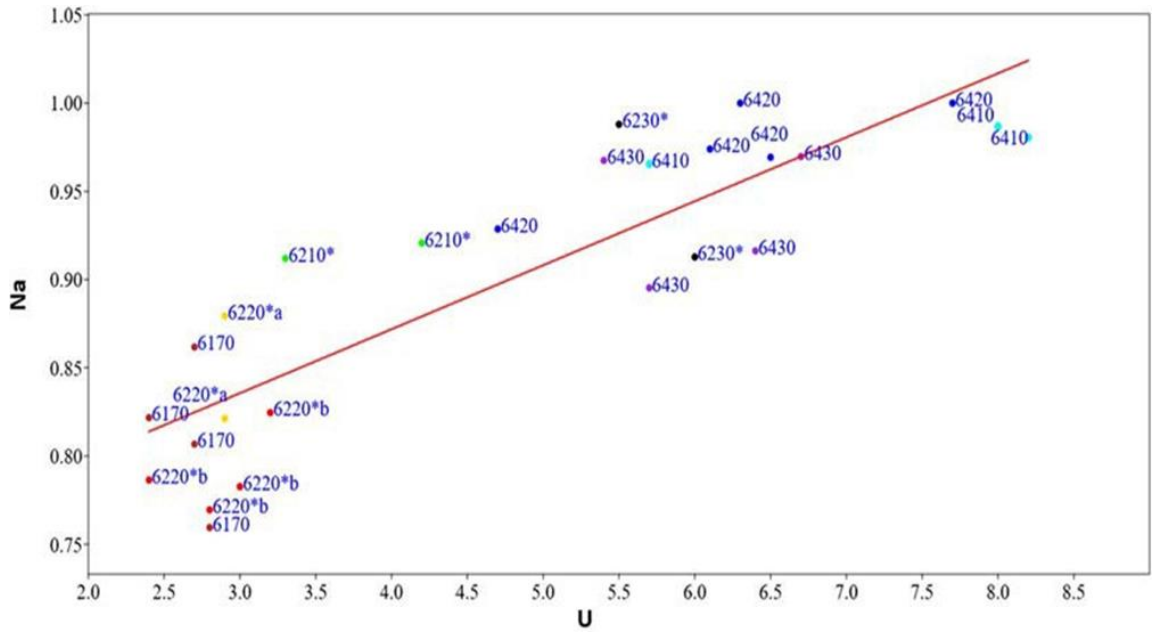


Figura 4.9. Linear regression model between the naturalness index (Na) and the Ellenberg indicator values of humidity (U) of the representative relevés for each habitat type: in yellow 6220\*a, in red 6220\*b, in black 6230\*, in green 6210\*, in brown 6170, in dark blue 6420, in blue 6410, in violet 6230\*.

Table 4.5. Linear regression model between the naturalness index (Na) and the values of the eco-logical factors of Humidity (U) of the representative surveys for each type of habitat.

Ordinary Least Squares Regression: Na-U			
Slope a:	20,687	Std. error a:	2,4385
t:	8,4837	p(slope) :	1,0994E- o8
Intercept b:	-13,842	Std. error b:	2,203
95% bootstrapped confidence intervals (N=1999):			
Slope a:	(16,007, 24,597)		
Intercept b:	(-17,145, - 9,6914)		

Correlation:			
r:	0,86598		
r <sup>2</sup> :	0,74993		
t:	8,4837		
p (uncorr.):	1,10E-08		
Permutation p:	0,0001		
Durbin-Watson Statistic		Breusch-Pagan statistic	
1,7		1,40	
p (no pos. autocorr.)		p (homoedastic)	
0,09		0,23	

### 4.3. Discussion

Cluster analysis on grasslands vegetation allowed us to identify eight different groups attributed to as many habitats of EEC Directive 43/92 in accordance with the interpretation manual (Biondi et al., 2009). These groups are in agreement with the alliances recognized in the phytosociological literature (Biondi et al., 2015; Mucina et al., 2016).

Principal component analysis (PCA) allowed us to recognize three groups in the matrix of phytosociological relevés based on ecological factors: habitats 6210\* and 6170 are characterized by species that prefer base-rich substrates, also showing high values of continentality; habitats 6410, 6430 and 6420 are those with the greatest availability of moisture and nutrients in the soil; and habitats 6220\*a and 6220\*b are the most thermophilous ones as they are located at low altitudes in purely Mediterranean bioclimatic conditions (Spampinato et al., 2018).

Box plots of Ellenberg indicator values confirm ecological differences between habitats. In fact, the box plots show a significant difference for the continentality indicator between habitat 6210\* and the other habitats, which is related to the

fact that the typical vegetation of this habitat, referring to the class *Festuco valesiacaе-Brometea erecti* Br.-Bl. & Tüxen ex Br.-Bl. 1949, characterizes the continental grasslands of Central and Eastern Europe, which develop in areas with low annual rainfall, in agreement with Biondi et al. (2015). This habitat, in the analysis carried out, is similar to 6170, characterized by the vegetation of the *Ranunculo pollinensis-Nardion strictae* Bonin 1972 alliance distributed in the mountain range on calcareous or dolomitic substrates and compacted soils rich in organic substances, often in stations characterized by prolonged snowfalls which guarantee greater soil humidity (Biondi et al. 2012).

The high biodiversity values of habitats 6230\*, 6430, 6420 and 6210\* are associated with the high value of the Ellenber indicator moisture value (U) and this is consistent with (Chytrý et al., 2015), which emphasises high biodiversity values for semi-natural wet grassland habitats.

The ecological factors that contribute to the differentiation of habitat types are mainly temperature

(T) and humidity (U), which play an important role in defining the floristic composition of the identified grassland habitats. Indeed, grassland habitats are widespread in the region from sea level to the mountain belt and occupy a wide altitudinal range, where temperature and humidity factors play a fundamental role in the ecological characterisation of the different habitat types.

The nutrient factor (N) showed significant differences between the findings belonging to habitat type 6430, characterized by nitrophilous communities, and those belonging to groups 6220a and 6220b; this could be due, in agreement with the evidence of other studies (Loiseau et al., 2005; Rodriguez- Iturbe et al., 1999], to a higher soil moisture influencing nutrient availability. In fact, habitat 6430 presents higher humidity values, but, above all, high values of naturalness and diversity are characterized by a variable phytocoenosis consisting also of species from other communities (Myśliwy et al., 2023), some of which are rare and threatened, which,

in agreement with other studies, guarantees a greater conservation value for the habitat (Oroiano et al., 2019).

Overall, the analysis performed, in agreement with some studies (Acic et al., 2015), shows that the most important ecological gradients influencing the diversity of grassland vegetation are moisture and nutrients. Furthermore, the results show that grassland habitats characterised by species with higher moisture values are more natural.

This is evident in habitat 6410, of grasslands with high floristic diversity and a very broad ecology developing on mesotrophic, oligotrophic, moist and cool soils (Biondi et al., 2015, Utratna et al., 20011). The vegetation of this habitat is linked to the water table, which determines the differentiation of species in these environments (Chytrý et al., 2015).

A Mediterranean, thermo-xerophilous vegetation characterizes the 6220\*a and 6220\*b habitat types; they grow at low altitudes in the driest stations where ecological factors such as temperature and brightness are greater and therefore reduce water availability within the soil (Spampinato et al., 2018). These habitats are the least natural, as intensive land use at low altitudes, associated with fires, soil disturbance and anthropisation, plays a fundamental role in structuring grassland plant communities (Spampinato et al., 2018; Foster et al., 2016), affecting diversity and naturalness and causing changes in biodiversity, both in terms of a reduction in species richness and the replacement of typical species by disturbed ones (Facioni et al., 2012; Lotze et al., 2006).

Many of the species typical of grasslands are threatened with extinction (Lotze et al., 2006), and the decrease in surface area and quality shows that grasslands are now among the most endangered European habitats (veen et al., 2009; Willems et al., 1993).

#### 4.4. Conclusions

Our study shows that the plant assemblage composition is the best tool to characterize grassland habitats from an ecological and typological point of view, indeed the analysis of grassland vegetation can provide information on ecological factors that influence the species composition and distribution of plant communities. In particular, the species diversity indices (Shannon, Evenness) applied in this study show that naturalness is greater in wet than dry grasslands. However, knowledge of land use and the environmental context of ecosystems varies due to the interaction between the effects of human activity and other environmental factors. Ecological indicators, such as those used here, can therefore be equally effective to define patterns and processes of change and are a useful tool for identifying areas of high natural value. To counter the continuing loss of grasslands and their typical species, it is important to understand the causes of vegetation change, which are likely to differ between different habitat groups. Therefore, the results of this study showed that the diversity and naturalness indices applied, together with the assessment of ecological factors, are useful tools for implementing both an appropriate interpretation and a management and conservation strategy under EEC Directive 43/92. Understanding the ecological features and assessing habitat biodiversity allows us to interpret evolutionary dynamics and predict future scenarios due to climate change (Henle et al., 2013; Hoffmann et al., 2018).

**Supplementary Materials:** The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/land13060719/s1>, Table S1: matrix of phytosociological relevés; Table S2: Relevés' dispersion biplot on PCA in relation to ecological factor; Table S3: The mean values of the ecological index and the non-parametric Kruskal–Wallis test; Table S4: Values of biodiversity indices for each habitat type ( $H^+$  = Shannon total species,  $J$  = Evenness,  $H^+$  sp. dist/alien = Shannon index of alien and disturbance species); Table S5: Values of the naturalness index ( $N_a$ ) of habitat types; Table S6: Percentage values of the  $H^+$

index of alien and disturbance species on total biodiversity in the various types of habitat; Table S7: Linear regression model between the naturalness index (Na) and the values of the ecological temperature factor (T); Table S8: Linear regression model between the naturalness index (Na) and the values of the ecological factors of humidity (U) of the representative surveys for each type of habitat.

**Author Contributions:** Conceptualization, A.M., C.M.M. and G.S.; methodology, A.M.; software, A.M.; analysis, A.M.; data curation, C.M.M.; writing—original draft preparation, A.M. and C.M.M.; writing— review and editing, A.M., C.M.M. and G.S.; visualization, G.S.; supervision, G.S. All authors have read and agreed to the published version of the manuscript.

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**CHAPTER 5. Fragmentation, ecological assessment  
and diversity of EU forest habitat types: a case study  
in the Calabria region oak woodlands (Southern Italy)**

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## Abstract

Habitat fragmentation is a major cause of biodiversity loss and alteration of the structure and function of habitat types. In this study, after characterising forest habitats by analysing plant assemblages and some ecological indicators, we aim to assess the conservation status of these habitats by analysing fragmentation and naturalness. As a case study, we considered the oak forests of Calabria, a predominantly mountainous region in southern Italy, characterised by extensive and diverse forest formations in which species of the genus *Quercus* play an important structural and ecological role. The analysis of forest habitats involved examining the structure and species composition of the vegetation using the phytosociological method. At the same time, the ecological characteristics were defined using the Ellenberg-Pignatti indicators. The species-relevés matrix subjected to cluster analysis and principal component analysis (PCA) allowed the definition of six groups of forest communities attributed to as many habitats of the EEC Directive 43/92: 91AA\*: Eastern white oak woods; 9340: *Quercus ilex* and *Quercus rotundifolia* forests; 91Moc: Pannonian-Balkan turkey oak-sessile oak forests dominated by *Quercus petraea* subsp. *austrotyrrhenica*; 91Mob: Pannonian-Balkan turkey oak-sessile oak forests dominated by *Quercus frainetto* Ten.; 91Moc Pannonian-Balkan turkey oak-sessile oak forests dominated by *Quercus cerris* L.; 9330: *Quercus suber* forests. The analysis of the ecological indicators shows that temperature (T) and humidity (U) are the most statistically significant factors in differentiating the different habitat types. The analysis of diversity, which also aims to assess the naturalness of plant communities using the Shannon and Evenness indices, showed that it is strongly correlated with the ecological indicators temperature (T) and humidity (U). The analysis of landscape parameters showed that the most fragmented and easily drilled habitats are 91AA\* and 9330 and that there is a correlation between naturalness and patch density, a parameter expressing the number of patches per

unit area. The study of ecological characteristics, correlated with biodiversity and landscape indices, contributes to the characterisation of oak woodland habitats and provides guidelines for implementing active conservation measures for these habitats.

**Keywords:** Directive Habitat types; Biodiversity; Fragmentation; Naturality

## **5.1. Introduction**

Landscape structure, often described by the composition amounts of different habitat types on the landscape and by configuration, as size, shape and spatial arrangement of individual habitat patches (Fahrig et al., 2011), play a significant role in guiding ecological processes (Forman and Godron 1986; Turner et al. 1989; O'Neill et al. 1988; Gardner and O'Neill 1991; Gustavson and Parker 1992). For the long-term conservation of biodiversity in the face of global climate change, it is essential to define and assess anthropogenic disturbances that impact ecosystems and landscape structure, such as the invasion of alien species, land use change, and alteration of natural and semi-natural habitats. In particular, the fragmentation of habitat into smaller and isolated patch affects the migration and colonization potential of species at the landscape level (Ahlqvist and Shortridge 2010; Ibáñez et al. 2014) and poses a serious threat to the conservation of biological diversity (Henle, 2004; Krauss et al., 2004; Kolb & Diekmann, 2005; Lindenmayer & Fischer, 2007).

Today, numerous studies analyse the relationship between biodiversity and landscape structure (Bissonette, 1997; Li and Reynolds 1994, Hunter 1990; Gustafson 1998 Dufour et al., 2006; Schindler et al., 2008, Bailey et al, 2007). In fragmented habitats, there is a decrease in their quality that can be measured by assessing the assemblage of plant species (Powell and Powell, 1986; Canterbury et al., 2000), which are often incorporated into national and supranational regulations to monitor the ecological integrity of ecosystems (Brooks et al., 1998). Vegetation studies are important tools for ecology, biodiversity, nature conservation and environmental monitoring (Novák et al., 2020). Species are a

useful vector of ecological information for identifying and describing vegetation patterns and interpreting their characteristics and dynamics (Mucina et al. 2016). The fragmentation of natural habitats impacts plant communities' structure and species composition, exposing them, due to expanding margins, either directly or indirectly, to anthropogenic disturbances. This leads to the disappearance of ecologically demanding species and the emergence of synanthropic species. As highlighted by various authors, the invasion of synanthropic and alien species results in severe alterations on ecosystems by varying physical processes (Gordon 1998; Gritti et al. 2006; Macdonald et al. 1989) and species composition and diversity (Alvarez and Cushman 2002; Crooks 2002; Vitti et al. 2020). Several studies (Cantarello & Newton, 2008; La Mela Veca et al., 2006; Pavone et al., 2007; Shaw & Wind, 1997; Velázquez et al., 2010), highlight that the habitats of community interest under EEC Directive 43/92, are useful for defining environmental diversity and interpreting the naturalistic value of the landscape.

In this study, we investigate the relationship between landscape structure parameters and habitat naturalness by comparing the analysis of habitat fragmentation and diversity, taking into account the ecological characteristics of plant communities. The forest formations characterized by the dominance of species of the genus *Quercus* in the Calabria Region, for which an updated distribution map is available thanks to the recent publication of Carta Natura (Aramini et al. 2023), were used as a case study. Oak forests are an important component of the mediterranean forest ecosystems that would potentially occupy a wide belt from sea level to the mountain range Quézel & Médail, 2003). The forest vegetation of Calabria, a region in the center of the Mediterranean, is quite well known thanks to various studies that have examined its ecological, floristic and structural characteristics. (Avena & Bruno, 1975; Bonin & Gamisans, 1976; Barbagallo et al., 1982; Schneider R. & Sutter R., 1982; Signorello, 1984, 1986; Abbate et al., 1987; Spampinato, 1990; Abbate & Paura, 1995; Scelsi & Spampinato, 1996; Brullo et al, 1999b, 2001; Maiorca & Spampinato, 1994, 1999;

Brullo & Spampinato, 1997, 1999, 2001; Caminiti et al., 2002; Maiorca et al., 2003, 2006, 2008; Mercurio & Spampinato, 2003, 2006; Biondi et al., 2003; Cameriere et al., 2003; Caneva et al., 2004; Maiorca et al., 2006; Mercurio et al., 2007, 2009; Spampinato et al., 2008; Musarella & Spampinato, 2012a,b; Musarella et al., 2012; Morabito et al.; 2023). Other authors have dealt only marginally with the oak forests of Calabria, limiting themselves to reports and/or considerations on the distribution of various oak species (Caldart, 1932, 1935; Avolio, 1994, 2003; Caridi & Iovino, 2002; Cameriere et al., 2004; Musarella & Tripodi, 2004).

The specific objectives of this study are: (i) to identify the different habitat types of ECC Directive 43/92 dominated by species of the genus *Quercus* through species assemblages; (ii) to analyse habitat fragmentation at patch scale; (iii) to define the main ecological factors responsible for the variation in species composition of habitat vegetation; (iv) to assess the biodiversity and naturalness of the different habitat types; and (v) to assess the relationships between species diversity of a habitat and ecological factors that influence it. Overall, the study aims to provide useful analytical tools to assess the conservation status of habitats and adopt effective management measures to contrast degradation and fragmentation processes.

## 5.2. Materials and methods

### 5.2.1. Study Area

The study was conducted on oak forests growing in Calabria (Figure 5.1.), a southern Italian region located in the centre of the Mediterranean. The region has a strong climatic gradient due to the presence of the



Figura 5.1. In red the study area represented by Calabria.

southern Apennine Mountain range that runs through the entire region, with heights reaching almost 2000 m, resulting in the presence of two distinct bioclimatic regions: The Mediterranean region from sea level up to about 1000 m and the Temperate region in the mountain belt above 1000 m.

Starting from the habitat mapping of Carta Natura of the Calabria Region (Aramini et al.; 2023), habitats characterized by the dominance of species belonging to the genus *Quercus* were considered.

#### 5.2.2. Vegetation analysis

The analysis of oak woodland habitats was based on vegetation relevés carried out in 2018-2022 using the Zurich-Montpellier school phytosociological method (Braun-Blanquet, 1964), which lists tracheophyte taxa present in different vegetation layers and their abundance/dominance within a homogeneous plant population. In order to capture environmental heterogeneity and facilitate a comprehensive analysis of the forest ecosystem, we carried out the surveys in a stratified manner within the areas that the nature map showed to be affected by forests dominated by species of the genus *Quercus*. 59 unpublished georeferenced relevés were carried out with 237 species (Supplementary Materials S14). The matrix of phytosociological relevés was subjected to multivariate analysis to define homogeneous groups on an effective statistical basis. To this end, the abundance-dominance values of each species reported with the Braun-Blanquet scale were converted with the scale of numerical values proposed by Van der Mareel (1979). Raw data was organized using Microsoft Excel 2010 software.

To interpret the habitats, the directive ECC 43/92 we use the manuals for the interpretation of habitats of community interest in Italy and Europe (Biondi et al., 2009; EC/European Commission, 2013) and manual for habitat monitoring (Angelini et al., 2016).

The ecological characteristics of the habitats identified by the statistical analysis

were highlighted using the values of the Pignatti-Ellenberg ecological indicator in the version modified by Pignatti (2017a; 2017b, 2018) for the Italian flora. The ecological indicator under consideration were continentality (C), substrate reaction (R), temperature (T), moisture/water availability (U), light (L) and soil nitrogen (N). The PCA was performed considering the Pignatti-Ellenberg ecological indicator assigned to each species in the survey matrix to show the distribution of ecological traits

### 5.2.2. Diversity Analysis

Habitat diversity was evaluated with Shannon's index (Shannon and Weaver, 1949) applied to phytosociological relevés of vegetation:

$$H^+ = - \sum_{j=1}^s p_i \log p_i$$

where  $p_i$  = coverage percentage of the  $i$ th species compared to the entire community;

$S$  = number of species

This index considers the diversity of species and relative importance of each habitat. We also calculate the evenness ( $J$ ) of each habitat type, which expresses the degree of homogeneity with which individuals are distributed among the different species that make up a community.

$$J = H/H_{max}$$

$$H_{max} = \ln S$$

Where  $H_{max}$  is the maximum level of diversity possible within the habitat type. This index depends on the abundance and uniform distribution of species (Lloyd & Ghelardi 1964; Pielou 1966). Evenness ( $J$ ) varies between 1 when the species of the community are equally distributed, 0 when only one species is present.

The  $H^+$  index, also allows us to assess Naturalness ( $Na$ ), however, unlike other

studies (Grunewald and Schubert 2007, Pinna et al., 2019, 2015b, Caldaresi et al., 2023), in addition to considering diversity due to native and alien species, to the latter we also considered those related to anthropogenic disturbance (Morabito et al., 2024)

$$Na = H^+ (\text{without alien and disturbing plant species}) / H^+$$

The Na index ranges from 0 to 1, where 0 indicates that plant diversity consists entirely of alien and disturbance species, while 1 indicates the absence of the latter in the plant communities (Grunewald and Schubert 2007; Pinna et al., 2019, 2015b; Caldaresi et al., 2023). Alien species were identified with the "Portal to the Flora of Italy" (2023), while disturbance species were identified by consulting the "Prodrome of Italian Vegetation," but also other studies (Brullo et al., 2001, Biondi et al., 2015). In particular, we considered disturbance species those characteristic of anthropogenic vegetation classes were: *Stellarietea mediae* Tüxen, Lohmeyer & Preising ex Von Rochow 1951, (vegetation of mainly annual, nitrophilous, ruderal weeds), *Gallio aparines- Urticetea dioicae* Passarge ex Kopecký 1969 (nitrophilous vegetation, mainly consisting of perennial plants, linked to mesophilous to more or less hygrophilous environments by edaphic humidity or shading) and *Filipendulo ulmariae-Convolvuletea sepium* Géhu & Géhu-Franck 1987 (Vegetation of perennial megaforbs, of humid environments, on eutrophic to mesotrophic soils).

### 5.2.3. Statistical Analysis

The R Core Team 4.1.1 (2021) software was used to classify the phytosociological relevés matrix using hierarchical cluster analysis. R software was also used to test the significance of the differences observed between the different habitat groups for the ecological factors using the non-parametric Kruskal-Wallis test and to create box plots.

Principal Component Analysis (PCA) and dispersion biplot of habitat relevance were performed using the PAST 4.13 software referring to Pignatti-Ellenberg

indicator values, and Durbin-Watson and Breusch-Pagan tests were applied to the linear regression model (Farebrother, R.W. 1980, Rousseeuw, P.J. & van Driessen, K. 1999, Warton et al., 2006, Wooldridge, J.M. 2012).

#### 5.2.4. Landscape metrics

Landscape metrics are tools for statistically measuring and describing the spatial-temporal patterns and structures of a landscape. Numerous metrics exist in the literature to assess landscape structure (Mc Garigal et al., 2002). Landscape metrics are useful for understanding the dynamics between anthropogenic interaction with natural habitats and anthropogenic land use, as well as for assessing their fragmentation [Ramachandra et al., 2012]. Because class-level parameters are better correlated with ecological response variables than landscape-level parameters (Tischendorf 2001; Luck and Wu 2002), fragmentation in this study was analyzed at the class level using FRAGSTATS software (Version 4.2.1) (McGarigal and Ene 2015; McGarigal et al., 2012], created to calculate many parameters of landscape fragmentation (McGarigal et al., 2002, Paudel and Yuan, 2012, Lamine et al., 2017; Singh et al., 2017).

In this study, we considered some categories of landscape parameters to assess habitat fragmentation useful for quantifying landscape configuration and composition. The shape index (SHAPE) measures the complexity of the patch shape compared to a standard (square) shape of the same size. This shape index is widely applied in ecological landscape research (Forman and Godron 1986). In ecological landscape research, patch forms are often characterized by the fractal dimension of the object (Ripple et al. 1991). The fractal dimension (FRAC) quantifies the degree of complexity of flat shapes. The patch number (NP) of a given habitat type is a simple measure of its subdivision or fragmentation, while the patch density (PD) expresses the number of patches per unit area. We also considered the mean patch size (AREA\_MN) at the class level, which depends on the number of patches in the class and the total area of the class and the total area of the habitat in hectares (SURFACE).

The formulas of the parameters considered to quantify the configuration and composition of the landscape are reported below:

$$\mathbf{NP} = \mathbf{n}_i$$

**NP** = patch number;  $n_i$  = Number of patches in the patch type landscape (classe)<sub>i</sub>.

$$\mathbf{PD} = \frac{\mathbf{n}_i}{\mathbf{A}} (10.000)(100)$$

**PD** = patch density;  $n_i$  = number of patches in the patch-like landscape (class) <sub>i</sub>;  
**A** = total landscape area (m<sup>2</sup>).

$$\mathbf{FRAC} = \frac{2 \ln(.25 \mathbf{p}_{ij})}{\ln \mathbf{a}_{ij}}$$

**FRAC** = Fractal dimension index;  $p_{ij}$  = perimeter (m) of patch <sub>ij</sub>;  $a_{ij}$  = area (m<sup>2</sup>) of patch <sub>ij</sub>.

$$\mathbf{SHAPE} = \frac{.25\mathbf{p}_{ij}}{\sqrt{\mathbf{a}_{ij}}} \sqrt{\mathbf{a}_{ij}}$$

**SHAPE** = SHAPE index;  $p_{ij}$  = perimeter (m) of the patch <sub>ij</sub>.;  $a_{ij}$  = area (m<sup>2</sup>) of the patch <sub>ij</sub>.

### 5.3. Results

#### 5.3.1. Habitat types

The classification resulting from the Cluster Analysis of the Quercus-dominated woods relevés x species matrix produced the dendrogram in Figure 5.2, where the abscissa shows the distinctive number of relevés, while the ordinate shows the scale of similarity. The first subdivision is at a similarity level of 1.4; the subsequent subdivisions (similarity coefficients 1.3, 1.2, 1.1, and 1.0) show six different oak relevés groups.

According to the European and to Italian interpretation manual of the Habitats Directive 92/43/EEC (EC/European Commission, 2013; Biondi et al, 2009) and

considering diagnostic species, the group of relevés 1-10, is to be referred to priority habitat g1AA\*: Eastern white oak woods; the group 11-28 to habitat 9340: *Quercus ilex* and *Quercus rotundifolia* forests, the group 29-36 to habitat g1Moc: Pannonian-Balkanic turkey oak-sessile oak forests characterized by the dominance of *Quercus petraea* subsp. *austrotyrrhenica*, the group 37-41 to habitat g1Mob: Pannonian-Balkanic turkey oak-sessile oak forests dominated by *Quercus frainetto*, the group 42-46 is framed in habitat g1Moc Pannonian-Balkanic turkey oak-sessile oak forests dominated by *Quercus cerris*, and finally group 47-59 belongs to habitat 9330: *Quercus suber* forests.

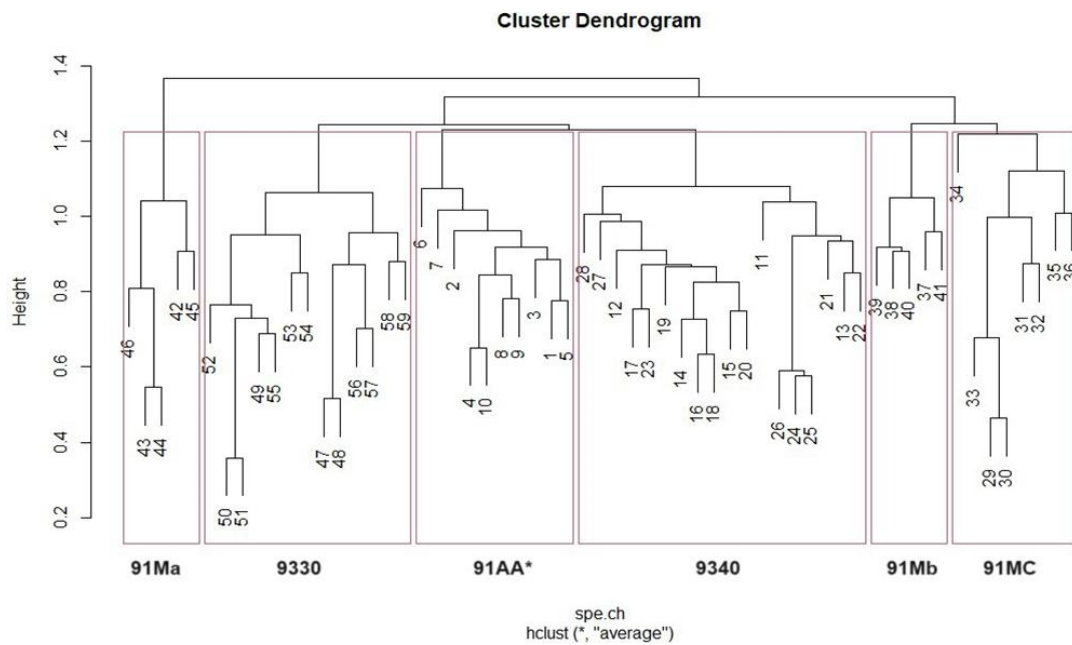


Figura 5.2. Hierarchical cluster analysis dendrogram of vegetation data from oak woodland habitat types (Chord as distance coefficient and UPGMA as clustering algorithm) showing 6 habitat types: g1AA\*: Eastern white oak woods; 9330: *Quercus suber* forests; 9340: *Quercus ilex* and *Quercus rotundifolia* forests; 91Moa Pannonian-Balkanic turkey oak- sessile oak forests dominated by *Quercus cerris*; 91Mob: Pannonian- Balkanic turkey oak-sessile oak forests dominated by *Quercus frainetto*; 91Moc: Pannonian-Balkanic turkey oak-sessile oak forests dominated by *Quercus petraea* subsp. *austrotyrrhenica*;

### 5.3.2. Ecological Analysis

The PCA, performed taking into account the value of the Pignatti-Ellenberg ecological indicator, showed the distribution of relevés based on ecological characteristics of the habitat and explained 76.7% of the total variation in the dataset with the first two components, with PC1: 55.2% and PC2: 21.6% (Figure 5.3., Table 5.1).

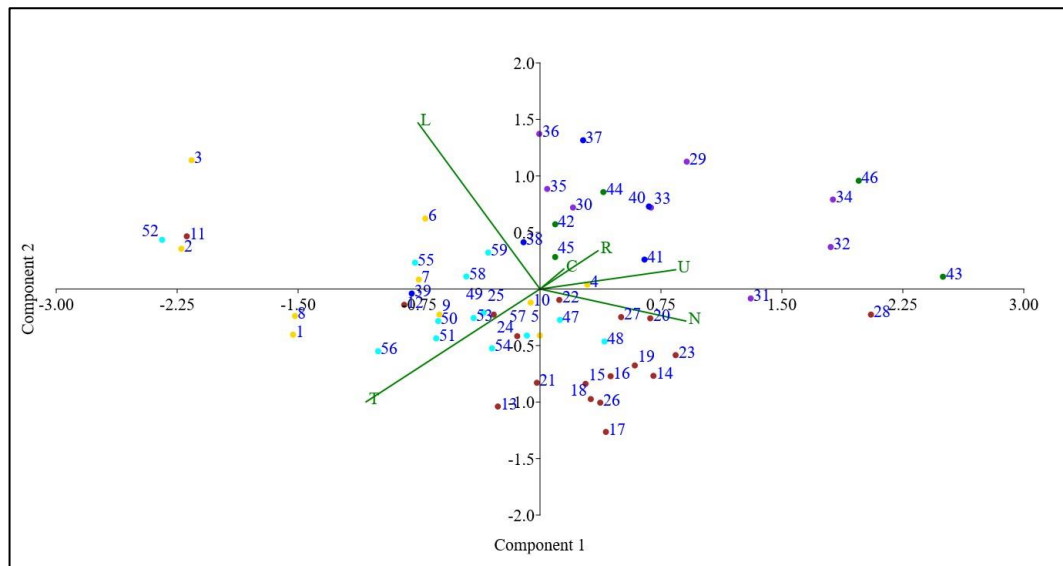


Figura 5.3. Dispersion biplot of habitat relevés related to PCA referring to Ellenberg-type indicator values. The numbered points correspond to the reliefs of the various habitat types: purple: habitat 91Moc; brown: habitat 9340; green: habitat 91Mo; blue: habitat 91Mob, yellow: habitat 91AA\*, light blue: habitat 9330. The green lines indicate the direction of maximum correlation of the values of the Ellenberg-type indicator values (U = humidity; C = continentality; R = substrate reaction; T = temperature; L = light; N = nutrients).

Table 5.1. Total change in the dataset with principal components.

Principal component	Eigenvalue	% variance
1	1,01666	55,2
2	0,3973	21,6
3	0,304739	16,5
4	0,0867941	4,7
5	0,0204816	1,1
6	0,0174843	0,9

The PCA highlights the different habitat groups. Habitats 91Moa, 91Mob, 91Moc are mainly related to the ecological factors of soil moisture (U) and nitrogen (N); these are habitat types located in the upland belt, typical of the temperate or sub-Mediterranean macro-bioclimate, where there is greater water availability and soils are more developed and structured. Another group brings together the relevés of habitats 91AA\*, 9340 and 9330, arranged along ecological gradients of temperature (T) and light (L), as is typical of habitats in the Mediterranean bioclimatic belt.

The ecological characteristics of the six identified habitats are shown in Figure 5.4, Table 5.2. using boxplots with the ecological indicator values of moisture (U), temperature (T), light (L), soil nitrogen (N), continentality (C) and substrate reaction (R). The Kruskal-Wallis test was applied to quantify the separability of the various habitat groups considering the mean values of the ecological index.

The ecological characteristics of the six identified habitats are shown in Figure 5.5 using boxplots with the ecological indicator values of moisture (U), temperature (T), light (L), nutrients (N), continentality (C) and substrate reaction (R). The Kruskal-Wallis test was applied to quantify the separability of the various habitat groups considering the mean values of the ecological index.

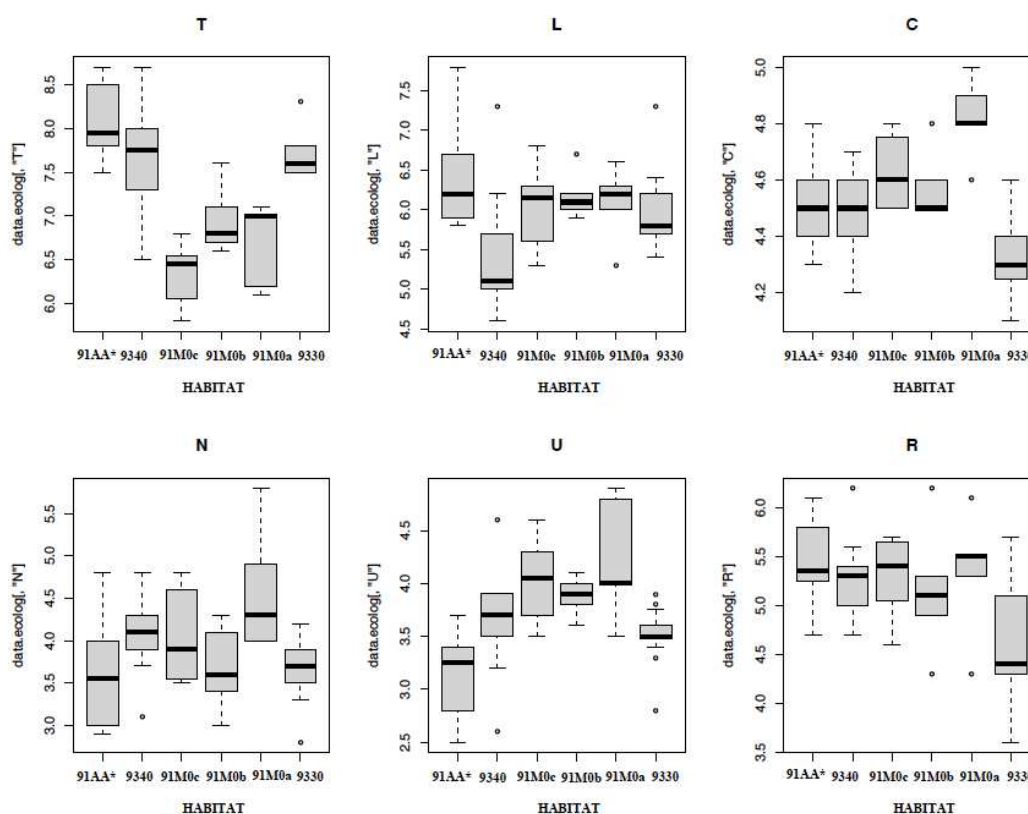


Figura 5.4. Box showing the Ellenberg indicator values for each habitat type: 91AA\*: Eastern white oak woods; 9340: *Quercus ilex* and *Quercus rotundifolia* forests; 91M0c: Pannonian-Balkan turkey oak-sessile oak forests dominated by *Quercus petraea* (Matt.) Liebl. subsp. *austrotyrrhenica* Brullo, Guarino & Syracuse; 91M0b: Pannonian-Balkan turkey oak-sessile oak forests dominated by *Quercus frainetto* Ten.; 91M0c Pannonian- Balkanic turkey oak-sessile oak forests dominated by *Quercus cerris* L.; 9330: *Quercus suber* forests.

Table 5.2. The mean values of the ecological index, the Kruskal-Wallis. test.

Significant Differences in the Ecological Light Index (L) between Habitat Groups			
Habitat groups	Difference	p-value	Significance
1, 2	26,63889	0.0002	***
2, 3	-20	0.0268	*
2, 4	-24,54444	0.0200	*
2, 5	-22,58889	0.0402	*
2, 6	-16,85043	0.0289	***
Significant Differences in the Ecological Continentality Index (C) between Habitat Groups			
Habitat groups	Difference	p-value	Significance

1, 5	-22,8	0.0284	*
1, 6	18,49231	0.0165	*
2, 5	-24,54444	0.0054	**
2, 6	16,74786	0.0101	*
3, 6	28,44231	0.0001	***
4, 6	24,69231	0.0081	**
5, 6	41,29231	0.0000	***

Significant Differences in the Ecological Temperature Index (T) between Habitat Groups

Habitat groups	Difference	p-value	Significance
1, 3	39,7625	0.0000	***
1, 4	28,85	0.0003	***
1, 5	34,55	0.0000	***
2, 3	28,92361	0.0001	***
2, 4	18,01111	0.0354	*
2, 5	23,71111	0.0015	**
3, 6	-28,96635	0.0000	***
4, 6	-18,05385	0.0498	*
5, 6	-23,75385	0.0025	**

Significant Differences in the Ecological Moisture Index (U) between Habitat Groups

Habitat groups	Difference	p-value	Significance
1, 2	-21	0.0017	**
1, 3	-33,7875	0.0000	***
1, 4	-32,1	0.0004	***
1, 5	-37	0.0000	***
3, 6	21,11058	0.0077	**
5, 6	24,32308	0.0092	**

The ecological light factor (L) is highest in habitat 91AA\*, while lower values are observed in habitat 9340; significant differences for this ecological indicator are found between habitat 91AA\* and habitat 9340 (p-value = 0.000) other significant differences are observed between habitat 9340 and habitats 91Moc (p-value = 0.02), 91Mob (p-value = 0.04) 91Moa (p-value = 0.04) and 9330 (p-value = 0.02).

The ecological temperature indicator (T) is highest in habitats 91AA\* and 9330

and lowest in habitats 91Moa, 91Mob and 91moc. Statistically significant differences are found between habitat 91AA\* and habitats 91Moc (p-value = 0.0002); 91Mob (p-value = 0.0268) and 91Moa (p-value = 0.02). Finally, habitat 9330\* also shows differences with habitat 91Moc (p-value = 0.0000), 91Mob (p-value = 0.04) and habitat 91Moa (p-value = 0.0025).

Continentality indicator (C) are highest in habitats 91Moc, 91Mob and 91Moa, while they are lowest in habitats 9330 and 9340. There are significant differences between habitat 9330 and habitats 91Moc (p-value = 0.0001), 91Mob (p-value = 0.0081), 91Moa (p-value = 0.0000). Finally, habitat 9340 also shows minimal differences with habitat 91Moa (p-value = 0.0284).

Moisture indicator (U) values are highest in habitats 91Moc, 91Mob and 91Moa, while they are lowest in habitats 91AA\* and 9330. Statistically significant differences are observed between habitats 91AA\* and 91Moc (p-value = 0.0002), 91Mob (p-value = 0.0314;), 91Moa (p-value = 0.0490;) and 9340 (p-value = 0.0017).

Other significant differences were found between habitat 9330 and habitats 91Moc (p-value = 0.000) 91Moa (p-value = 0.0092).

Overall, this analysis showed that the ecological indicators of moisture (U), continentality (C), temperature (T) and light (L) are the most important in characterising species composition in the analysed dataset.

### 5.3.3. Diversity and naturalness of habitats

The analysis of the biodiversity of oak woodland habitats (Figure 5.5.), shows maximum values of the total Shannon index ( $H^+$ ) and of equiriparation (J) in habitats 91Moc, 9330, 9340, while minimum values are found in habitats 91Moa and 91Mob. Figure 5.6 shows the naturalness values of the habitats, which take into account the ratio between the values of total  $H^+$  and  $H^+$  without disturbance and exotic species. Maximum values are found in habitats 91Moa, 91Mob and 91Moc while habitats 9330 and 91AA\* show lower naturalness values and

therefore a higher contribution to the total disturbance species diversity for the habitat (Table 5.3).

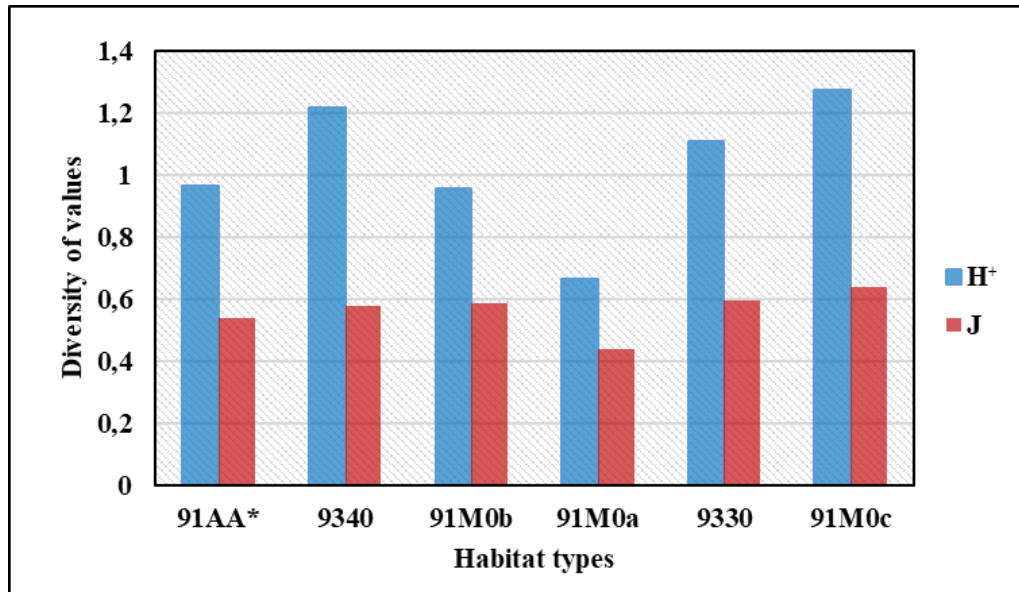


Figura 5.5. Values of the biodiversity indices of the different habitat types ( $H^+$  = Shannon species,  $J$  = Uniformity).

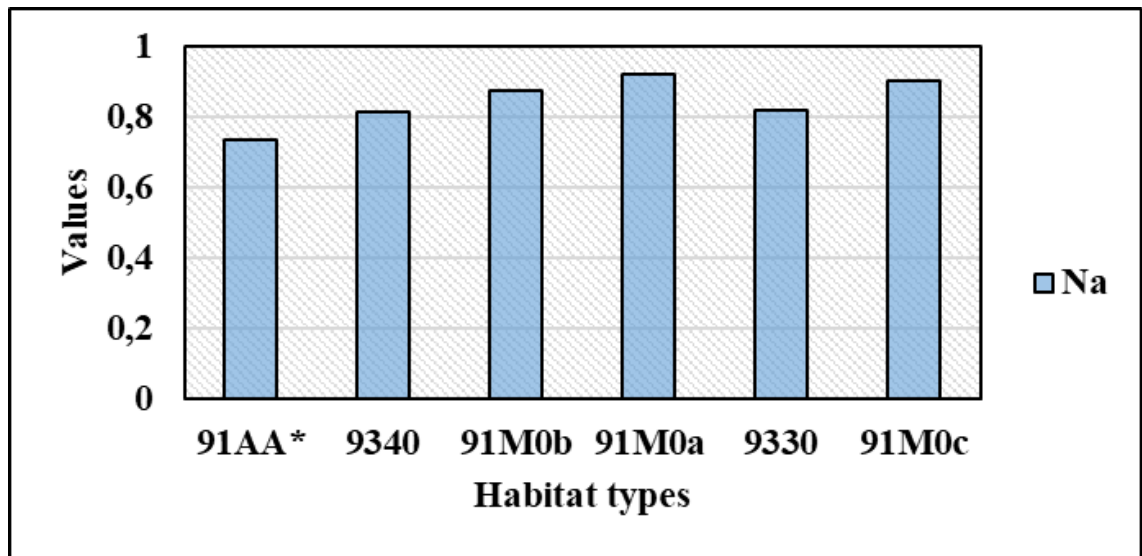


Figura 5.6. Naturalness index ( $Na$ ) values for different habitat types.

Table. 5.3. Values of biodiversity indices for each habitat type ( $H^+$ = Shannon total species,  $J$ = Evenness,  $Na$ =Naturalness).

Habitat types	$H^+$	$J$	$Na$
91AA*	0,9680502825	0,5400885801	0,7347512488

9340	1,218050533	0,5808787816	0,8154453581
g1Mob	0,9572066742	0,5859964243	0,8761759174
g1Moa	0,6652026344	0,4380615923	0,9210806294
9330	1,111295595	0,5945199746	0,8210056918
g1Moc	1,274050009	0,6398319229	0,9005586215

#### 5.3.4. Relationship between diversity and Ellenberg indicator values

The linear regression model (Figure 5.6, tab.5.4) between the naturalness index (Na) and the ecological temperature index (T) shows a significant slope value ( $p$ -slope)  $< 0.05$  (0.0000010016), correlation index  $r = -0.82$  and regression index  $r^2 = 0.67$  (Table 5.4).

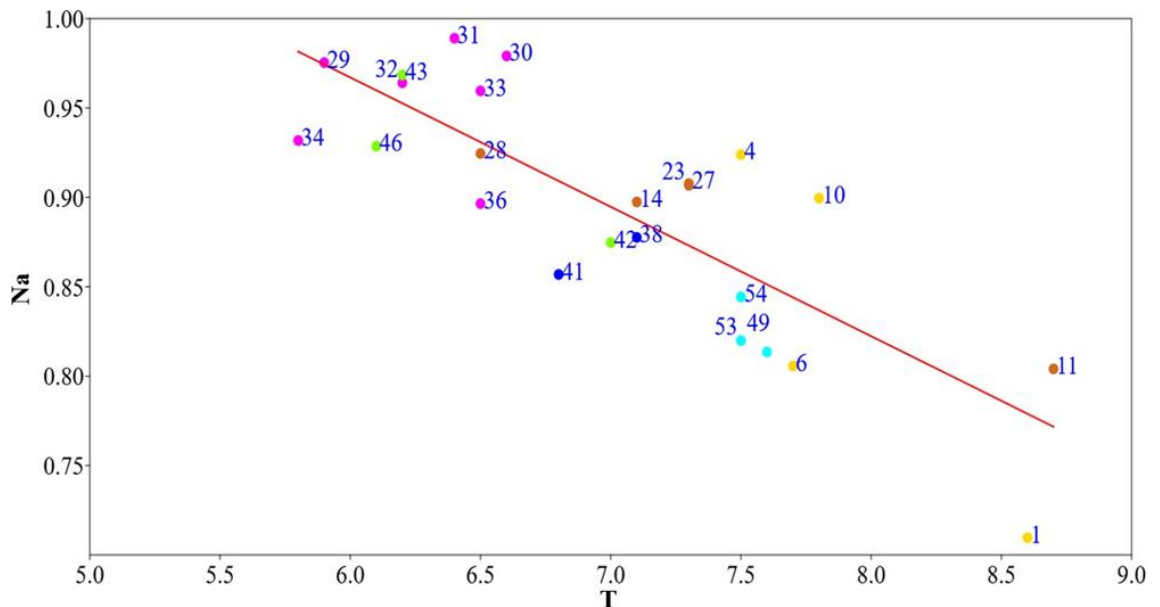


Figura 5.6. Linear regression model between the naturalness index (Na) and the Pignatti- Ellenberg temperature indicator value (T) yellow g1AA\*, brown 9340, blue 9330, green g1Moa, dark blue g1Mob, fuchsia g1Moc.

To check the autocorrelation analyses, the Durbin-Watson statistical test was applied, which assumes a value of 1.71 and an autocorrelation probability of 24%, while the variance of the residuals and thus the homoscedasticity was calculated using the Breusch-Pagan test, with a value of 3.26 and a homoscedasticity probability of 0.07%. This analysis shows that the naturalness of habitats

decreases with increasing temperature, as low habitats are more affected by human activity and are often close to urbanised areas.

Table. 5.4. Linear regression model between the naturalness index (Na) and the values of the ecological temperature factor (T).

Ordinary Least Squares Regression: T-Na			
Slope a:	-0,07236	Std. error a:	0,010815
t:	6,6907	p (slope):	1,00E-06
Intercept b:	1,4012	Std. error b:	0,076241
95% bootstrapped confidence intervals (N=1999):			
Slope a:	(-0.097082, -0.048709)		
Intercept b:	(1.239, 1.5673)		
Correlation:			
r:	-0,82		
r <sup>2</sup> :	0,67		
t:	-6,6907		
p (uncorr.):	1,00E-06		
Permutation p:	0,0001		
Durbin Watsonn statistic	Breusch-Pagan statistic		
1,7	3,27		
p (no pos outocorr.)	p (homoskedastic)		
0,24	0,07		

In Figure 8, a regression model is applied between the naturalness and the ecological wetness index (U) for each relief of each habitat of the genus *Quercus*. The model plot shows (Tab) a significant p- slope < 0.05 (0.000019976), correlation index  $r = 0.76$  and regression index  $r^2 = 0.57$ . (Table 5.5).

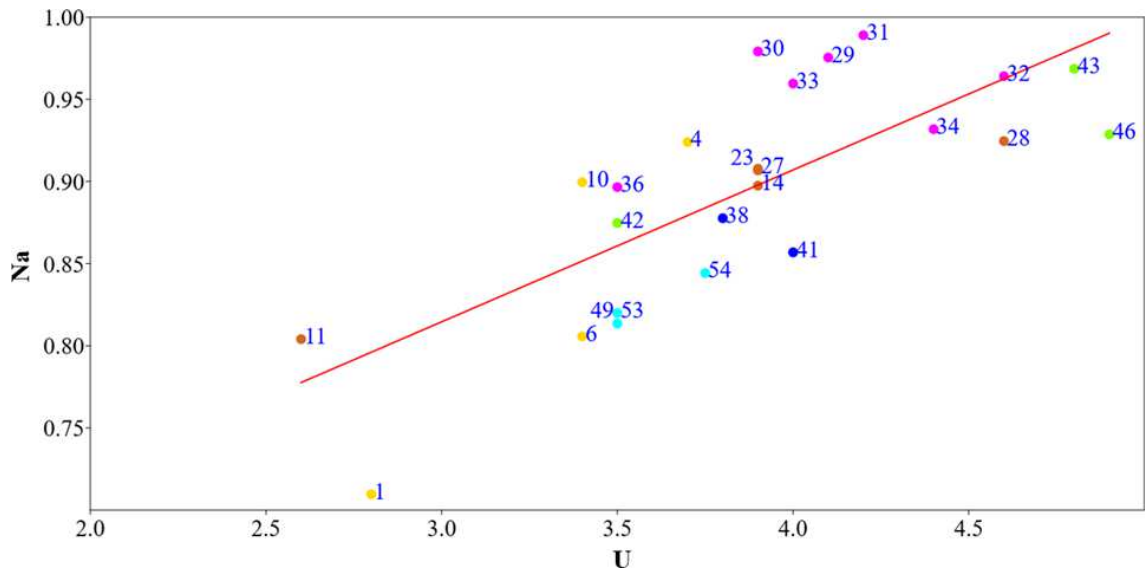


Figura 5.8. Linear regression model between the naturalness index (Na) and the values of the Pignatti-Ellenberg moisture indicator (U); yellow 91AA\*, green 91Moa, brown 934o, dark blue 91Mob, light blue 933o, fuchsia 91Moc.

To check the autocorrelation analyses, the Durbin-Watson statistical test was applied, which assumes a value of 1.54 and an autocorrelation probability of 13 %, while the variance of the residuals and thus the homoscedasticity was calculated using the Breusch-Pagan test, with a value of 0.82 and a homoscedasticity probability of 13 %. This analysis shows that the naturalness of habitats decreases with increasing temperature, as low habitats are more affected by anthropogenic activity and are often close to urbanised areas.

Table 5.5. Linear regression model between the naturalness index (Na) and the values of the ecological Moisture factor (U).

Ordinary Least Squares Regression: U-Na			
Slope a:	0,09243	Std. error a:	0,017108
t:	5,4029	p (slope):	2,00E-05
Intercept b:	0,53732	Std. error b:	0,06671
95% bootstrapped confidence intervals (N=1999):			
Slope a:	(0.052019, 0.12767)		
Intercept b:	(0.3916, 0.6944)		
Correlation:			

r:	0,76
r2:	0,57
t:	5,4029
p (uncorr.):	2,00E-05
Permutation p:	0,0001
Durbin Watsonn statistic	Breusch-Pagan statistic
1,5	0,8246
p (no pos outocorr.)	p (homoskedastic)
0,13	0,36

### 5.3.5. Landscape metrics

Starting from the Carta Natura habitat map of the Calabria Region (Aramini et al.; 2023), all polygons coded as habitats characterised by the dominance of *Quercus* species were highlighted (Figure 5.9). The largest habitats are 91AA\* and 9340. (tab. 5.6.)

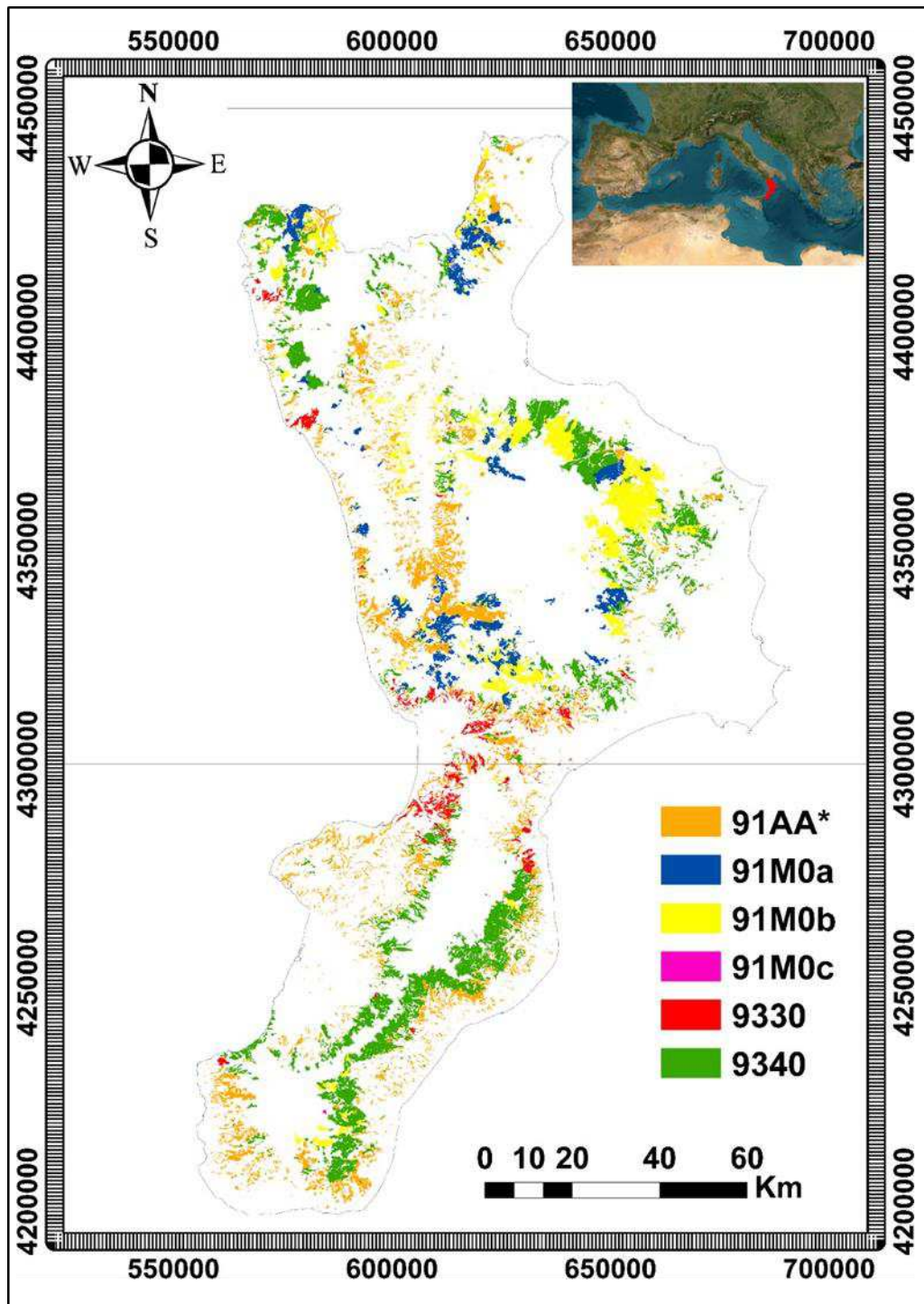


Figura 5.3. Distribution of oak-dominated forests Habitat in Calabria region: 91AA\* (orange), 91M0a (blue); 91M0b (yellow); 91M0c (violet); 9330 (red); 9340 (green).

The Landscape metrics to analyse the fragmentation of habitat dominated by species of the genus *Quercus* of the Calabria Region are reported in Table 1.

Table 5.6. Landscape metrics of habitat types. (NP - Number of patches; AREA\_MN - Mean patch area; PD - Patch density; FRAC\_MN - Mean Dimension fractal; SHAPE\_MN - Shape index; Surface - Total surface (ha).

Table 5.6. Values of fragmentation indices and total surface of habitat type. (NP - Number of patches; AREA\_MN - Mean patch area; PD - Patch density; FRAC\_MN - Mean Dimension fractal; SHAPE\_MN - mean shape index.

Habitat type	NP	AREA_MN	PD	FRAC_MN	SHAPE_MN	Total surface area (ha)
g1AA*	6,193	11.6	0.4107	1.1113	1.9304	71,988
9340	2077	56.1	0.0689	1.1062	2.05135	95,430
g1Mob	1332	33,9	0.0883	1.1086	1.9556	45,136
g1Moa	449	64,5	0.0298	1.0986	1.9943	28,986
9330	545	19,6	0.0361	1.1105	2.0509	10,678
g1Moc	8	10,3	0.0005	1.0751	1.4928	83

The number of patches (NP) varies greatly across habitat types (Table 10). The highest values of this parameter were found for the oak forest habitat *Quercus pubescens* (g1AA\*), which is undoubtedly the most fragmented habitat.

The Mean Area (AREA\_MN) have maximum values were found for habitats 9340: *Quercus ilex* and *Quercus rotundifolia* forests, g1Mob: Pannonian-Balkan turkey oak-sessile oak forests dominated by *Q. frainetto*; g1Moa: Pannonian-Balkan turkey oak-sessile oak forests a dominated by *Q. cerris*.

Patch density takes on higher values in habitat g1AA\* (Eastern white oak woods), and in habitat 9340 (*Quercus ilex* and *Quercus rotundifolia* forests mesomediterranean), while low values are found in habitat g1Moc (Pannonian-

Balkanic turkey oak-sessile oak forests dominated by *Q. petraea*).

The Shape Index (SHAPE\_MN) shows higher values in habitats 9340 and 9330 (2.11; 2.05) due to an irregular shape. Shapes with greater irregularity are less effective in protecting the integrity of ecosystems as they are to the loss of surface area and the gradual increase in the presence of anthropogenic species in the area (Forman et al., 1981).

The values of the Mean Dimension fractal index (FRAC\_MN) are high for habitats 91AA\*, 9340 and 9330 are characterised than habitats 91Mo, thus showing higher fragmentation.

#### 5.3.6. Relationship between fragmentation and the naturalness index

The Patch Density (PD) values were compared with the naturalness values of the various habitat types (Figure 5.10). Although the number of cases is not very high, can be observed that habitat 91AA\* is characterised by a lower naturalness while the Patch Density is higher confirming a high fragmentation of this habitat. The model shows a significant p-slope < 0.05 (0.00000048404) and a correlation of 0.82 (Supplementary Material Table S7)

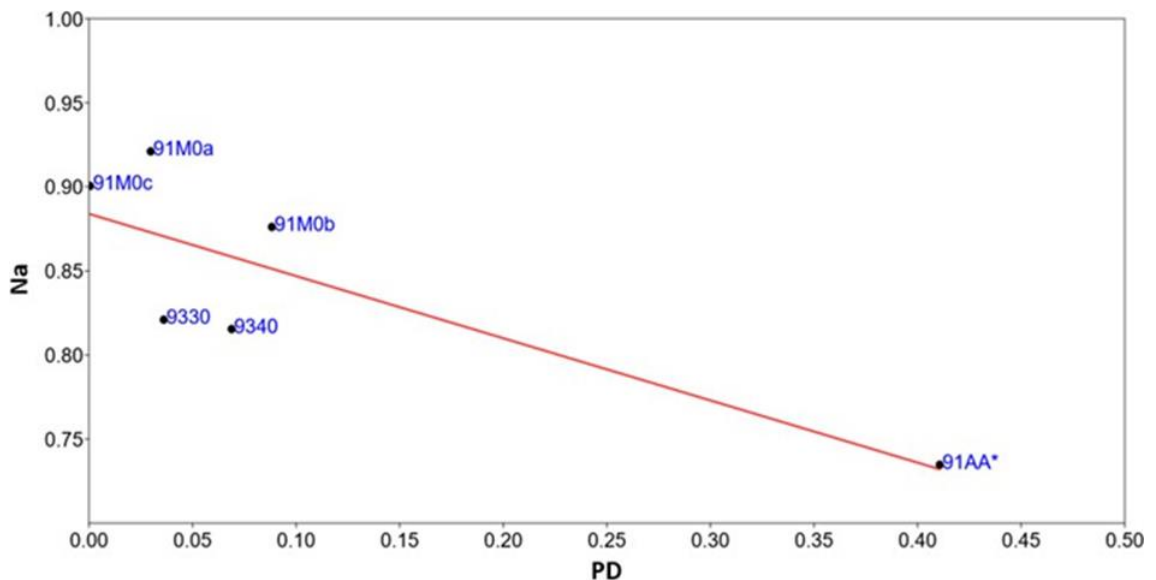


Figure 5.10. Comparison of patch density (PD) and naturalness values (Na) of different habitat types.

## 5.4. Discussion

The forests characterized by oak dominance are an important naturalistic heritage of the Calabria Region and also for the local economy. They occupy 252,301 ha and represent 44.8% of the region's wooded surface, which amounts to 563,541 ha (Aramini et al. 2003).

The cluster analysis of the relevés carried out on oak forests has made it possible to identify six different groups attributed to as many EEC Directive 43/92 habitat types, or subtypes, defined under the European [EC/European Commission 2013] and Italian [Biondi et al., 2009] interpretation manuals. These groups also correspond to phytosociological syntaxa following phytosociological literature [Biondi & Blasi 2015, Mucina et al., 2016], in fact, phytosociological analysis of vegetation and formally defined plant community or syntaxa classifications have played a fundamental role in the development and interpretation of EEC Directive 43/92 habitats [Rodwell, 2018].

In particular, Habitat 9340, characterised by forests dominated by holm oak (*Quercus ilex*), is distributed in the Mediterranean area without specific soil requirements (Biondi and Blasi 2015) and it is the one that occupies the largest surfaces in Calabria (Tab. 1, Fig. 9). Habitat 9330 is characterized by cork (*Quercus suber*) dominated forests spread on limited areas characterized by acid sandy soils especially on the Tyrrhenian side of Calabria (Mercurio et al. 2022).

Habitat 91Mo is rather heterogeneous, in the Calabria region it consists of deciduous mesophilous meso-termophilous oaks tending towards silicicolous and subacidophilous, which form multilayered forests, in the supra-Mediterranean and mesotemperate bioclimatic zones. This habitat includes deciduous forests dominated respectively by Turkey oak (*Quercus cerris*) (91Moa), Hungarian oak (*Q. frainetto*) (91Mob), or sessile oak (*Q. petraea*) (91Moc). Habitat 91AA\* is characterized by Mediterranean and sub-Mediterranean, thermophilic and often

edaphic-xerophilous forests dominated by *Quercus pubescens*, a complex species within which various entities have been identified that are classified differently from a taxonomic perspective (Brullo et al., 1999, Pignatti 2017a, Musarella et al. 2018, Di Pietro et al. 2020). This habitat is widely distributed throughout the Italian Peninsula (Biondi et al., 2009) and is particularly widespread in Calabria (Tab.1, Fig. 9).

The ecological indicators that differentiate habitat types primarily include temperature (T), light (L), soil nitrogen (N), and humidity (U). These factors significantly influence the floristic composition of the identified oak forest habitats (Figures 3 and 4).

From a phytosociological perspective, the two groups of habitats highlighted by the biplot clearly correspond to the two main classes of forest vegetation found in Mediterranean regions. The first group of habitats comprises plant communities classified within the *Quercio-Fagetea* class, which encapsulates the mesophilic winter deciduous forest vegetation typical of temperate macro-bioclimate areas of Europe. In contrast, the second group brings together forest communities of the *Quercetea ilicis* class, which brings together thermophilic woods and scrub, mostly evergreen and sclerophyllous, widespread throughout the Mediterranean bioclimatic region.

Indeed, holm oak forests (habitat type 9340) are widespread in the region, occupying a wide altitudinal range from sea level to the mountain belt, and temperature and humidity factors play a key role in the ecological characterization of this habitat type. The lowest values of continentality (higher oceanicity) are observed in habitat 9330, which explains the distribution of cork oak forests mainly in the Tyrrhenian regions of the peninsula (Pignatti, 2017) and in the vegetation of the western Mediterranean countries towards the Atlantic Ocean (Selvi et al., 2015); also, in Calabria they are distributed mainly on the Tyrrhenian side of the region. The habitat 91Mo presents a higher continentality;

in particular, the habitat subtype 91Moa characterised by the dominance of *Quercus cerris*, presents the highest continentality values, which explains the distribution of these forests in continental biogeographical regions according to the literature (Biondi et al., 2014).

In addition, the results show that habitats with lower values of humidity index (U) and higher temperature index (T) have lower values of naturalness index, such as habitats 9330 and 91AA\*, affected by major changes in community composition due to the arrival of alien species (Touza et al. 2008, Montecchiari et al., 2020). Habitat 91AA\* showed higher values of the ecological indicator of light (L) reaching the ground, increasing the diversity of the herbaceous layer (Von Oheimb and Härdtle 2009), and a greater presence of ruderal species in agreement with Pérez-Ramos et al. (2008). The deciduous forests of habitats 91Moa, 91Mob, and 91Moc demonstrate high naturalness, which is positively correlated with ecological indicators of humidity and soil nitrogen, and negatively correlated with temperature values. This confirms that environmental factors such as light availability (Dormann et al., 2020) and soil conditions (Chytrý et al., 2003) affect species richness in the herbaceous layer.

Spatial heterogeneity at landscape scales significantly influences habitat conservation (McGarigal and McComb, 1995). The complexity of the shape is related to fragmentation, as more complex forms have more edges than polygon areas, showing harmful effects on fauna and flora (Rivas et al., 2022). Complex-shaped areas can be more easily divided into smaller areas, increasing habitat fragmentation (Ewers et al., 2007). The results obtained from the landscape analysis show that habitat 91AA\* is the most fragmented, characterized by a greater number of patches, a smaller average area, a higher density, and a larger fractal size than other habitats.

Habitats 9330 and 91AA\* show elevated values of the SHAPE index and FRAC\_MN, leading to polygons with irregular shapes that are easily penetrated

and susceptible to fragmentation. According to literature data (Mercurio et al., 2022; La Mela Veca et al., 2006; Caridi & Iovino, 2002), this fragmentation is caused by repeated fires, excessive grazing, and the replacement of these forest formations in the Calabria region by crops or artificial plants, leading to patches of forest habitats scattered across areas designated for agricultural or pastoral use. This explains the low naturalness of habitats g1AA\* and g330, located at lower altitudes in areas most impacted by agriculture and urbanization, compared to g1Moa and g1Moc, which are frequently found at higher altitudes within protected areas and exhibit greater naturalness values.

Several authors (Southworth et al., 2004; Abdullah and Nakagoshi, 2007; Kumar et al., 2018) have pointed out that the increase in population, with the consequent demand for new land for agriculture and urban settlements, is a major cause of habitat degradation, particularly in forests, as it causes changes in dominant species, diversity, and covered areas (Valladares et al., 2008). The increase in artificial and agricultural land is also linked to the spread of alien species, as many of them are closely related to elements of landscape structure such as roads, edges, and certain types of land use (Brososke et al., 1999). Several studies (Butchart et al., 2015; Woodley et al., 2012) highlight that protecting areas is essential for preserving ecosystems, habitats, and species threatened with extinction by land use change and the spread of alien species.

## **5.5. Conclusion**

Forest fragmentation is one of the main causes of alteration of these habitats. Forest fragmentation often begins with selective logging and progresses through agricultural development, leading to isolated forest patches. Urbanization and infrastructure development have accelerated this process in developed countries over the past 50 years. Fragmented forests exhibit reduced biodiversity and compromised ecological processes compared to contiguous forests. (Seidler, 2017).

Our study indicates that there is a correlation between the most fragmented habitats and lower levels of naturalness, which contradicts findings from other studies (Petrášová-Šibíková et al., 2017). Consistent with previous research (Kettunen et al. 2009; Pyšek et al. 2010; Malcolm 1994), structural and microclimatic changes are the primary causes of the establishment of invasive and ruderal species.

Our results show that monitoring activities should mainly focus on g1AA\* habitat in the vicinity of urban centres, due to increased fragmentation, and the presence of alien and disturbing species that affect these habitats, causing a reduction in biodiversity and posing a threat to the conservation of these habitats. Conservation measures should also focus on habitats that show very low coverage and are characterized by a naturalistic value as they correspond to EEC Directive 43/92 habitats such as cork oaks and forests dominated by *Quercus petraea* because they risk extinction in the immediate future as they are very rare habitats.

The characterization of habitat types from an ecological and diversity perspective is crucial for addressing forest resource management issues. Consequently, applying diversity indices linked to landscape analysis is apt for identifying the causes of change due to invasive and disruptive species. This approach can also be employed to monitor fragmentation and assess the conservation status of habitats of community interest.

## **CHAPTER 6 Analysis of the connectivity and biodiversity of the Natura 2000 network, a case study in the Calabria region (Southern Italy).**

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**Articles for submission**

**Abstract:**

Due to global changes, habitats are fragmented and lose connectivity due to an environmental matrix that isolates the remaining natural areas. To improve habitat quality, a system of connectivity and exchange between isolated areas and natural elements is therefore important to counteract fragmentation and its negative effects on biodiversity. This study carried out in the Calabria region based on the Nature Map in Italy, aims to define the optimal paths for identifying areas of high ecological importance for the connectivity of the Natura 2000 sites. To achieve this goal, both the minimum cost model and the circuit model, applied using Linkage Mapper and Circuitscape, and the use of Morphological Spatial Pattern Analysis (MSPA) (available from the freeware Guidos Toolbox) were tested. The methodology developed can be usefully applied to the Natura 2000 network across Europe. Habitat fragmentation often hinders and prevents the movement of species that influence their distribution, even when environmental conditions are suitable. This study suggests pathways that ensure greater connectivity of the Natura 2000 network and areas of greater biodiversity, as required by the Priority Action Frameworks (PAF), which prioritise the definition of connectivity areas (ecological corridors) necessary to define the 'Regional Ecological Network'. Therefore, our results highlight the importance of supporting the decision-making process for planning the Regional Ecological Network for effective biodiversity conservation to reduce habitat and species loss

Keywords: Habitat fragmentation, connectivity index, Natura 2000 network, Nature Map.

## 6.1. Introduction

Biodiversity is under serious threat today, and in different parts of the world (Maxwell et al., 2016). Protected areas are considered an important tool as they play a key role in conserving biodiversity (Watson et al., 2014). Natura 2000 is a protected area network covering species and habitats important for Europe's biodiversity conservation. Comprising the largest coordinated network of protected areas, it extends across all 27 EU Member States, encompassing Natura 2000 sites and sites designated under the Birds and Habitats Directives (Maiorano et al., 2007). Biodiversity loss is linked to multiple factors such as fragmentation, climate change, introduction of invasive species, land use change and habitat destruction (Prakash, 2017;). Several studies have shown that land-use change leads to processes of habitat fragmentation into small and isolated patches drastically affecting key ecosystem functions (Valiente-Banuet et al., 2015). Furthermore, climate change is also a threat to the maintenance of biodiversity, as it causes a significant intensification of habitat fragmentation, although specific conservation measures can help mitigate these negative effects (Pearce-Higgins et al., 2022). Protecting the ecological integrity of habitats and species diversity is at the heart of all conservation or restoration management actions. The connectivity of protected areas, such as the Natura 2000 network, is indispensable for the maintenance of ecosystems for the provision of ecosystem services in the territories in which they are inserted, but above all fundamental for the movement of animal species that transport genes, seeds and pollen from one protected site to another (de la Fuente et al., 2018). Connectivity is influenced by several processes such as habitat fragmentation resulting in changes in species composition, alteration of community structure and population dynamics,

reproductive success and individual suitability (Opdam and Wascher, 2004). Today, human action, with the process of urbanization and intensification of agricultural activities, has significantly altered the original landscape, as well as the spatial distribution and number of landscape units (Zhang et al., 2023).

Many studies have focused on assessing landscape connectivity in fragmented habitats, highlighting the need for systematic conservation assessment to improve connectivity. Jordán (2000) points out that connectivity planning promotes the movement of more animal and plant species, for which he considers the permeability of corridors to promote global connectivity. According to some studies (Rudnicke et al., 2012), the extent to which landscapes are fragmented or connected can also influence the rate and pattern of disease spread and invasion of non-native species. Scenario-based connectivity analysis can outline the main dispersal pathways of invasive species (Perry et al., 2017), allowing managers to identify areas where invasive species control measures would be effective (Volk et al., 2018).

Ecological corridors have been proposed in landscape conservation and planning programs to limit the effects of fragmentation (Salviano et al., 2021). As such, they enable the planning of more sustainable landscapes through the strategic distribution of habitat patches across all areas impacted by human activity. The objective of this network is to ensure the long-term persistence of Europe's most valuable and threatened species and habitats, listed in both the Birds Directive (79/409/EEC, amended as 2009/147/EC) and the Habitats Directive (92/43/EEC). Currently, the Natura 2000 Network consists of over 27,000 sites covering over 18% of the EU territory (European Commission, 2016). In Italy, the Natura 2000 Network consists of 2,646 sites, for a total land area equal to 19.4% of the national territory and a sea area equal to 6.4% (M.A.S.E., 2025).

Today, the connectivity and site selection of protected areas, including the Natura 2000 network, are planned at scales of low ecological relevance

(Opermanis et al., 2012), poorly coordinated (Evans, 2012) and poorly evaluated (Estreguil et al., 2014). The expansion of ecological networks is seen as an important measure to limit the effects of fragmentation on biodiversity and is now an important policy tool in many countries (de la Fuente et al., 2018; Lawton et al., 2010; Worboys et al., 2010). Ecological networks are defined as a series of central areas connected by corridors, which allow the movement of species or their propagules (Bennett, 2000; Humphrey et al., 2015). The interruption of ecological continuity in forests leads to the extinction of populations or even species. Many of these rare and endangered species such as bryophyte vascular plants, fungi (Schmidt et al., 2014; Mölder et al., 2015; Winter et al., 2015) and other organisms such as saproxylic beetles (Eckelt et al., 2018) are characterized by low dispersal capacities (Flensted et al. 2016).

There are several studies in the literature based on the importance of habitat connectivity that map functional links important for species movement and other ecological flows (Santini et al., 2016; Saura and De la Fuente, 2017). Other studies that have mapped connectivity have assessed the specific contribution of forests or other specific elements of green infrastructure (Gurrutxaga and Saura, 2017, Dickson et al., 2017). Finally, several studies have considered different land uses (de la Fuente et al., 2018). No studies applying connectivity models to the Habitats Directive were found in the literature.

Identifying priority areas and ecological corridors, as well as ecological restoration, are essential for protecting and enhancing connectivity (Zhang et al., 2023). Establishing protected areas is a key pillar of regional conservation strategies (Maiorano et al., 2007) and an important tool for combating biodiversity loss (Chazdon et al., 2003). The main objective of ecological assessment is to provide criteria and information to identify conservation priorities (Roberts et al., 2003).

In this study, we considered the habitats of the Habitats of Directive 92/43/EEC,

the most important tool for biodiversity conservation in Europe (European Commission, 2020) which aims to protect the natural and seminatural habitat types and animal and plant species listed in Annexes to the Directive (Campagnaro et al., 2018). We utilise a new combination of methods and tools to model functional connectivity in heterogeneous landscapes, employing the Natura 2000 network in the Calabria region (Italy) as a case study. First, we mapped the connections between the core points of the Natura 2000 sites. We have prioritized key connectors on which to focus conservation and restoration efforts. In this evaluation, we paid particular attention to the role of Directive habitats inside and outside the Nature Network in the Calabria Region. The research findings can provide a scientific basis for guidance to the management and restoration of ecological functionality on a large planning scale as it allows the identification of the areas where to concentrate future efforts to improve or maintain the connections, a reference for constructing the ecological network in the Calabria Region.

## **6.2. Material and methods**

### **6.2.1. Study area**

The study concerns the assessment of the connectivity of the Natura 2000 network in Calabria, a region of southern Italy in the central Mediterranean Sea (Figure 6.1), which consists of 185 Special Areas of Conservation (SACs) designated under the Habitats Directive and 4 Special Protection Areas (SPAs) designated under the Birds Directive 79/409/EEC (Figure 1). A detailed and updated Nature Map is available for this region (Aramini et al., 2023) that covers an area of 15,079 km<sup>2</sup> and contains 135304 biotopes representing 132 different habitat types, grouped together into the following habitat macro-categories: Coastal and halophilic communities, Non-marine waters, Scrublands and grasslands, Forests, Swamps and marshes, Inland rocks, scree and sands,

Agricultural lands and artificial landscapes.

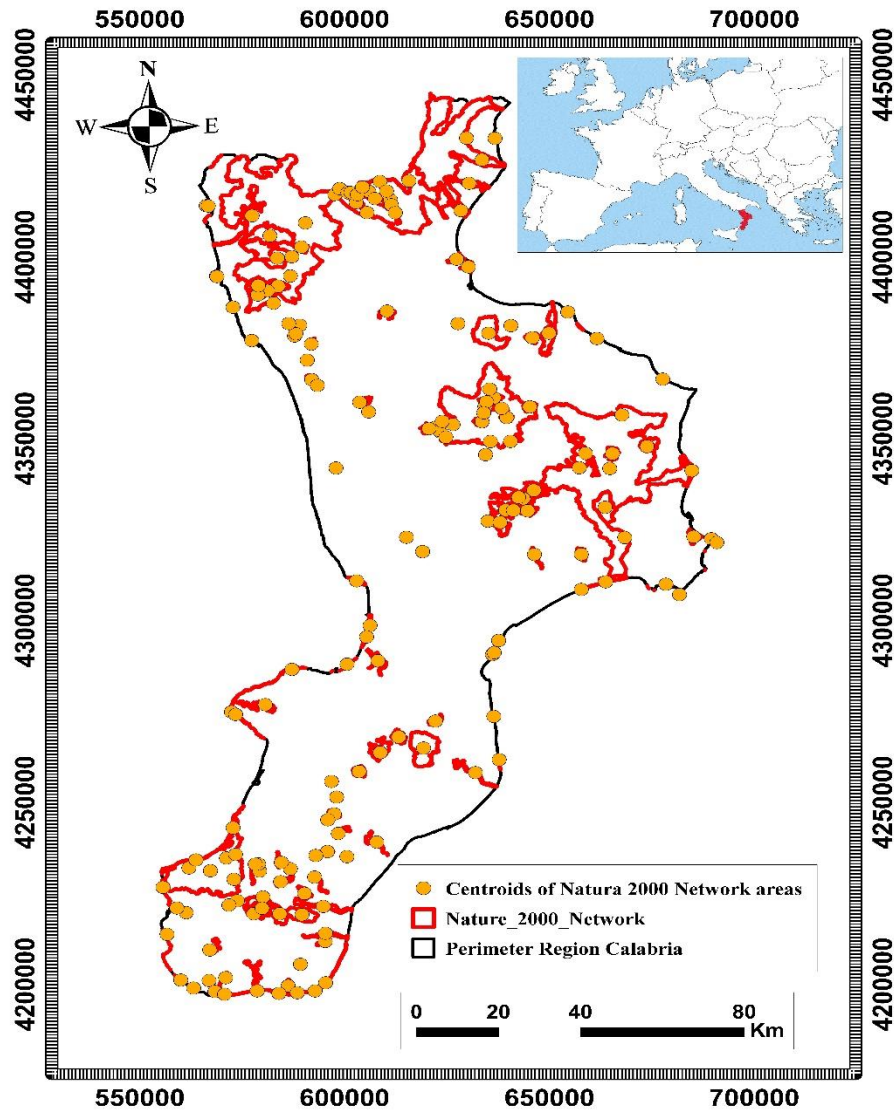


Figura 6.1. Study area with the Natura 2000 network (SAC, SPA) (blue line) and its site centroids (red dots).

#### 6.2.2. Methodology

Arc Map 10.7 was used for the analysis, with the geographical coordinate system WGS84 UTM Zone 33. Firstly, the habitat map for the Calabria region (Aramini et al., 2023) was used to create a layer of resistance surfaces. The morphological spatial pattern analysis (MPSA) was used to better distinguish landscape types and structures and to identify habitat patches that play an important role in

landscape connectivity at the pixel level. Then circuit theory was used through the Linkage Mapper software to identify ecological corridors in the Calabria region. In summary, the steps of the methodology used in this study are illustrated in Figure (6.2).

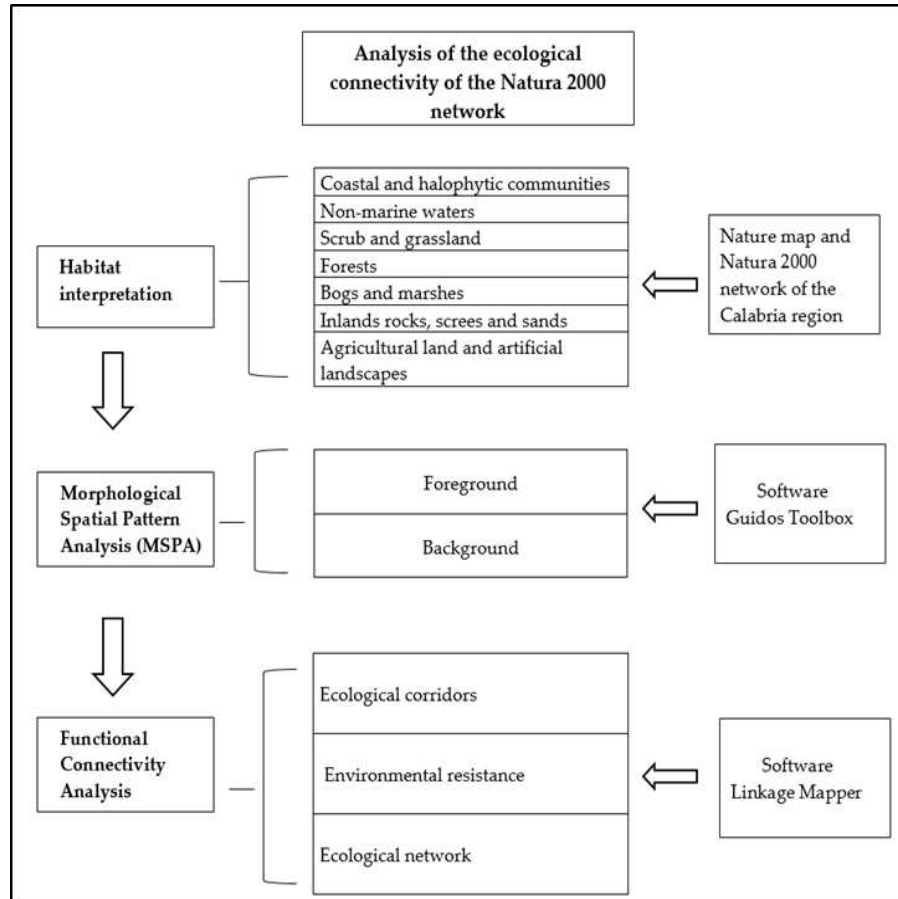


Figure 6.2. Methodology for the analysis of connectivity of Natura 2000 areas: Interpretation of habitats, MPSA analysis, analysis of connectivity (Linkage Mapper

### 6.2.3. Connectivity analysis of the Directive habitats

Morphological Spatial Pattern Analysis (MSPA), based on a series of morphological transformations, is an image processing method for measuring, identifying, and segmenting the spatial pattern of a raster image, which can be adapted to describe the geometry and connection between panels (Soille and Vogt, 2009). In this study, the Guidos Toolbox software (<https://forest.jrc.ec.europa.eu/>) was used to segment the foreground area

occupied by different types of Directive habitats in the Calabria region. The binary input image is divided into seven visually distinct MSPA classes: Core, Islet, Perforation, Edge, Loop, Bridge and Branch (Figure 6.3, Table 6.1) (Vogt and Riitters, 2017; Vogt, 2009). For this analysis, we transformed the Carta Natura shapefile (.shp) into a raster (10x10 m resolution) containing three classes of data: foreground, background and missing data. In our case, the foreground consisted of all the directive habitats found in the Calabria region, while the background consisted of all the non-directive habitats.

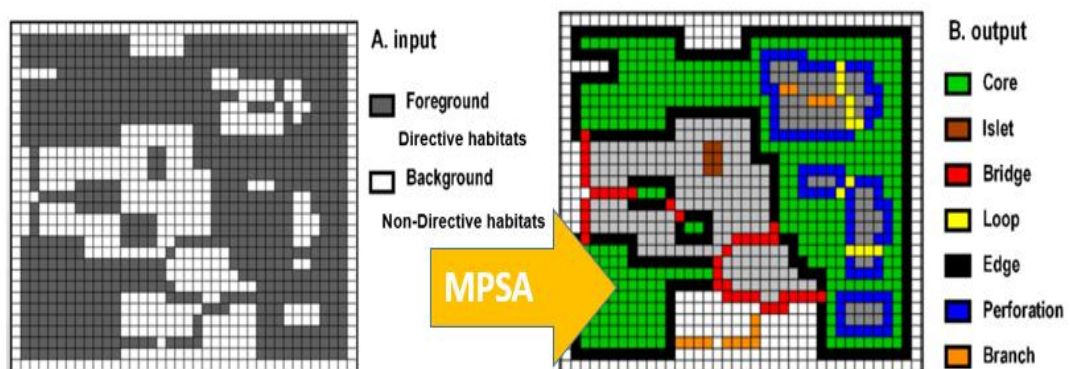


Figura 6.3. Esempio di classi di analisi di modelli spaziali morfologici (Vogt e Riitters, 2017).

Table 6.1. Descriptions of the morphological categories (Vogt et al., 2007).

Morphologica l category	Description
Core	Central area of Directive habitats.
Edge	Perimeter of pixels that usually surround the core areas.
Perforation	Similar to edges, holes within a core area that are transition zones between areas occupied by Directive habitats and unprotected habitats found within them.
Bridge	Connection surfaces between central areas occupied by Directive habitats, separating them from areas characterized by non-directive habitats.

Loops	Like bridges but with the ends of the element connecting to different parts of the same central area.
Branch	Connected at one and end to Edge, Perforation Bridge or Loop. Extending area of green space, only one end is connected to the green space.
Islet	Areas occupied by isolated Directive habitats too small to be considered central areas.
Core opening	Surfaces inside core areas and surrounded by perforation pixels.

#### 6.2.4. Functional Connectivity Analysis

Circuit theory in physics uses the electronic phenomenon of random walk to simulate the process of species migration or the flow of energy in an ecological process (McRae et al., 2008). Functional connectivity was assessed using tools that consider minimum cost paths (LCPs). We used the Linkage Mapper a GIS toolbox designed to support regional wildlife habitat connectivity analyses (McRae and Kavanagh, 2011) in ArcGIS 10.9 to map corridors and least-cost paths (LCPs) between the midpoints of all adjacent Natura 2000 sites. The least-cost route is the single route associated with the lowest cost-weighted distance between a source and a destination (Adriaensen et al., 2003).

For the connectivity assessment, a raster layer (20 x 20 m) was created showing the resilience values for each habitat (Table 6.2), taking into account different studies (Velázquez et al., 2022; de la Fuente et al., 2018; Gurrutxaga et al., 2011; Saura and De la Fuente, 2017; Gurrutxaga et al., 2010). Resistance values were assigned to the different habitats mapped in the nature map. Minimum values (equal to 1) were assigned to European protected habitats (Habitats Directive 43/92), which are important for conservation as they generally host a unique range of flora and fauna (Kleining, 2017), while progressively increasing values were assigned to unprotected habitats. Finally, maximum values were assigned to roads, urban areas, agricultural areas and all areas modified by human activity.

Table 6.2 Resistance values for each habitat macro-category.

Macro - Categories	Resistance values
Directive habitats	2 - 10
Non-Directive habitats	10 – 50
Agricultural habitat	80
Urban area	100

## 6.3. Results

### 6.3.1. Connectivity analysis of the Directive habitats

The Morphological Spatial Pattern Analysis (MSPA) allowed us to calculate the areas in hectares and percentages for the various classes. In the Calabria region, 35 percent of the area occupied by Directive habitats corresponds to cores (a total of 179,853 hectares), 1.24 percent (7,139 hectares) to bridges, and 0.24 percent (1,382 hectares) to areas with perforation (Table 6.3, Figure 6.4).

Tabella 6.3. Area in percent and hectares of Directive Habitats (HD) in the different MSPA classes in the Calabria region.

MSPA Class	Area % HD	Area (ha) HD
Core	35.24	179,853
Islet	0.13	748
Bridge	1.24	7,139
Edge	4.32	24,871
Loop	0.08	461
Perforation	0.24	1,382
Branch	0,94	5,412
Background	61.92	356,481

The individual components of the graph theory network showed 6,933

connectors, of which 3,382 are defined as isolated areas because they lack connections, while 3,551 have connections between different core areas thus defined as connected areas. Regarding landscape habitats, ECA\_rel (Relative Equivalent Connected -Node/Core- Area), is the percentage of reachable habitat. ECA\_rel describes the degree of network connectivity in an image. The Calabria Region has a relative equivalent connected area of 60 per cent (Table 6.4).

Tabella 6.4. Statistical values obtained from the analysis of the network of components (NW componets)

<b>Macro - Categories</b>	<b>Values</b>
Networks components (NW)	6,933
ECA_rel:	60 %
NW with links (Connected cores)	3,551
NW with no links (Connected cores)	3,382

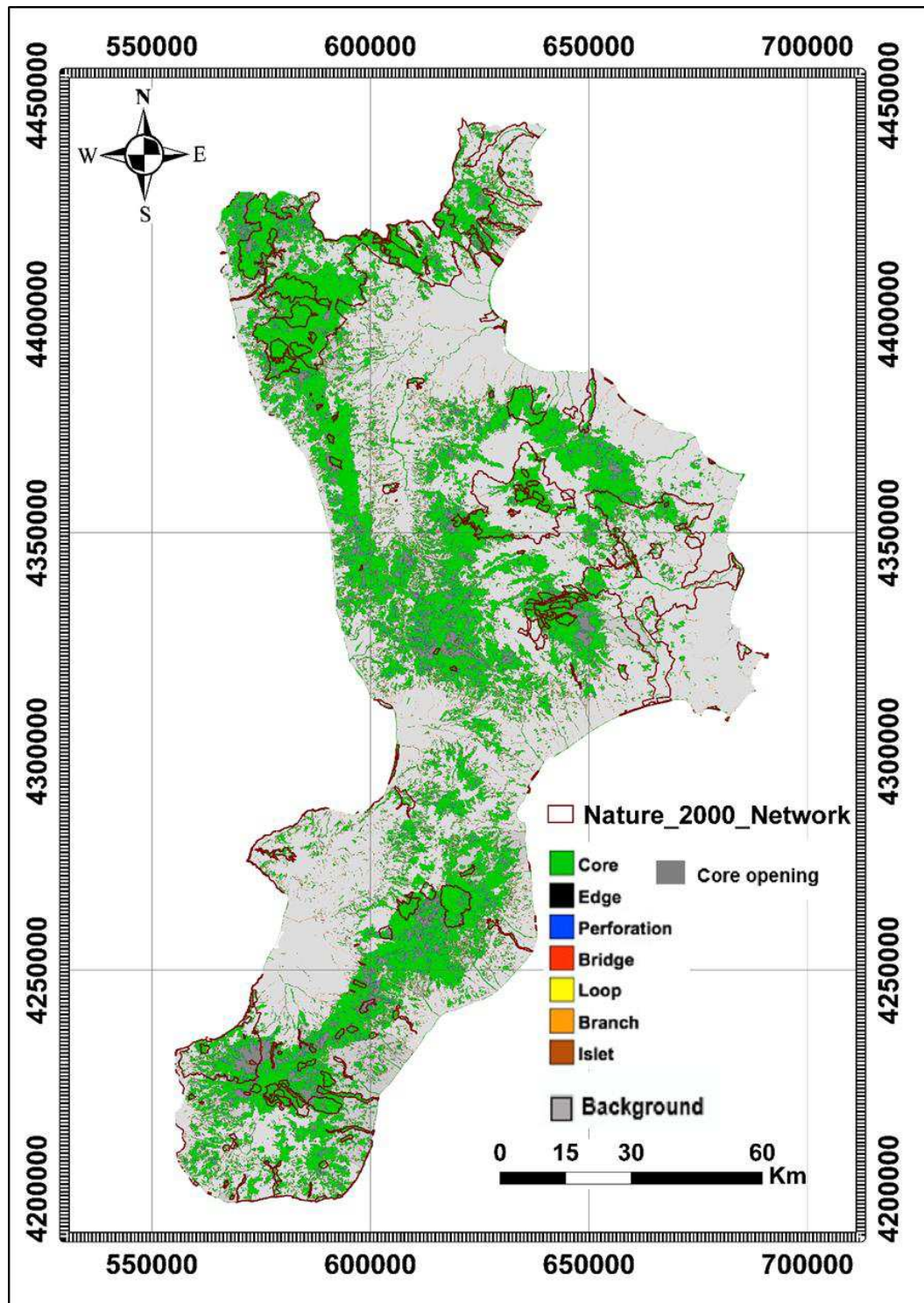


Figura 6.4. Analysis of the morphological spatial model Illustrations of the MSPA

### 6.3.2. Structural Connectivity Analysis

The results obtained by the Linkage Mapper tool were fundamental for

identifying the ecological corridors that connect the centroids of the Natura 2000 Network areas.

We have identified a comprehensive network of connections between Natura 2000 sites in the Calabria region (Figure 6.5), as illustrated by the central axes (LCP lines) of these connections. In Figure 5, darker colours indicate greater resistance encountered by different species in reaching other areas than lighter colours. Linkage Mapper has indeed established links in regions where species require less time to move between sites within the Natura 2000 network of the Calabria region. Significant differences were observed in the spatial distribution of connectors, with some areas exhibiting a high density of connectors, particularly in or near national parks, and others featuring very few units located in the southern part of the region, such as the Gioia Tauro plain and some coastal areas along the Ionian coast, especially where the impacts of urbanization and agriculture are pronounced.

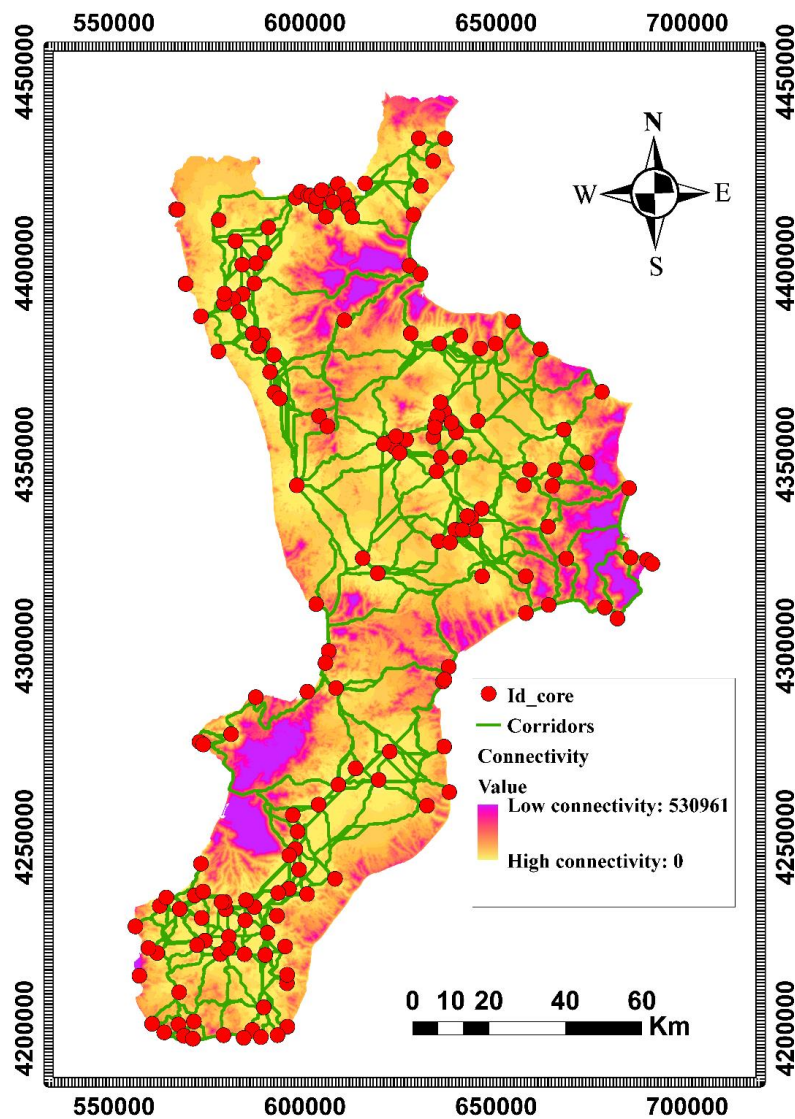


Figure 6.5. Ecological corridors (green lines) connecting core areas represented by the centroids of Natura 2000 sites (red dots).

Sixty percent of the connectors cross forested habitats such as beech forests (Directive habitat 9210\*/9220\*), oak forests (9340), and riparian habitats 91E0\* and 92A0. and, to a lesser extent (14%), semi-natural scrub and grassland habitats (Figure 6.6). The supplementary material shows for each habitat the number of polygons crossed by the connectors. (Supplementary Materials Table S1).

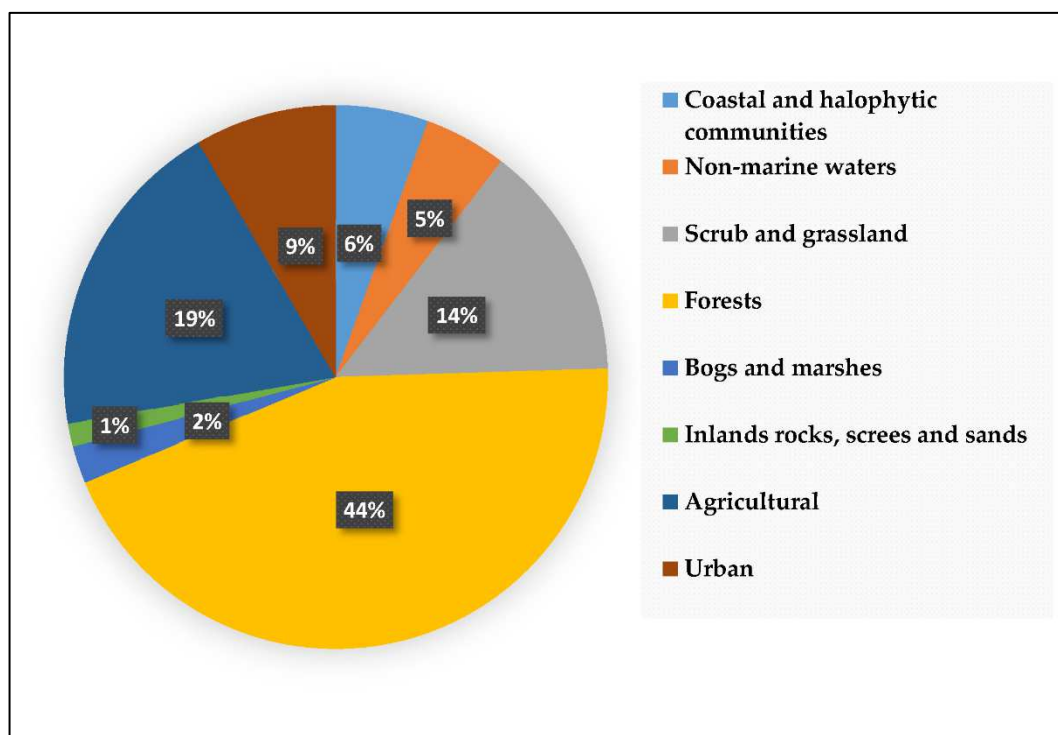


Figura 6.6. Percentage values of the connectors crossing the various habitat macro-categories: in light blue coastal habitats, in orange Non-marine waters, in grey grassland and scrub habitats, in yellow forest habitats, in dark blue marsh and bogs habitats, in green rocky habitats, in blue agricultural, in brown urban,

The resistance within and beyond the Natura 2000 Network Sites is shown in Figure 6.7. Notably, most areas reveal low resistance, indicating a predominance of agricultural environments over urban ones. The areas with higher resistance, and thus darker colouration, are in the plains and generally in coastal areas of the region, while lower values are found in the interior mountainous areas.

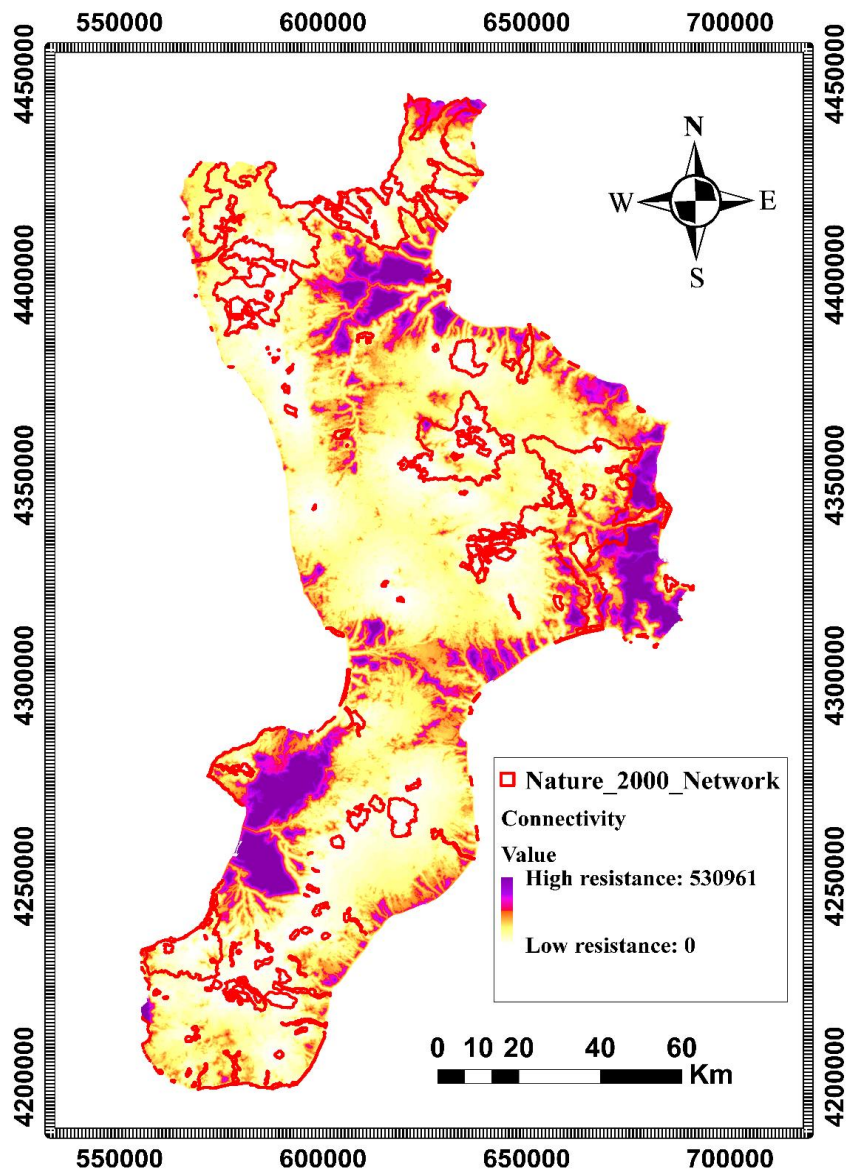


Figura 6.7. Gradient of environmental resilience indicated by the variation of purple color inside and outside the Natura 2000 network (red polygons).

The final product of the habitat connector and naturalness analysis, processed using the Linkage Mapper software, was the ecological network of the Calabria region (Figure 6.8), which highlights areas of high naturalness both inside and outside the Natura 2000 network and their interconnection. The analysis performed shows that most of the sites in the Natura 2000 network have both a high number of connections and a high degree of naturalness.

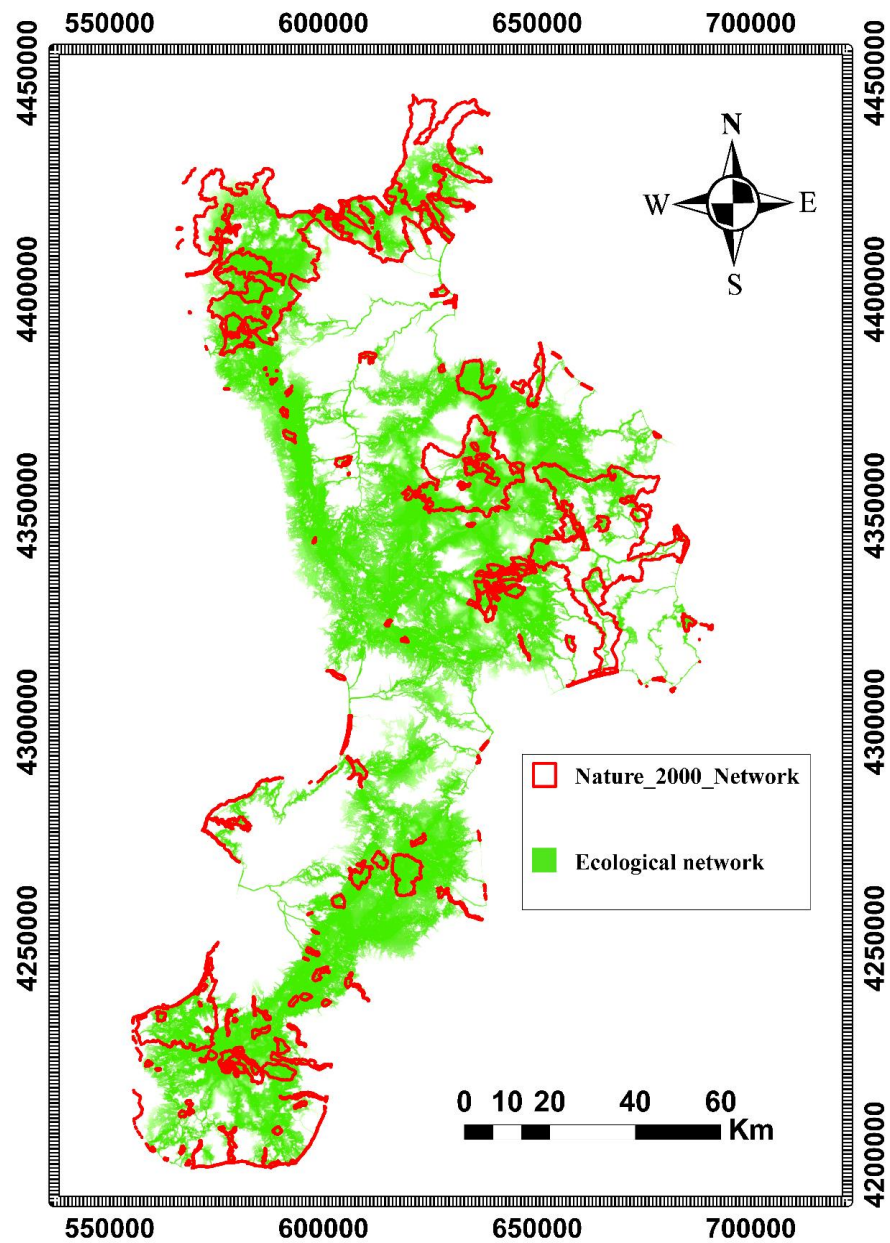


Figura 6.8. Ecological network processed with Linkage Mapper (green), Natura 2000 network in red.

#### 6.4. Discussion

Our results suggest that the ecological network, structured around Directive habitats both inside and outside the sites Natura 2000 network, could meet all the requirements to be considered an effective conservation measure based on areas that contribute to functional connectivity.

By comparing the analyses carried out with the two methods, it was possible to identify areas with high perforation and therefore high resistance, as high ecological value areas with elevated connectivity. As highlighted by various studies [Kleining, 2017; Dickson et al., 2017) the areas with high resistance hinder species migration, in contrast to low resistance areas, which allow greater circulation of ecological flows and increased species migration. Furthermore, as noted by Thompson et al., (2017) the presence of perforations within core cores results in the loss of habitat and species diversity. The reduction of suitable habitats causes a serious threat to numerous endemic or rare species limited to one or a few sites, especially if these sites are surrounded by habitats unsuitable for colonization and dispersal (Bennett, 2003). The MPSA analysis shows that the core opening area affects 3.24% of the area of the directive habitats, thus highlighting discontinuities within the central areas (Praticò et al., 2022).

The connectors avoided crossing agricultural areas and even more urban areas, giving greater preference to Directive habitats, following the resistance classes considered here. Agricultural areas in the Calabria region are much spread, especially olive groves the largest surface area among all habitats and therefore are more decisive for connectivity than urban areas. Overall, the habitats of macro-category 8: "agricultural land and artificial landscapes" occupy 43.7% of the regional area, (Spampinato et al., 2024), which implies that the connectors that connect the Natura 2000 Network sites must, with a certain frequency, cross these agricultural areas. This study shows that the corridors with the best conditions for species and habitats are those least affected by agriculture and urban land use. Of particular importance are beech forests (Directive habitat 9210, 9220), holm oak forests (Dh 9340) and riparian woods (Dh 92A0, 91E0) in supporting the connectivity of Natura 2000 sites. Riparian forests in addition to specifically contributing to connectivity between various habitats and landscape management, show high biodiversity, provide a wide range of ecosystem services (De la Fuente et al., 2018; Alimpić et al., 2022), and allow faunal species to reach

coastal ecosystems (Modica et al., 2021) often isolated from the urban or agricultural environmental matrix. The Holm Oaks forests play an important role because often connect unprotected areas of high biodiversity with those protected in parks and sites of the Natura 2000 Network. This habitat type therefore can help preserve some species on the red list (Rada et al., 2022). The analysis shows that 14% of these corridors also cross semi-natural habitats, including grasslands and scrub, most of which are covered by Habitats of Directive as habitat 6220 and 5330. Consistent with other studies (Morabito et al., 2024; Ameztegui et al., 2021; Wimberly et al., 2018), the presence of ecological corridors appears to be important for maintaining connectivity and improving the quality of these habitats for many native species, especially those growing in areas surrounded by agricultural territory. Indeed, the literature suggests that many organisms, including insects (Swengel et al., 2013) and plants (Wagenius et al., 2010), appear to be sensitive to the size of grassland patches.

Protected areas, as the sites of the Natura 2000 network, can contrast human land-use change and limit pressures and threats to species diversity and habitat richness, leading to better conditions for connectivity, naturalness and thus positive conservation outcomes. (Gray et al., 2015; De Oliveira et al., 2017). Connectivity is one of the most important factors to consider when assessing the conservation status of habitats and Natura 2000 sites (Rincón et al., 2021). Consistent with other studies (Thompson et al., 2017), the biodiversity of each habitat patch in the whole (regional) network decreases with habitat loss. Within the Ecological Network, species richness decreases with habitat loss (Villard and Metzger, 2014).

Establishing an ecological network can reduce the negative impacts of fragmentation and support continuity between areas of high naturalistic value. Furthermore, according to Saura et al. (2011), another fundamental aspect of these structural connectors is that they are important physical entities for biological conservation and biodiversity assessment.

## 6.5. Conclusion

The innovative combination of methods for mapping, characterizing, and prioritizing the conservation of Directive habitats and Natura 2000 sites has led to the elaboration of the ecological network map of the region. This map allows the assessment of the most valuable habitats to support connectivity aimed at maintaining high biodiversity values. Our results provide critical spatially explicit information to guide land-use planning efforts to improve Natura 2000 site connectivity in the Calabria region.

Our approach is potentially applicable to support and encourage the design and implementation of land management measures that support biodiversity conservation and connectivity of functional ecological systems. It can serve as a guide for different countries or regions

Landscape connectivity represents an ecosystem service of great importance for plant and animal biodiversity, for the maintenance of ecosystem services and for the reduction of extinction rates (Haddad et al., 2015)

In particular, the Calabria Region, despite having a fairly complete and updated cognitive framework thanks to the Nature Map (Aramini, et al., 2023), has not yet planned an ecological network created on a scientific basis as desired by the "Prioritised Action Frameworks" (PAF) (Regione Calabria, 2023), which considers it a priority to define the connection areas (ecological corridors) necessary for the definition of the "Regional Ecological Network" concerning the important role it plays for the conservation of biodiversity on a regional scale.

**Supplementary Materials:** Supplementary Materials Table S1.

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Action 6.5.A.1—Actions provided for in the Prioritized Action Framework (PAF) in the  
Natura 2000 Network Management Plans, scientific manager Giovanni Spampinato.

## **CHAPTER 7 Landscape assessment through Carta**

### **Natura habitats**

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**Proceedings Papers**

## **Abstract:**

The Nature Map information system is provided by Law 394/1991, with the aim of identifying the state of the environment in Italy and evaluating the quality and fragility of its territories. Carta Natura is an information system useful for evaluating biodiversity; it evaluates the state of conservation of ecosystems, estimates the ecological value of environmental units, identifies regional critical issues and ecologically connected areas. This data is vital for effective regional ecological network planning. For the creation of Carta Natura, the methodology proposed by Ispra was considered. In the preliminary phase the habitats were mapped starting from the "Land use map" provided by the Calabria Region (map scale 1:5000). During the analysis of the cards created with Google Earth Pro, each polygon was marked with placeholders, the habitat code of the Nature Map 2019, and any mosaics or subdivisions of the polygon were highlighted. Subsequently, on the shp file with the polygons arranged according to the Legend of the Nature Map, QGIS was used to correct any errors in the assignment of the biotopes mapped thanks to the orthophotos, and to highlight the habitat types according to the preliminary phase or in the previously prepared maps. Subsequently, the 53 habitats belonging to different macro-categories were identified. The work focused on the evaluation of the ecological integrity of the habitats that characterize the environmental units of the Amendolea Basin, thanks to the comparison of the following data: phytosociological analyses, phytosociological surveys of the vegetation, evaluation of the index of biological forms. This research has led to a real representation of the vegetation and environmental state of the entire area of one of the most important rivers in Calabria, allowing an overall assessment of the naturalness and anthropological pressure to be carried out. The study of all the floristic, vegetation and ecological components, linked to the evaluation of biodiversity and environmental quality, are important for evaluating development dynamics, useful for predicting future

scenarios on climate change and land use, and for strengthening management activities.

**Keywords:** Carta Natura, Landscape, Conservation, Calabria, Vegetation.

## **7.1. Introduction**

The Nature Map is a territorial information system compliant with the Italian Law on Protected Natural Areas (no. 394/1991), which, by representing the spatial distribution of habitats, allows the quality and fragility of the state of the natural environment in Italy to be assessed. The definition of habitats is in accordance with Corine Biotopes criteria, which has been adapted by ISPRA (2009) Italian territory. Classification and assessment levels are achieved through the use of widely shared indices and indicators (Ceralli et al., 2014) that aim to describe and classify the complexity of ecosystems and their conservation status. Among the various ways of studying terrestrial ecosystems, the most widespread and accepted is based on the analysis of vegetation (Musarella et al., 2020; raposo et al., 2023; Glemarec et al., 2023), also used to map the distribution of habitats [Rivieccio et al., 2022, Morabito et al., 2023; Rivieccio et al., 2023]. Vegetation changes as a result of ecological processes acting at different spatial and temporal scales, and it is critical to assess and understand vegetation changes to manage natural habitats (Cantoral et al., 2019). As known in the literature (Van der Maarel 2005) the methods used for the assessment of biodiversity and nature conservation at the level of species and habitats on a European scale, are based on the study of vegetation, indicative for the functioning and structure of the ecosystem (Cano et al.; 2017, Cano et al., 2022). Several studies have evaluated the naturalistic-environmental value of territorial units through the use of vegetational and floristic data (Poldini et al., 1989; Cano et al., 2022). Each vegetational association reflects a certain ecological space that synthesizes the ecological processes that organize the vegetation model for the expected spatial scale of the applied mapping system (Rivas-Martinez 1987; Biondi et al., 2004; Pedrotti 2013). Assessing habitat quality helps to understand the conditions of

biodiversity and the benefits and health of ecosystems (Raposo et al., 2022; Musarella et al., 2020). Habitat maps make it possible to organise ecological models useful in the conservation and management of ecosystems (Guisan et al., 2000; Česnulevičius et al., 2022). Research on habitat monitoring and conservation status assessment is critical to enrich monitoring protocols and clarify definitions of conservation status parameters (Angelini et al., 20018). Landscape biodiversity is very sensitive to land use change (Sala et al., 2000). Landscape metrics indicators, assessed on habitat coverage, can be useful in estimating vegetation naturalness (Szabò et al., 2013). Assessments based on the landscape model are increasingly used in monitoring programmes, as in the case of forest vegetation (Noss 1999). Landscape characteristics can modify ecological processes (Turner et al., 2015) and the species distribution of a habitat, especially for environments with a higher degree of fragmentation (Branks et al., 2011). The fragmentation of natural landscapes is one of the greatest threats to biological diversity at the planetary level. Evaluating and quantifying the shape, size, distance between the various polygons and connectivity of each habitat have become important tools in ecological research (McGarigal et al., 1995). Numerous studies assess the degree of naturalness of vegetation using maps of habitats (Capotorti et al., 2012; Ferrari et al., 2008; Baiamonte et al., 2008; Fanfarillo et al., 2018). Today, in the various researches, many methodologies are being experimented with in order to correlate the study of vegetation with the analysis of the landscape. The purpose of this research is to develop a methodology to assess the ecological integrity of ecosystems, based on Nature Map habitats, which allow an estimation of the quality of the environment, ecological value, ecological sensitivity and anthropogenic pressure, considering the last two parameters it is possible to estimate environmental fragility. The Nature Map, therefore, allows us to evaluate the naturalistic value and the sensitivity that indicates the intrinsic aptitude of each habitat to suffer damage or in any case changes. With these analyses it is possible to evaluate environmental quality and

define the areas of greatest naturalistic value and those with greater fragility in order to offer tools for reflection to implement actions aimed at protection and territorial planning.

## 7.2. Materials and methods

### 7.2.1. The case study of the Fiumara Amendolea territory

The analyses were carried out on the territory of the Amendolea river (Ionic slope of Southern Calabria) (Figure 7.1, 7.2). The area includes a large part of the "Fiumara Amendolea - IT9350145" SAC, the Torrente Menta - IT9350154 SAC and the "Contrada Scala- IT9350180" SAC, which are part of the Natura 2000 Network) and two thirds of it is part of the Aspromonte National Park. In this study, to create the Nature Map, we started from the Map of the Use of the Territory provided by the Calabria Region (Map of places scale 1:5000).

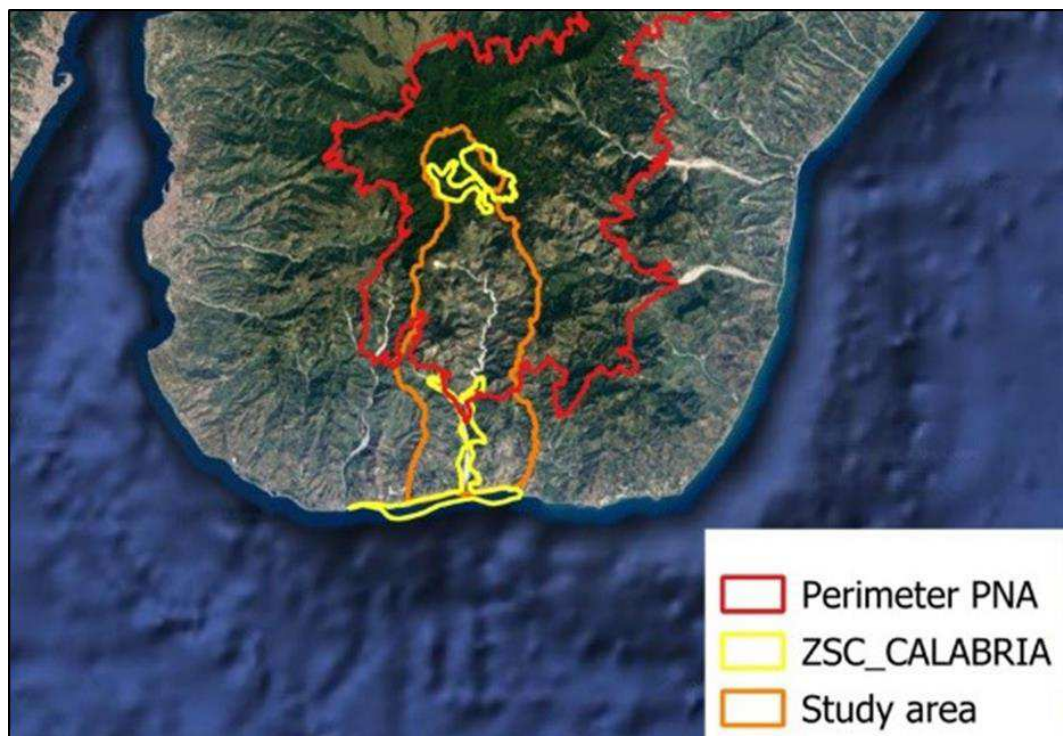
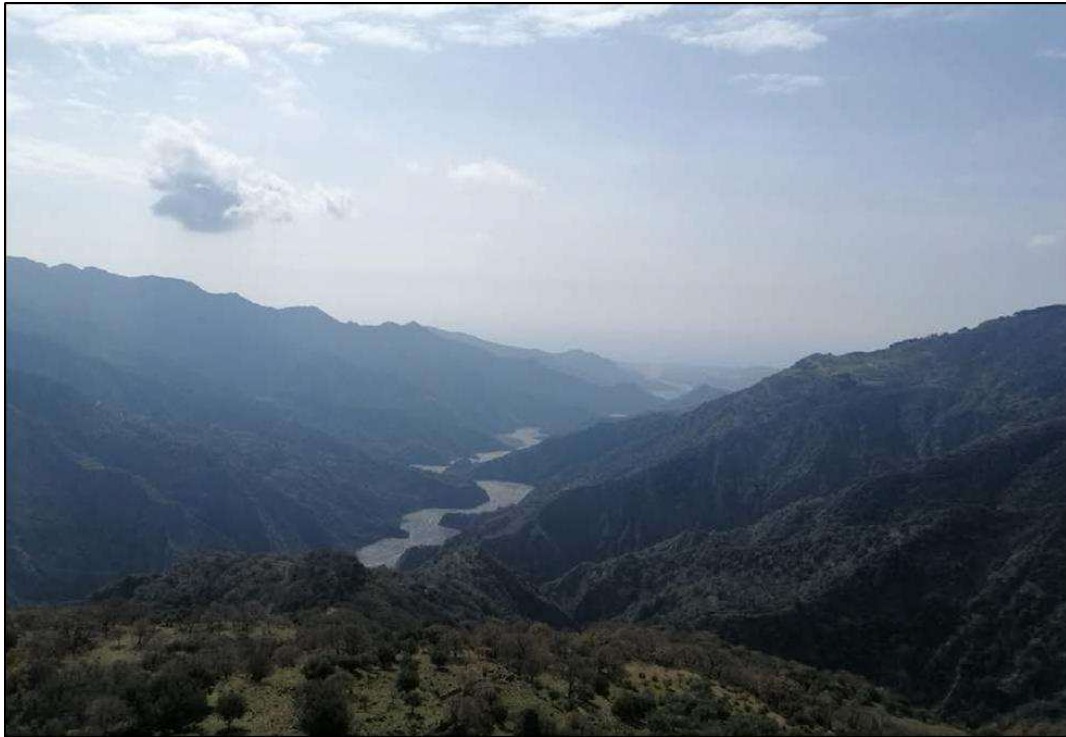


Figura 7.1. Study area



*Figura 7.2. Fiumara Amendolea*

Using Google Earth Pro, each polygon was resampled in accordance with the legend of Carta Natura (ISPRA 2009), highlighting any mosaics or subdivisions of the polygon. Subsequently, field checks were initiated through two types of surveys: expeditious surveys, through the recognition of habitat guide species with related photos and surveys on the vegetation characterizing the habitat with the Braun-Blanquet phytosociological method (Braun-Blanquet 1928) which is based on the recording of the presence and abundance of plant species in habitat types. In addition, useful pressures and threats were recorded by means of a three-level estimate, to highlight the critical issues and problems of conservation of the habitat detected in the territory. For the nomenclature of the species, the "Portal of the Flora of Italy" (2023) was used, while for the biological forms reference has been made to Pignatti (2017). Then, the shp file containing the reinterpreted polygons according to the Nature Map Legend, was reviewed and corrected by QGIS taking into account both the updated field and orthophoto contacts (Bagnai et al., 2017). For the assessment of eco-logical integrity (EI) at the

landscape level, several indicators were considered: naturalness, habitat fragmentation, diversity of habitat types, dominant habitat types. Naturalness was assessed through the Landscape Conservation Index (LCI) (Pizzolotto et al., 1996), which varies between 0 and 1 and is proportional to the importance of the natural habitats present in the territory analysed.

$$ILC = 1 - (A/A_{max})$$

$A = \sum x_i - 100$ ;  $x_i$  = cumulating percentage value end area;  $A_{max} = 100 * (nc - 1)$ ;  $nc$  = is the number of categories

The evaluation of fragmentation was carried out through the use of spatial analysis indices (Bagnaia et al., 2017), using Fragstats software (Version 4.2.1) (McGarigal and Jan 2015; McGarigal et al., 2012). In particular, the number of patches for each class (NP), the density of the individual patches for each class (PD) and the average area (Area\_MN) of each class were calculated. Fragmentation was also assessed by taking into account the number of polygons and the total area occupied by various types of habitats in the GIS.

$$NP = n_i$$

**NP** = patch number;  $n_i$  = Number of patches in the patch type landscape (classe)<sub>i</sub>.

$$PD = \frac{n_i}{A} (10.000)(100)$$

**PD** = densità della patch  $n_i$  = numero di patch nel paesaggio di tipo patch (classe)<sub>i</sub>;

$A$  = area totale del paesaggio (m<sup>2</sup>).

#### **AREA\_MN**

Class-level average area is a function of the number of patches in the class and the total area of the class.

The various indices were subjected to an exploratory survey through cluster

analysis with the PAST<sub>3</sub> statistical analysis program (Hammer 2009). To investigate any relationships between some of the parameters detected, a Pearson correlation model was applied (Warton et al., 2006).

### 7.3. Results

Figure 7.3 shows the Nature Map of the study area and its legend. The map shows the various mapped biotopes belonging to 53 different habitats.

The largest area is occupied by semi-natural habitats (Figure 7.43) with 45%, the most representatives are: Habitat 32,215 Macchia in *Cytisus laniger*, *Cytisus spinosus*, *Cytisus infestus*, the considerable area of this habitat is directly linked to the degradation of habitat 45.31 Thermal and mesomediterranean holm oak woods (Cammareri et al., 2002), and habitat 31,844 Bushes in Italian hilly and mountain brooms. Natural habitats cover 30% of the surface, among these there are habitat 41.18 (Faggete of southern Italy) dominant in the supertemperate range at altitudes between 1000- 1900 m (Brullo et al., 2001), habitat 42.65 of pine forests that settles on more acclivity and sunny surfaces with poorly developed soils (Spampinato et al., 2009). Finally, the habitat 41,732 Mediterranean oak trees widespread in the mesomediterranean belt at altitudes between 200-800 m on deep acid soils originated from crystalline rocks such as especially gneiss and schists (Spampinato et al., 2009)] Agricultural habitats cover 19% and urban habitats 6%.

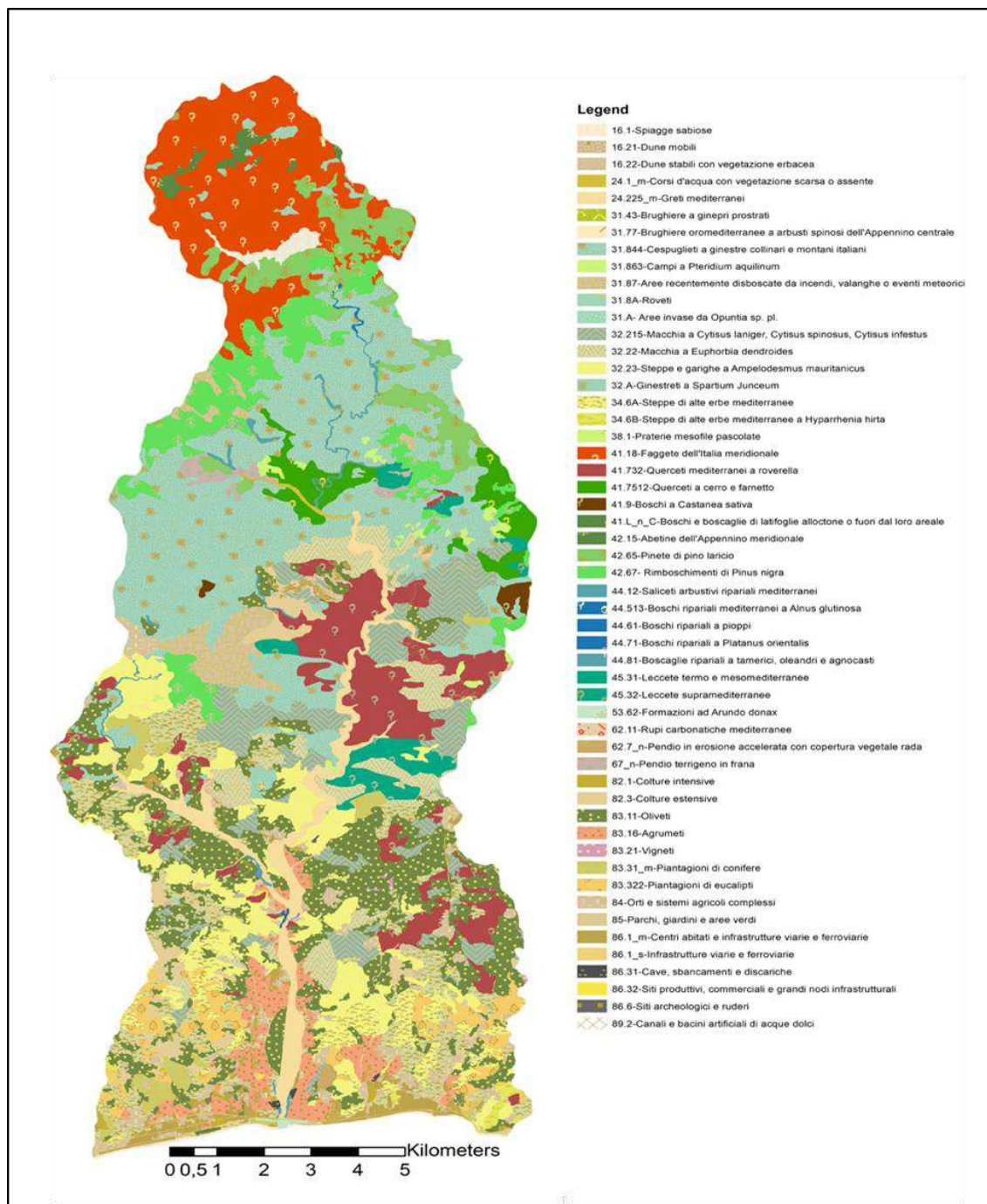


Figura 7.3. Nature Map of the territory of Fiumara Amendolea (RC).

The naturalness value of the studied area, taking into account the mosaic of habitats of each polygon is 0.56 (Figure 7.5), while it is 0.69 if we take into account only the dominated habitats. In Fig. 4 these values are compared with those on a national scale, from which it can be seen that the study area is located between

the values of medium-high naturalness.

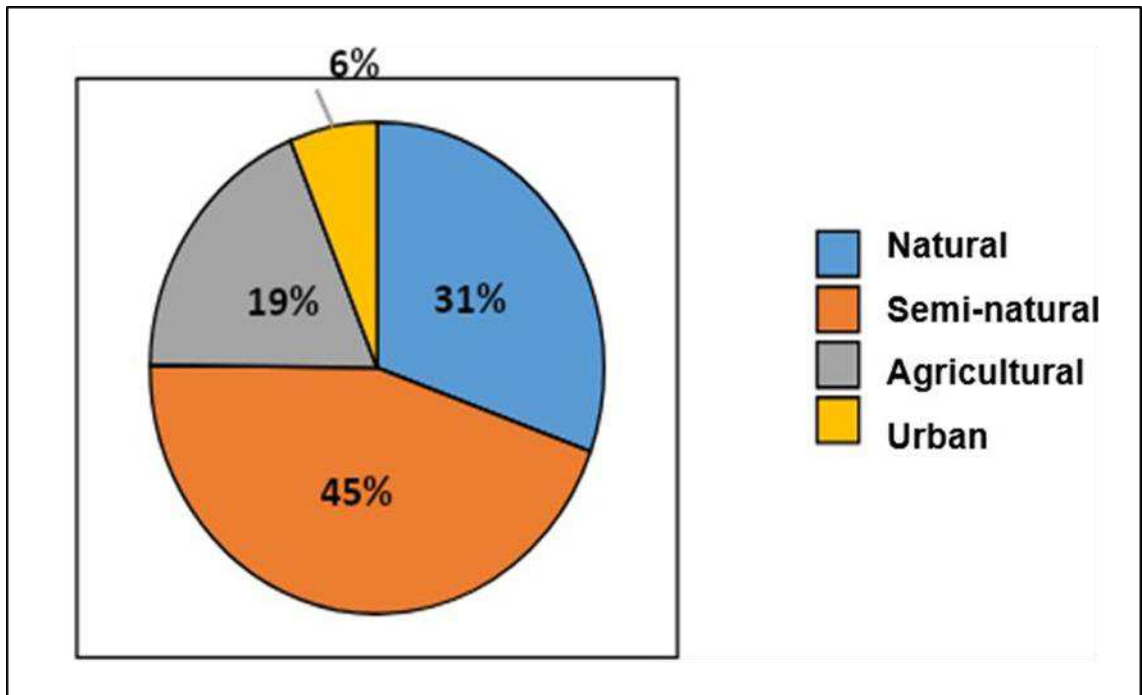


Figure 7.4. Total area occupied by the various habitats combined according to naturalness: Semi-natural; Natural; Agricultural; Urban.

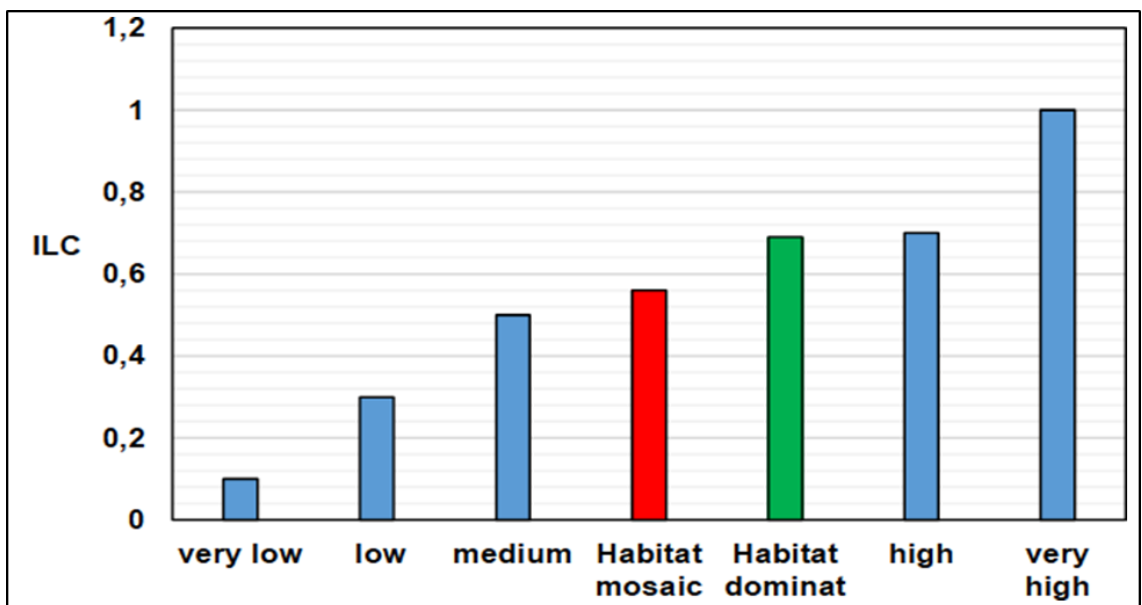


Figure 7.5. ILC index value calculated for the study area and compared to the values on a national scale. In red the index was calculated on the mosaic between main habitat and secondary habitat (ILC 0.56), in green considering only the main habitat (ILC 0.69).

The analysis of the fragmentation indices (Figure 7.6) highlighted the greater compactness of the habitats (41.18: Beech forests of southern Italy, 42.15 Abetine of the central and southern Apennines, 42.65 Pine forests of larch pine) compared to the others. These habitats, in fact, consist of a smaller number of patches and polygons, with a larger average surface area, compared to fragmented habitats such as sub-nitrophilic grasslands (34.8\_m), rivers (24.225\_m) and psammo-philic habitats (16.1, 16.21. 16.22).

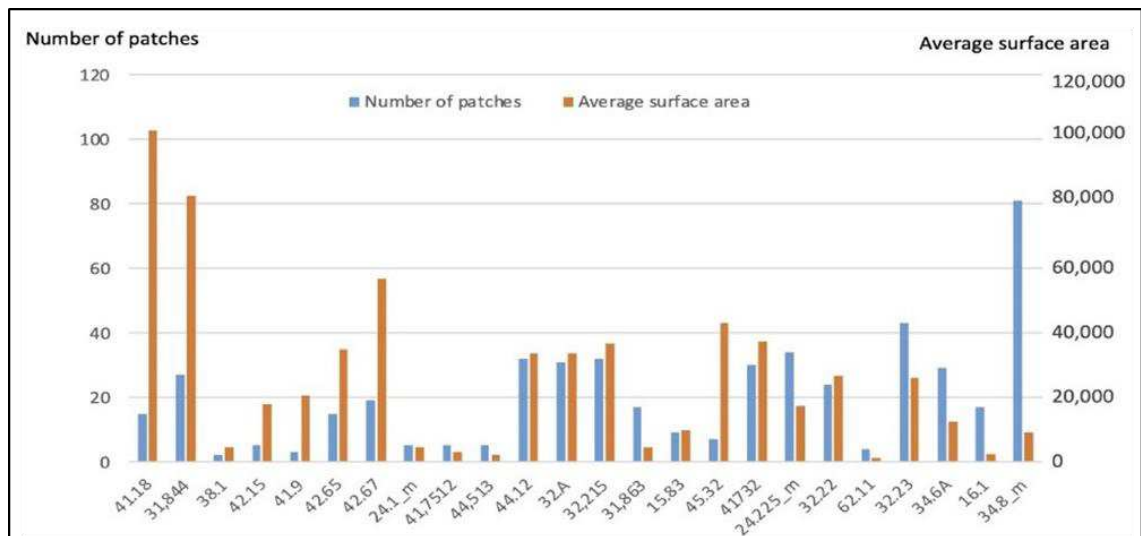


Figure 7.6 Number of patches and average surface area (ha) by habitat type, from Fragstats analysis.

The results of these indicators developed by the GIS were compared with those obtained from a different approach, in which the conservation status of the habitats is assessed through a series of indices that, using phytosociological surveys of the vegetation, take into account the floristic composition of the habitats. In particular, the following indices were evaluated:

$$IT = \sum \frac{[C(t)]i}{C_{tot}} * 100 \quad IF = \sum \frac{C(f)j}{C_{tot}} * 100 \quad IH = \sum \left[ \frac{[C(h)]j}{C_{tot}} * 100 \right]$$

$$IP = IH + IF$$

IT= Index of the therophytic component;

IP= Index of the perennail component;

IH= Index of the hemicryptophytic component;

IF= Index of the perennial non-hemicryptophytic component

$[c(t)]_j$  ;  $[c(h)]_j$  ;  $[c(f)]_j$  = coverage values of each therophyte species (t), and perennial hemicryptophyte (h) or non- hemicryptophyte (f) species, given as the absolute value relative to a single sampling, or as a mean value of samplings from a table;

C(tot) = total coverage value, obtained by summing the values of c for all of the species present, according to the formula  $[C(\text{tot})= \sum c_i]$

The values of the indices of the biological forms (Table 3.2; Figure 7.7), stand out for the habitats of the rivers (24.225\_m, 24.1\_m, 44.81) and those of the beaches (16.1. 16.22.16.22) maximum values of IT (index of terophyte species) that expresses the pioneering trend of herbaceous communities characterized by high human disturbances (e.g. fires, grazing), while the abundance of perennial species, which determines high values of IP and IH and IF is observed in habitats 41.18, 42.65 42.15, are to be linked by the evolution of vegetation towards stable cenoses with low levels of disturbance.

Habitat	IT	IH	IF	IP
16.1	52,7	0,9	47,3	48,2
16.22	38,8	61,2	0	0
24.225_m	40,0	40,0	27,0	67,0
32.23	19,1	57,8	23,1	80,9
16.21	47,0	1,8	50,5	52,3
62.11	0,0	65,1	34,9	100
44.61	11,5	10,4	78,1	88,5
44.513	0,2	5,5	94,3	99,8
42.15	0,5	27,6	70,6	98,2
32.215	1,26	9,09	82,07	91,16
44.81	38,5	17,8	43,3	61,1

31.77	6,6	53,0	24,0	77,0
42.65	0	14,8	84,4	99,3
41.18	0	20,2	79,8	100
45.32	1,2	31,3	67,5	98,8
32.22	0,8	40,6	28,9	69,5
41.7512	2,4	29,7	67,9	97,6
34.6A	10,1	87,1	2,8	89,9
41.9	3,3	14,4	82,3	96,7

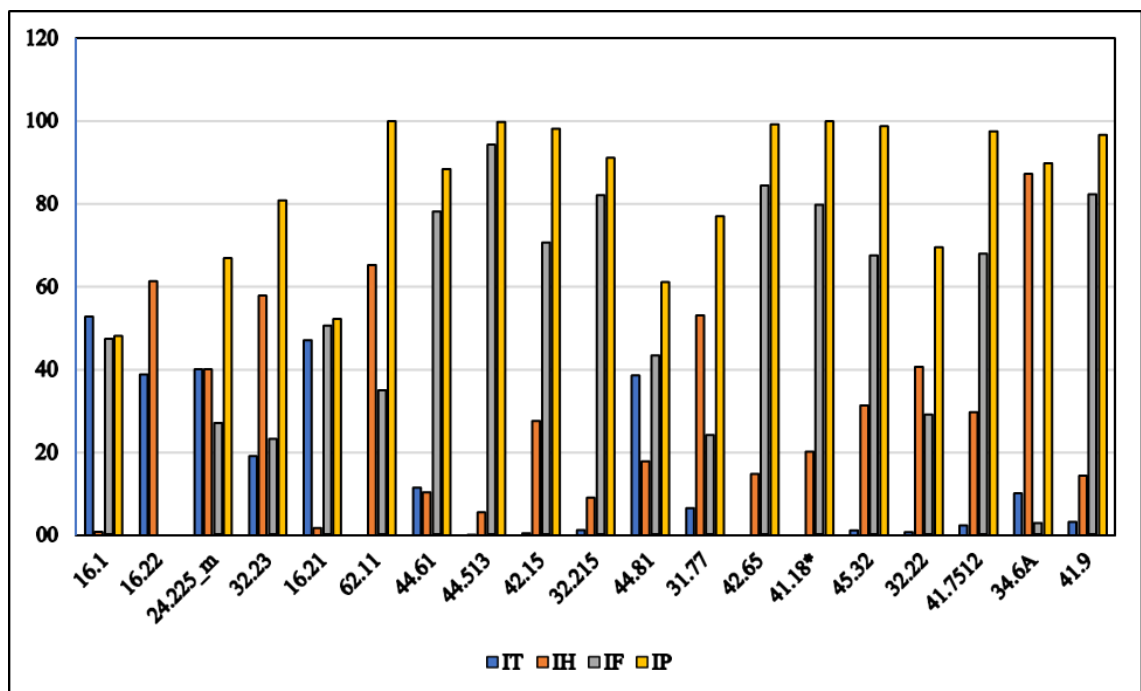


Figura 3. Assessment of habitat through phytosociological analysis of vegetation by Life forms index values.

## 7.4. Discussion

The analysis carried out in this study shows that the analysis of the habitats of Nature Map makes it possible to highlight the state of conservation of the environment. The habitats present at the highest altitudes show a better state of conservation such as that of beech forests, while the habitats with less naturalness are the beaches, the prairies and the waterways that show in both analyses a

strong disturbance, caused by a condition of "non-equilibrium" that determines the presence of continuous dynamics of the ecosystems. Anthropogenic activity affects vegetation, generating changes in dominant species, diversity and cover (Valladares et al., 2008). The high number of ruderal terophyte species of the class *Stellarietea mediae*, and nitrophilic and hygro-nitrophilic species of the classes *Artemisietea* and *Gallio-Urticetea* living along waterways and on beaches, is a clear sign of disturbance as suggested by the low IP value. The beech trees have a low fragmentation linked above all to the large area occupied, and to the smaller number of polygons. This is very relevant because these habitats host in accordance with other studies (Rosati et al., 2010) a greater number of rare, nemoral, and specialized species. While the 41,732 habitat characterized by a large surface area is a number of larger polygons, it has a greater fragmentation, in fact, according to (Mercurio et al., 2022) in Calabria these formations tend to form numerous groups, often very degraded by anthropogenic impact.

## **7.5. Conclusion**

The study of vegetation is one of the indispensable components for the conservation and recovery of the environment around us, allowing the identification of habitats of interest (Angiolini et al., 2017). According to several authors (Mustățea et al., 2022), nature maps can represent a suitable tool for the conservation of several rare and protected floristic elements located in highly fragmented habitats (Geacu et al., 2018).

As known in the literature (Peng et al., 2017; Wang et al., 2021) the compromising impacts of urbanization and the associated anthropogenic disturbance on ecosystems can be filled with the creation of ecological networks, so as to allow the ecological connectivity of distant habitats. Measuring ecological integrity is important for detecting environmental changes and assessing the condition of the landscape, providing an appropriate spatial framework to facilitate such assessment and landscape-level planning.

## **CHAPTER 8. State of the knowledge on the monumental trees of the Calabria region**

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**Articles for submission**

## **Abstract**

Monumental trees are an important biological, cultural and aesthetic heritage. They are defined as key structures for the functioning and maintenance of biodiversity in forests, sparsely vegetated landscapes and urbanised landscapes. Knowledge of the distribution of ancient trees in different biotopes can become an important element in the restoration and ecological maintenance of these landscapes through landscape planning and biodiversity conservation.

Thanks to various publications and to the work carried out on behalf of the Regional Department for Territorial and Environmental Protection of Calabria, 119 monumental trees have been identified. The aim of this study is to identify the habitats in which these monumental trees are found, using Carta Natura. The analysis of the regional database has made it possible to distinguish between native species, typical of the habitats that characterise the region's forest heritage, and non-native species, mostly cultivated for ornamental purposes.

The use of GIS has shown that Calabria's monumental trees are distributed throughout the region, but most are concentrated in the mountainous areas of the three National Parks: Aspromonte, Pollino and Sila. Thanks to the use of natural maps, it has been possible to identify that most of these ancient trees fall in natural environments, while only a small part fall in agricultural and urban environments.

The results show that nature maps are an important tool for acquiring spatial knowledge. The monumental trees make it possible to reconstruct past vegetation, highlighting the changes that the landscape has undergone over the years due to fires, urbanisation and agriculture. Despite the good availability of data and information, there is certainly a lot of work to be done to complete the knowledge framework of the Calabria region and to make the protection of the important heritage represented by the monumental trees fully operational.

**Keywords:** Biodiversity, Ecology, Habitats, Monumental Trees

## 8.1. Introduction

Monumental trees are an important biological, cultural and aesthetic heritage (Roggero, 2015; Fay and Butler 2017; Zapponi et al., 2017; Ciani et al., 2018) and defined as an important resource for species support and assembly (Amador-Cruz et al., 2021), and play an important role in carbon storage (Stephenson & al. 2014).

Monumental trees, due to the high presence of microhabitats, are defined as important biodiversity hotspots for the biological and ecological continuity of genetic resources, and habitats for numerous organisms (Larrieu et al., 2018; Di Santo, 2015; Manning et al. 2006 - 2009

Italy is particularly rich in this heritage with 2,407 specimen trees evenly distributed throughout the country (Farina et al., 2018).

These trees are located in different types of landscape, forest areas, urban centres, historic gardens and agricultural areas (Ninot & al. 2018, Waiter & al. 2021; Schicchi & al. 2021), this distribution is strongly influenced by anthropogenic activity (Skarpaas et al. 2017).

Today the number of monumental tree populations is greatly decreasing (Lindenmayer et al., 2017). According to several authors, the main threats are due to mortality (Gibbons et al. 2008, Le Roux et al. 2014), climate change (vAnderegg et al., 2013; Pfautsch et al., 2016), fires (Bluff, 2016; Crane et al., 2016), deforestation (Schiermeier, 2016), and urbanization (Forman, 2014).

Therefore, in cities and other densely populated areas, the presence of large trees should guarantee policy makers and resource managers greater attention on the part (Lindenmayer et al., 2014).

According to the authors Bennett et al. (2015) Allen et al. (2015) large trees are

more susceptible to increasing drought than small trees. The authors McDowell, 2015; Allen et al., 2010, suggest that these large trees subject to sapling cavities are also exposed to high radiation loads. While in mountain areas with higher humidity, the oldest monumental trees are found (Piovesan et al., 2018; Liu et al., 2019b).

According to Brodribb et al., (2012) gymnosperms compared to conifers show greater longevity. In recent times, the conservation of monumental trees has particular significance (Piovesan 2019) for the ecological role they play in the dynamics and functions of the ecosystem (Lindenmayer and Laurance 2017, Lutz et al.2018).

Secular forests are defined as an important source of data to study the processes that drive the various paths of succession (Petrian 2014).

The size, age and spatial distribution patterns of large trees allow us to interpret evolutionary dynamics on long-term environmental changes (Phillips et al., 2008) and disturbances (D'Amato and Orwig, 2008).

The spatial distribution of monumental trees can be influenced by a variety of factors acting on different temporal and spatial scales (Ikin et al.; 2015; Moga et al., 2016). Knowledge of the distribution of secular trees in different biotopes, through landscape planning and biodiversity conservation, can become an important element for restoring the ecological maintenance of different landscapes (Orłowski et al., 2007).

The Calabria Region shows a remarkable forest cover characterized by different types of forests, Mediterranean and temperate (Mercurio et al. 2022) and preserves a remarkable heritage of monumental trees of significant ecological and naturalistic value. In this article we aim to provide some general information on the monumental trees of the Calabria Region, including spatial distribution through the use of Nature Paper (Aramini et al.; 2023).

## 8.2. Materials and methods

This study was conducted in the Calabria Region, starting from the regional list of monumental trees, drawn up in accordance with current legislation on the subject. For each of the specimens registered in the list, the scientific name and the common name, the location with the coordinates, the dendrometric data and the monumentality criteria were reported; in addition, a webGIS was prepared for online consultation (Calabria Region, 2023) and for the purposes of enhancement, information panels were prepared for a better use of the peculiarities of each tree.

In 2023, based on the information available from various publications (Bevilacqua 2001, 2022; Picone & Spampinato 2003; Schettino & Travaglio 2015); Garcea 2003; Scalise et al., 2022; AA.VV. 2011; Piovesan et al., 2017, 2018; Sila National Park 2023; and Pollino National Park 2023; Monumental Tree, 2023), and the work carried out by the Department of Territory and Environmental Protection of the Calabria Region which carried out and coordinated the census activity pursuant to Law no. 10/2013, identifying 119 trees with monumental characteristics, belonging to 37 different taxa. (Figure1).

For the ecological interpretation of where these monumental trees fall, Nature Map () was used using Qgis with reference system WGS84 UTM Zone 33, (False\_East: 500000.00000 False\_North: 0.00000; Meridian\_Central: 15.00000; Factor\_Scale: 0.99960; Latitude\_Origin: 0.00000; Linear Unit: Kilometers), a distinction was made between native and non-native trees.

Finally, the shp of the polygons of the Natura 2000 Network of the Calabria region was used (Figure 8.1) in order to identify the monumental trees that fall within it. While the "Portal to the Flora of Italy" (2023) was used for the nomenclature of the species.

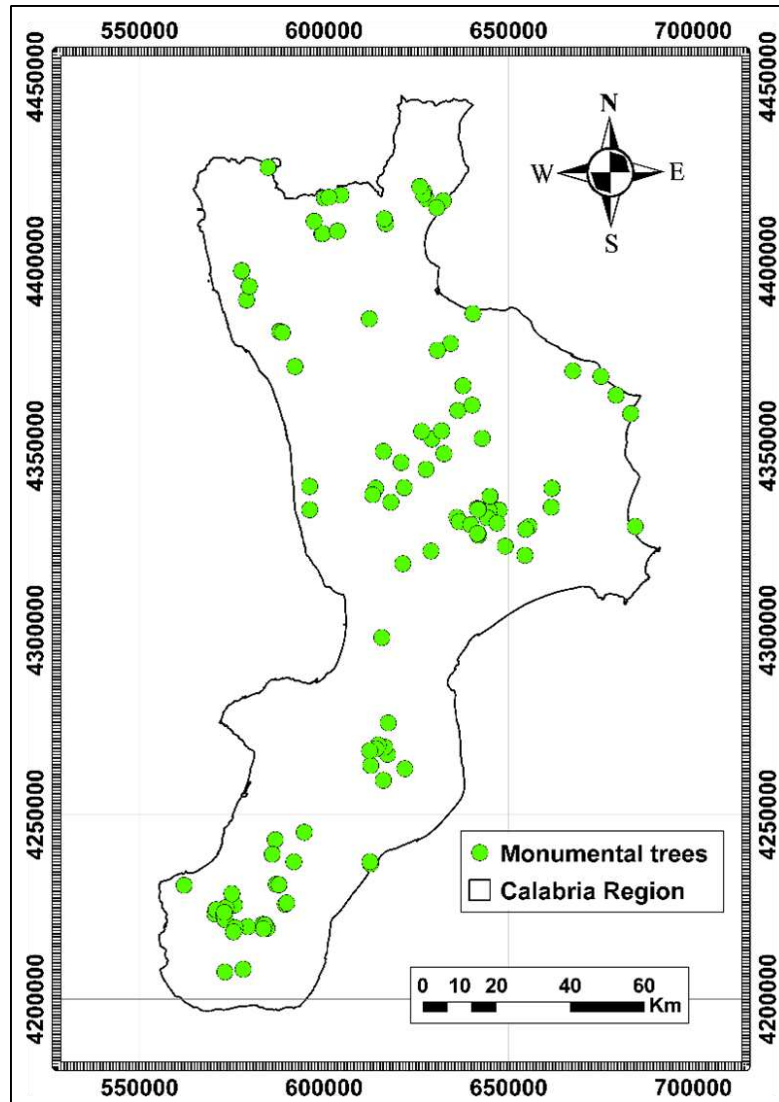


Figure 8.1. Monumental trees registered in the Calabria Region

Figure 8.2 shows the number of individuals characterised by autochthonous species in the natural forests present in the Calabria region. Figure 8.3 shows the monumental trees characterised by allochthonous species. Figure 8.4 highlights the individuals that fall within the Natura 2000 network areas (red colour).

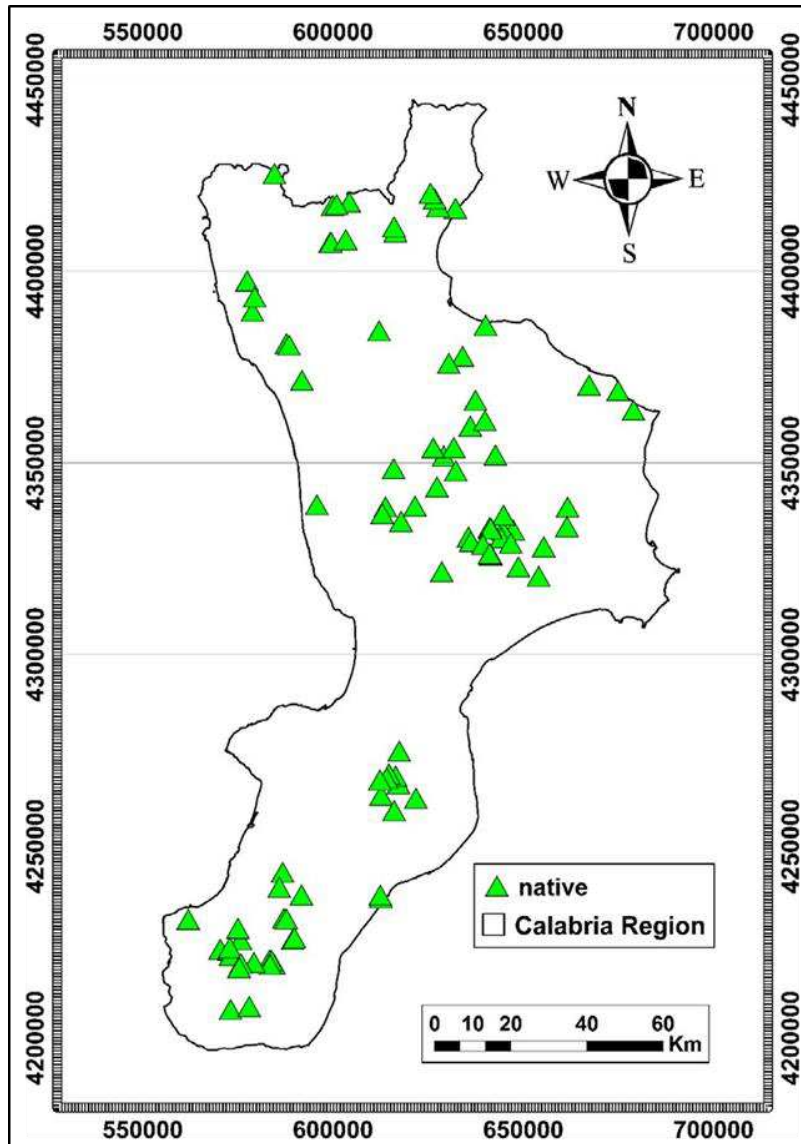


Figure 8.2. Monumental trees with native species

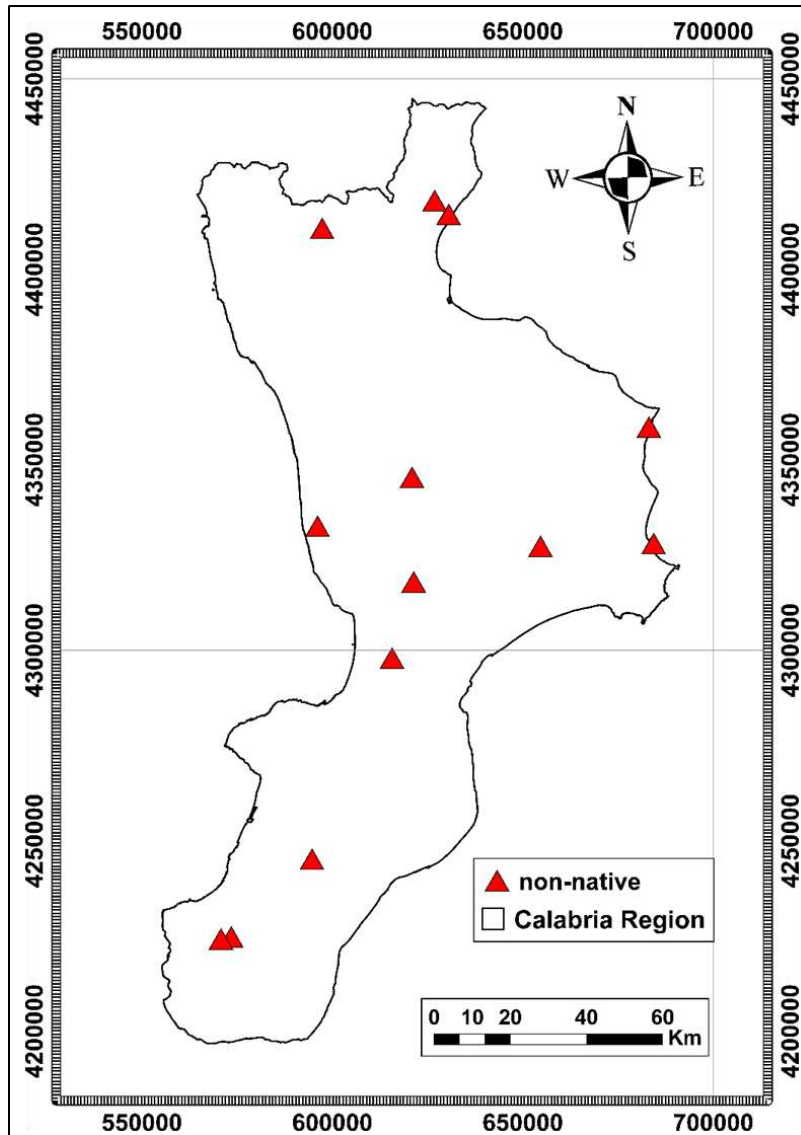


Figure 8.3. Monumental trees with non-native species

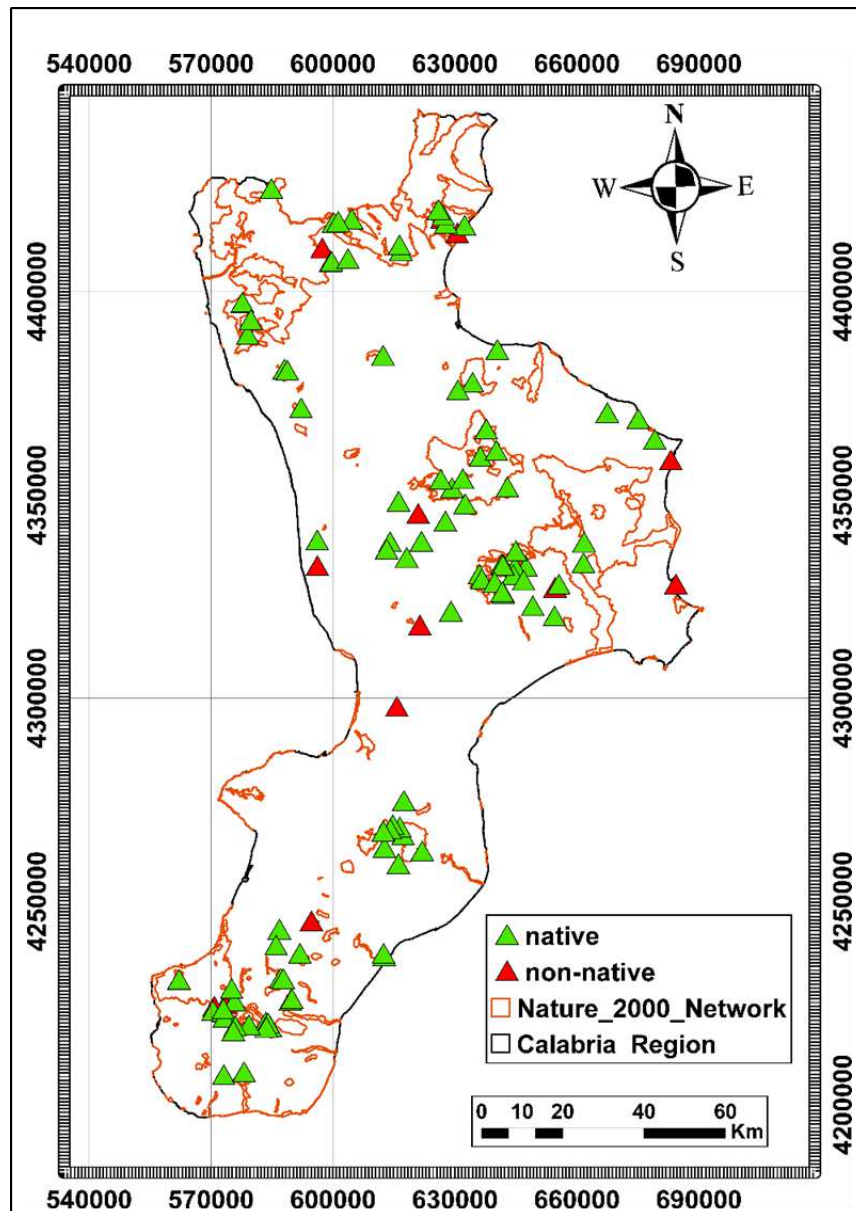


Figure 8.4. Monumental trees (green) in Natura 2000 sites in the Calabria region (red).

### 8.3. Results

Our results show that most of the monumental trees belong to the family of the phagaceae with 46 individuals; and the Pinaceae with 41 individuals (Figure 8.5). The most represented species is *Abies alba* Mill. subsp. *apennina* Brullo, Scelsi & Spamp. with 18 individuals, followed by *Castanea sativa* Mill. with 16 individuals. These are largely native species, but there are also allochthonous trees such as *Eucalyptus camaldulensis* Dehnh, *Populus* × *canescens*.

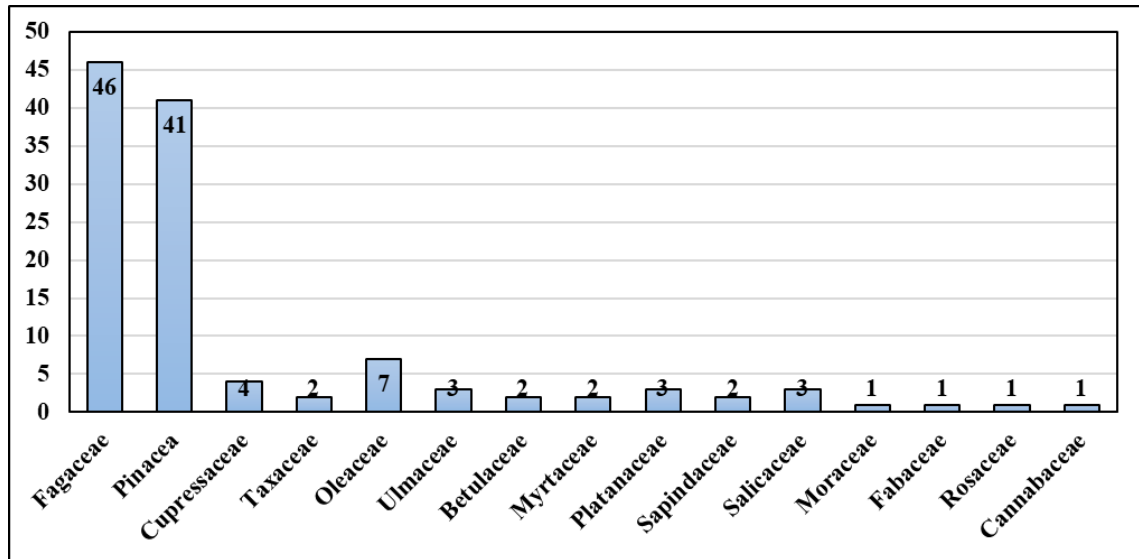


Figure 8.5. Number of monumental trees, grouped in families of tree species

The monumentality characteristics most frequently used for the census of ancient trees are the naturalistic criterion related to age and size and that related to shape and bearing (Figure 8.6).

Among the size parameters, those most evaluated are trunk circumference at 1.30 m and height. The age of monumental trees is not easily defined, although it is one of the criteria for monumentality. The least used parameter is that of crown architecture.

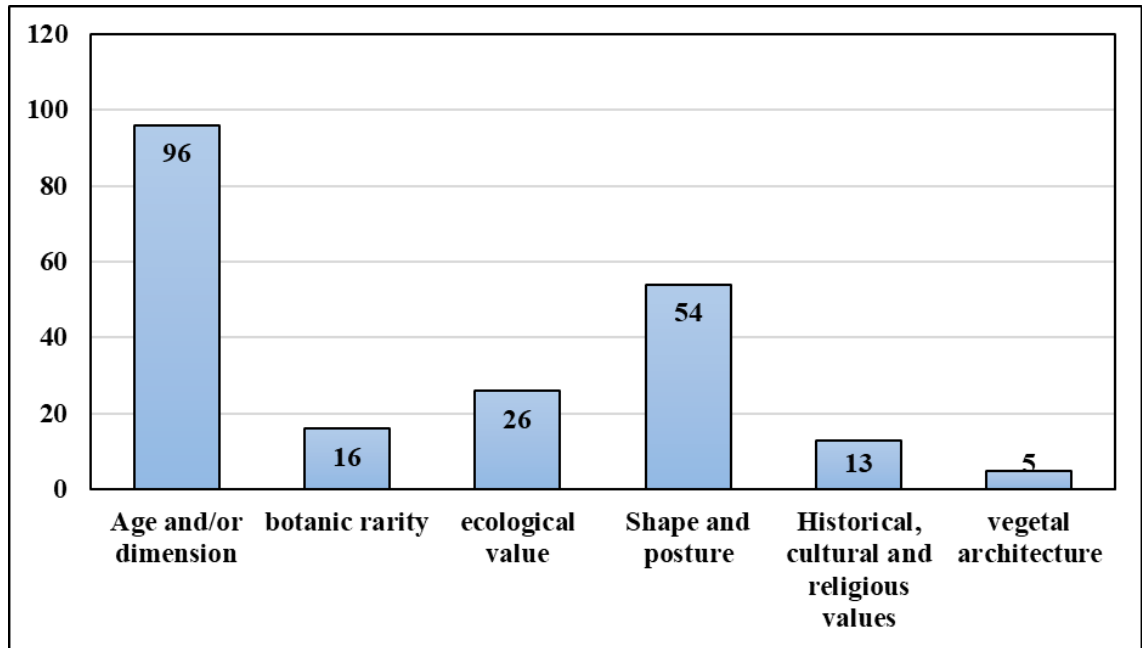


Figure 8.6. Characters of monumentality used to register the various Monumental Trees.

### 8.3.1. Monumental trees in the Natura 2000 network

Some of these monumental trees (48) fall within the areas of the Natura 2000 Network (Figure 8.7). From the graph it can be seen that the species with the largest individuals are *Abies alba* Mill., *Fagus sylvatica*, *Quercus pubescens* Willd., *Pinus nigra* subsp. *laricio* Maire and *Castanea sativa* Mill.). The presence, with low frequency, of two alien species (*Populus canescens* (Aiton) Sm., *Eucalyptus camaldulensis* Dehnh).

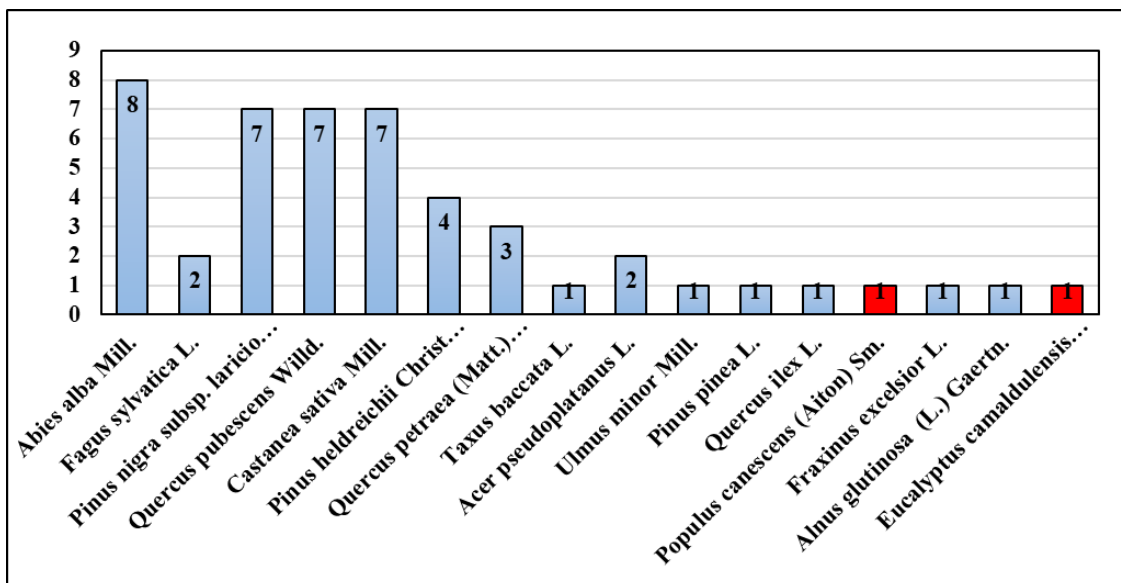


Figure 8.7. Number and species of monumental trees present in the Natura 2000 network of the Region of Calabria

### 8.3.2. Ecology of the monumental trees of the Calabria Region

The interpretation of the various habitats in which monumental trees fall has highlighted that the largest number of individuals (81) fall in forest contexts, while the lower the value that falls in grassland and scrub environments. (Figure 8.8),

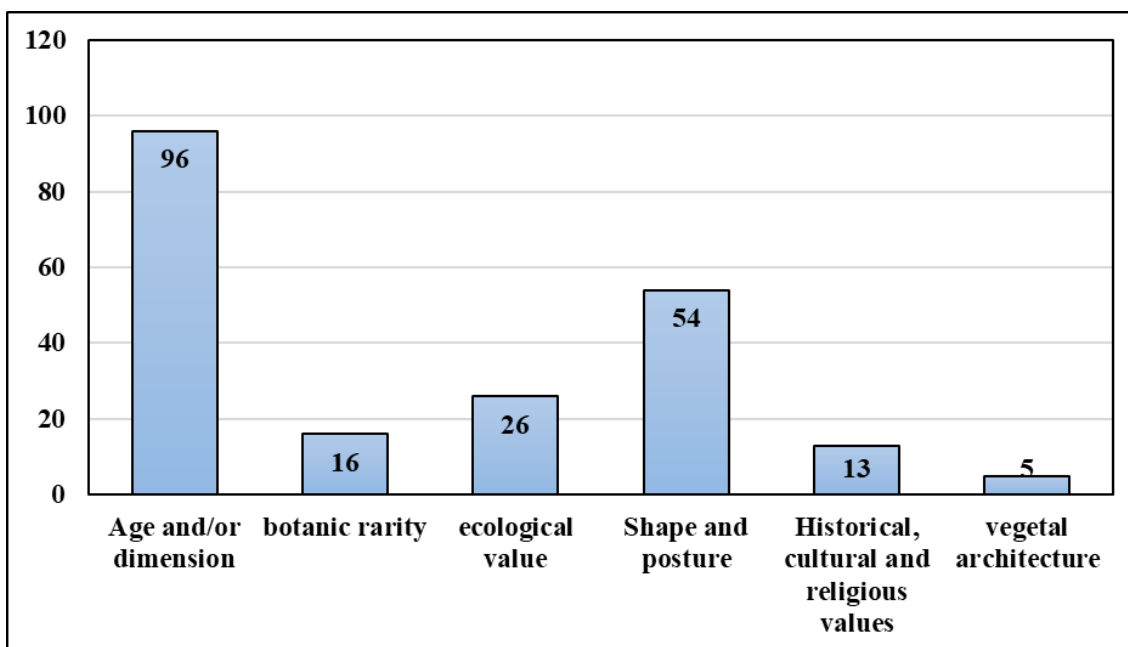


Figure 8.8. Monumental habitats registered for the Region of Calabria.

Figure 8.9 shows the number and species of individuals that fall into the agricultural environment. *Quercus pubescens* Willd. subsp. *pubescens* has a larger number of individuals.

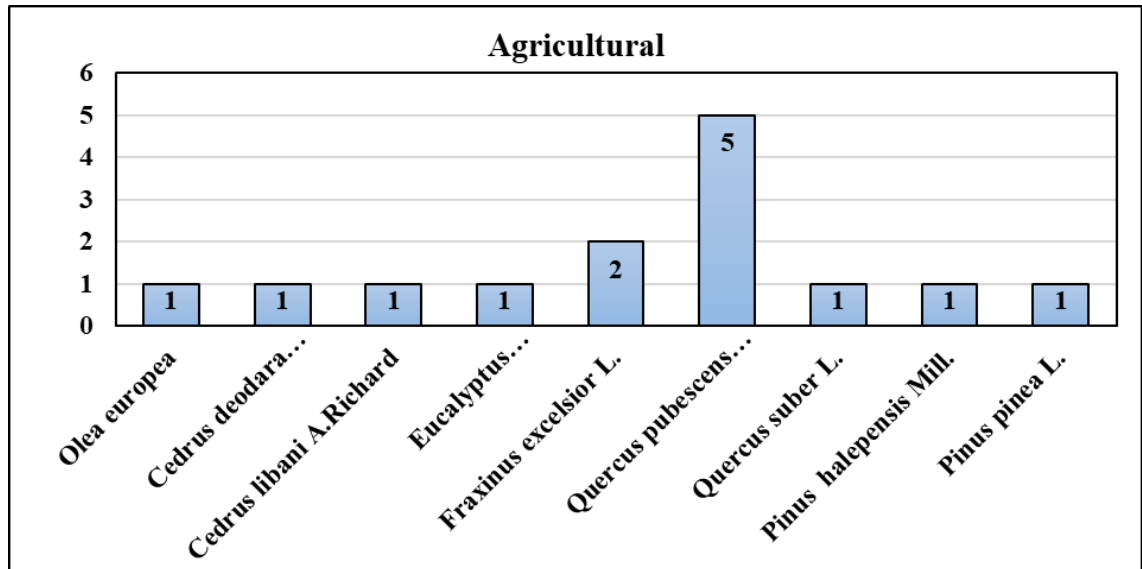


Figure 8.9. The number and type of monumental trees in the agricultural landscape

The graph (Figure 8.10) shows the species and the number of individuals that fall into forest environments. It is noted that the largest number is represented by species typical of the forests present in the *Calabria Region*, such as *Abies alba* Mill., *Castanea sativa* Mill., *Fagus sylvatica* L., *Pinus nigra* subsp. *laricio* Maire. The habitats highlighted in red are allochthonous species present with low frequency.

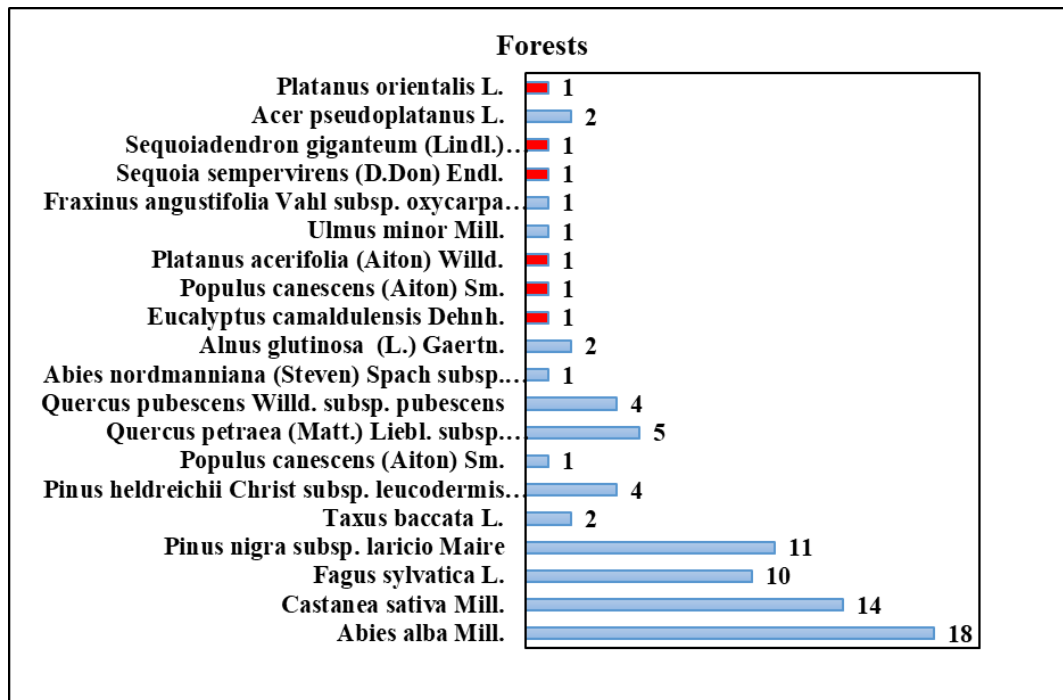


Figure 8.10. The number and type of monumental trees in the forest environment

Finally, the number of monumental trees and the species that characterize them in the urban context are also reported (Figure 8.11). It should be noted that the largest number is represented by *Olea europaea* L. with 3 individuals and by *Quercus pubescens* Willd. subsp. *pubescens* with 2 individuals. The greater the number of individuals characterized by non-native species cultivated for ornamental purposes.

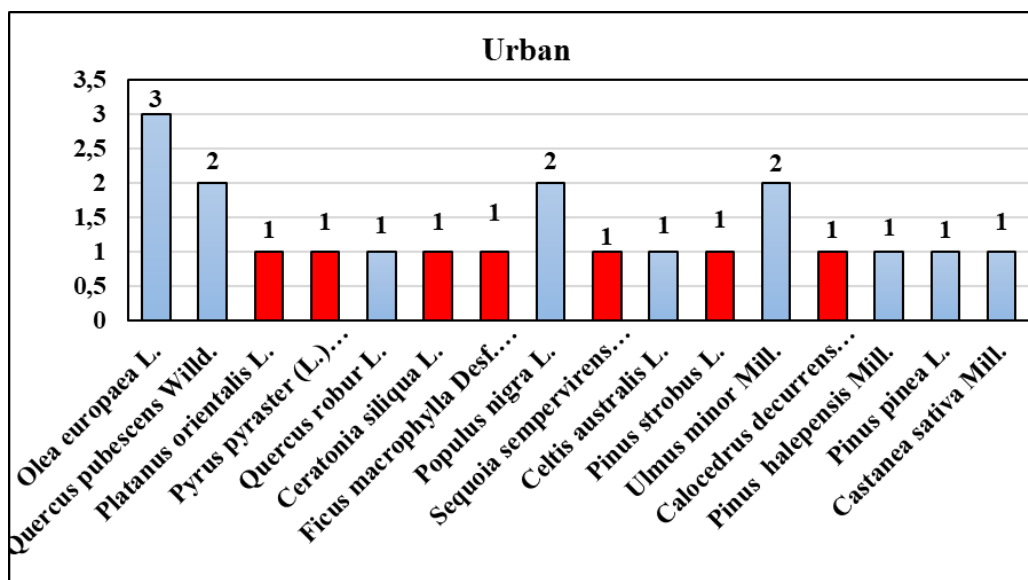


Figure 8.11. Number and type of monumental trees in the urban environment.

## 8.4. Discussion

The analysis carried out made it possible to identify the number of individuals and the habitat in which the monumental trees of the Calabria Region fall, including the areas of the Natura 2000 Network. Among the monumentality criteria, those most used to census monumental trees in the Calabria region were size (circumference and height) and shape and bearing.

From the results it was observed that most of these trees are among the species typical of the directive habitats (43/92), according to the manual of interpretation of habitats (Biodi et al 2009). Among these *Abies alba* that falls within habitat 9510\*, *Quercus pubescens* Willd. subsp. *Pubescens* nel habitat 91AA\*; *Pinus nigra* J.F. Arnold subsp. *laricio* Palib. ex Maire nel habitat 9510\*; *Fagus sylvatica* L. nel habitat 9210\* e 9220\*, *Castanea sativa* Mill nel 9260, *Pinus heldreichii* Christ subsp. *leucodermis* (Antoine) E. Murray) 95Ao and finally *Quercus petraea* (Matt.) Liebl. subsp. *austrotyrrhenica* Brullo, Guarino & Syracuse) in habitat 91Mo\*.

The results show that most of these monumental trees belong relatively to species typical of the temperate zone. The disappearance of these species would

cause a forest alteration in accordance with Lutz et al., (2018).

Most of the Calabrian monumental trees are concentrated in the mountain areas of the three national parks: Aspromonte, Pollino and Sila, which shows that these areas are characterized by a high naturalness in accordance with Bütler et al., (2013).

In addition, some of these trees fall within the sites of the Natura 2000 Network, which is essential given the important ecological roles (Lindenmayer et al., 2018) that they play in promoting the conservation of biodiversity.

The most widespread non-native tree species are *Eucalyptus*, *Pinus*, *Populus*, *Platanus*, *Pyrus* and *Cedrus*; widely planted in public and private gardens, in reforestation practices according to Brundu et al., (2018), Camarda, et al., (2021).

In the agricultural environment, a greater number of individuals of *Quercus pubescens*, a species typical of habitat 91AA\*, and the presence of *Quercus suber* typical of habitat 9330 have been highlighted. The presence of these species explains that the areas of the hilly belt in Calabria, where thermophilic oak trees were present, have undergone important alterations related to agricultural activity and grazing, transforming natural vegetation into small nuclei in accordance with various studies (Spampinato et al. 2022; Spampinato et al., 2008; Mercurio et al. 2022; Pasta et al., 2016; La Mela Veca et al., 2006).

The analysis showed that many monumental trees belonging to *Quercus Petraea* are located within beech habitats (9210\*/9220\*). This can be explained by the high competition of the beech, which related to the poor state of conservation as a result of fires and cuts (Aramini et al., 2023) make the beech a dominant species (Petritan et al. 2014; Rohner et al. 2012).

In this context, the main threats could be the fires that occur in dry periods affecting more and more areas, and the abusive cuts that can affect old individuals before they are registered and protected as monumental trees.

In Aspromonte, a serious fire in 2021 (Bombino et al., 2024) destroyed a homogeneous group of larch pines (Il bosco vecusto di Acatti) (Picone et al. 2003), which were irretrievably lost.

## **8.5. Conclusion**

On a regional scale, the study showed that nature paper is an important tool for acquiring territorial knowledge. Monumental trees allow the reconstruction of past vegetation. The distribution of these centuries-old trees is related to the distribution of vegetation. The comparison between monumental trees and habitats highlights the transformations of the landscape caused by agriculture and urbanization.

The protection of large trees in urban landscapes, where it is not possible to decide on the establishment of large ecological reserves, often requires small-scale management at the level of individual trees. (Lindenmayer 2017). This is due to the poor application of the "Guidelines for the care and protection of monumental trees" of the Departmental Decree of 31 March 2020.

The results of this study can be used both to identify hot spots for the conservation of these natural monuments, and to monitor naturalization processes of non-native species and provide ecological guidance to plan or prevent future introductions for management.

Conservation measures should reduce negative human effects and seek to mobilize local citizens for the protection of the large trees present in the Region.

## **CHAPTER 9. Landscape changes and habitat fragmentation in protected areas: The Aspromonte National Park case study**

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**Articles for submission**

## Abstract

Habitat fragmentation and landscape transformations are key drivers for species and biodiversity loss globally, as well as a serious threat to ecosystem conservation. Defining the methodologies to analyse these transformations is of fundamental importance to evaluate the effectiveness of the biodiversity conservation action carried out in protected areas. To this end, we have evaluated the changes in vegetation cover and habitat fragmentation that have taken place over a twenty-year period, taking as a case study the Aspromonte National Park, a territory for which we have a study of vegetation (1) and a vegetation map (2) dating back about 20 years. The protected area is characterized by a high floristic and vegetational richness to be linked to a series of current and historical factors as well as the geographical position, located in the center of the Mediterranean and in connection with other circummediterranean territories (1, 2).

In particular, the study aims to quantify, through a diachronic analysis, the changes in the areas occupied by vegetation and habitat types, in order to define the levels of fragmentation of the habitat landscape that have occurred over a twenty-year period within the protected area. The vegetation map of the Aspromonte National Park of 2002 (2) and the 'Nature Map' of the Calabria region of 2023 (3, 4) were used to assess the changes in habitat area using QGIS software. The Morphological Spatial Pattern Analysis (MSPA) FRAGSTATS v4.2 methods were used to assess habitat fragmentation. The results show that the *Pinus nigra* and *Quercus pubescens* forests of habitat 91Mo have undergone drastic fragmentation, while the area of *Fagus sylvatica* forests of habitat 9210\* within zone A has increased. This is related to the lack of buffer zone for forests. This is related to the lack of buffer zones in the mesomediterranean belt, where anthropogenic factors have a significant contribution, influencing fragmentation and habitat loss. These results provide an effective approach for assessing the degree of habitat fragmentation within protected areas and provide scientific

support for mitigating biodiversity loss and reducing habitat fragmentation.

**Keywords:** Fragmentation, Forests, Habitats Directive, Biodiversity

## **9.1. Introduction**

Changes in land use significantly affect ecosystem dynamics (Assanini et al. 2008), and therefore, the analysis of vegetation dynamics over time can be crucial for the management and conservation of ecosystems (Angiolini et al., 2018).

The study of land use changes focuses on environmental problems [Oukil, Y. et al 2020] related to natural processes, such as ecological succession, natural and anthropogenic disturbances [Siba et al.2022 Land use change analysis assesses land use conversions, including deforestation/degradation (Gao and Liu, 2010), biodiversity loss (Carranza et al. 2014) and urban expansion (Mertes et al. 2015) for a better understanding and sustainable management of the environment.

In assessing temporal changes an important aspect to consider is that biodiversity is one composed of many components (e.g. wealth, relative abundance, composition, presence of key species) that differently influence ecosystem characteristics (Hooper et al., 2005).

These ongoing changes cause higher rates of species extinction (De Vos et al., 2015) and a general loss of biodiversity (Thomas et al., 2004; Ceballos et al., 2015). To predict future threats, it is necessary to understand how the anthropogenic impact on habitats determines the new and different dynamics of species distribution.

In this regard, several studies have begun to use "key" or "diagnostic" species, to analyze the quality of plant communities and detect habitat alteration (Del Vecchio et al., 2016; Angiolini et al., 2018; Morabito et al; 2024). For the study of vegetation dynamics, two types of approaches were used: the diachronic one applied to the evaluation of the transformation of vegetation cover through cartography (Angiolini et al.2001; Smiraglia et al.2007), and the synchronous one

combined in the study of vegetation series and plant landscapes in Italy (Biondi & Bagella 2005; Blasi 2010). Other studies instead used a combined approach between the two (Gargano et al., 2012; Assini et al., 2014).

Diachronic studies are defined as powerful tools for monitoring changes in biodiversity (Sperandii et al.; 2018, Hédli et al. 2010, Kopecký et al. 2013), examine the causes of such changes and assess the conservation status of habitats (Pignatti and Pignatti 2014; Del Vecchio et al. 2015b; Gigante et al. 2016; Prisco et al. 2016a).

Today, changing forest cover has become a hotly debated issue given its influence on ecosystem services including climate regulation, water reserves, biodiversity richness, and carbon storage. [Ren et al 2019; Giles-Hansen et al., 2019, Jaafar, et al., 2020]

Fragmentation of forest landscapes causes a number of consequences, such as increased habitat isolation and area reduction (Bogaert et al., 2004; Barima et al., 2010). Within protected areas, forest fragmentation is a challenge in the search for new methodologies for biodiversity management and sustainability [Soverel, et al., 2010].

In forest ecosystems fragmentation is often caused by inadequate forest management techniques and some socio-economic issues (Sharma and Roy, 2007;). Often the various causes related to the fragmentation process are the invasion of non-forest plant species (Babbar et al., 2020), fires, insects (Coops et al., 2006), agriculture and urbanization (Ürker et al 2023).

Nowadays, thanks to the combination of historical cartography and remote sensing data, new solutions can easily be developed (Solano et al., 2021).

Therefore, the use of a combined diachronic approach that provides a comprehensive understanding of plant communities within a protected area can contribute to the achievement of conservation objectives. On this basis, this work

aims to investigate temporal trends using vegetation maps and the use of phytosociological surveys between 2001 and 2023. In particular, it is intended to (i) analyze changes in forest vegetation, (ii) evaluate the fragmentation of forest habitats.

## **9.2. Materials and Methods**

The study area in which the method was applied is part of the Aspromonte Natural National Park, in the Calabria region, established in 1994 and had a total area of 65,647.46 ha.

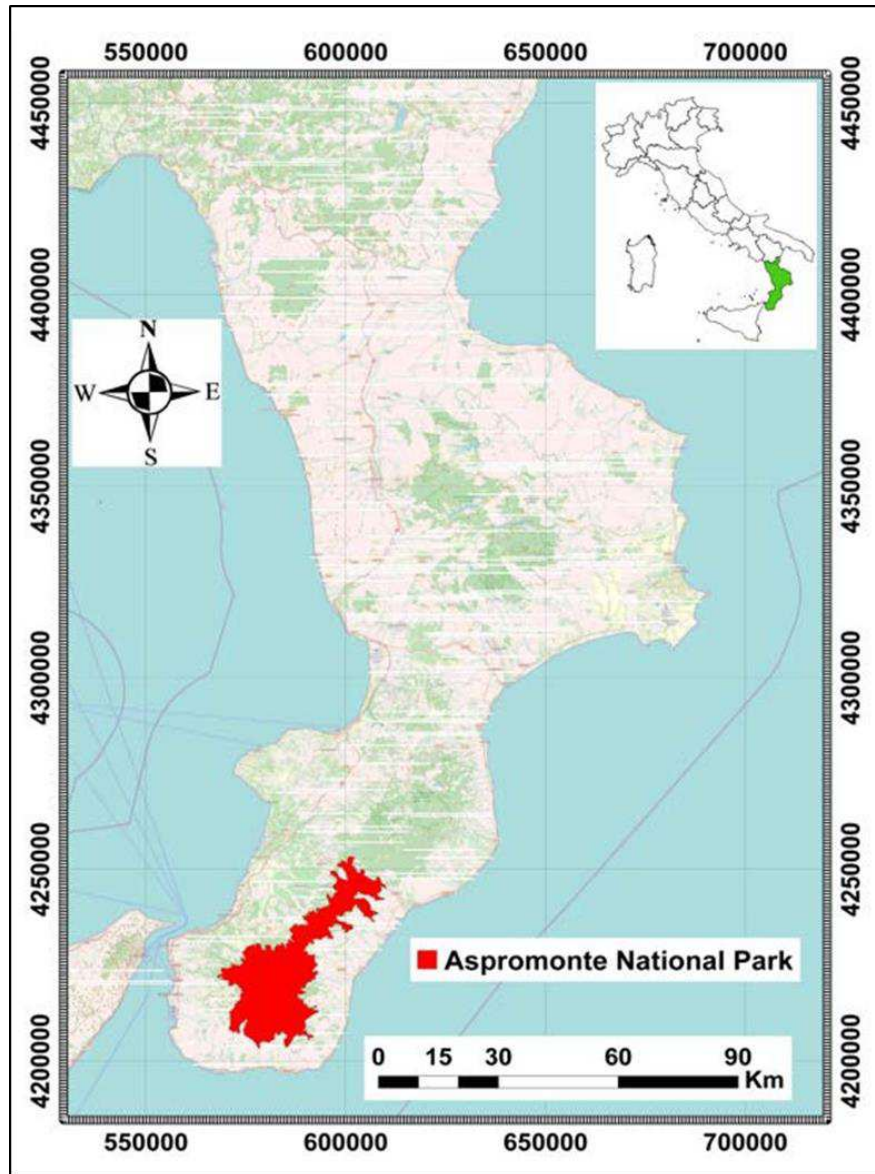
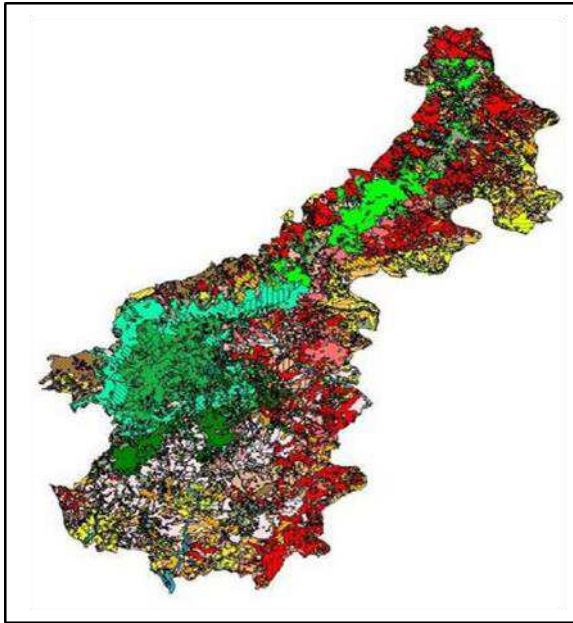
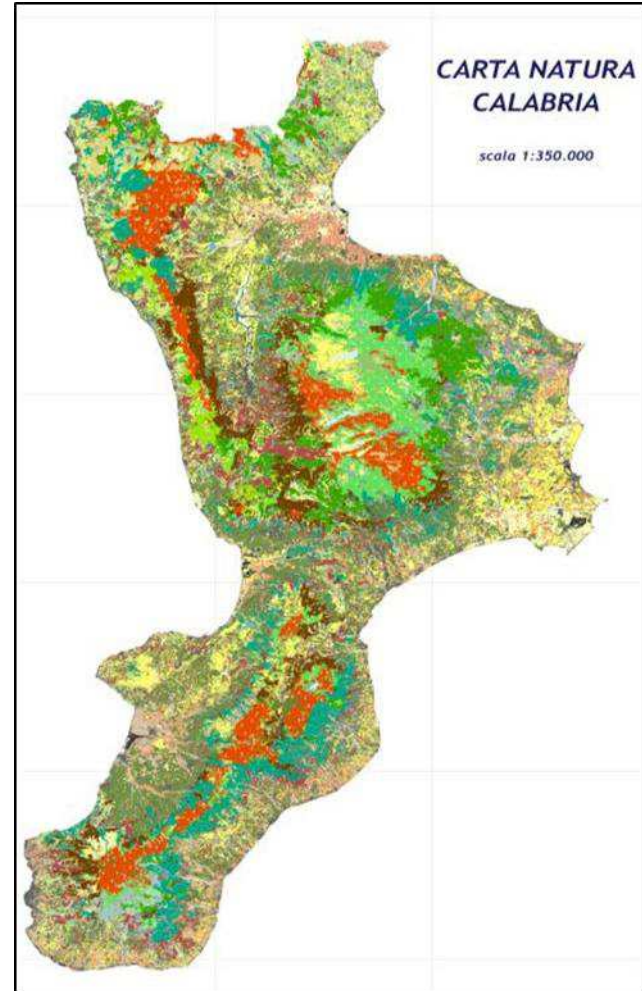


Figure 9.1. Study Area The boundary of the Aspromonte National Park is marked in red.

It is located in the extreme south of Calabria, and has altitudes ranging from 100 m above sea level to 1956 m above sea level, with the highest peak corresponding to Monte Montalto. The diachronic analysis was carried out using the Aspromonte National Park vegetation map of 2001 (Figure 9.2) (Spampinato et al.; 2008), and the Calabria Region Nature map of 2023 (Figure 9.3) (Spampinato et al.; 2023).



*Figura 9.2. Vegetation map of Aspromonte National Park 2001.*



*Figura 9.3. Nature map of the region of Calabria 2023*

The transformations undergone by the territory were highlighted through the comparison of the surfaces occupied by the various types of vegetation and land use detected in 2001 and 2023. This analysis was obtained through the use of GIS tools and, in particular, through geoprocessing processing between the polygonal roofs of the individual types.

#### 9.2.1. Landscape assessment and fragmentation

fragmentation in this study was analyzed at the class level of both 2001 and 2023, using the autonomous software FRAGSTATS (Version 4.2.1) (McGarigal and Jan 2015; McGarigal et al., 2012), created to calculate a great complexity of landscape parameters in order to understand fragmentation. (McGarigal et al., 2002, Paudel

e Yuan, 2012, Lamine et al., 2017; Singh et al., 2017).

In this study, to evaluate fragmentation, 4 categories of landscape parameters were considered to quantify the configuration and composition of the landscape: The index of shape, fractal size, number of patches and patch density:

Four categories of useful landscape parameters were considered to quantify landscape configuration and composition:

$$NP = n_i$$

NP = patch number;  $n_i$  = Number of patches in the patch type landscape (classe)i.

$$PD = \frac{n_i}{A} (10.000)(100)$$

PD = densità della patch  $n_i$  = numero di patch nel paesaggio di tipo patch (classe)i.;  
A = area totale del paesaggio (m<sup>2</sup>).

$$FRAC = \frac{2 \ln(.25 pij)}{\ln a_{ij}}$$

FRAC = Indice di dimensione frattale;  $pij$  = perimetro (m) della toppa  $ij$ ;  $a_{ij}$  = area (m<sup>2</sup>) della toppa  $ij$ .

$$SHAPE = \frac{.25pij}{\sqrt{a_{ij}}} \sqrt{a_{ij}}$$

SHAPE = Indice di forma;  $pij$  = perimetro (m) della toppa  $ij$ ;  $a_{ij}$  = area (m<sup>2</sup>) della toppa  $ij$ .

Mean patch size (AREA\_MN) = at the class level is a function of the number of patches in the class and total class area.

## 9.3. Results

### 9.3.1. Landscape assessment and fragmentation

The landscape analysis shows the nature map of the Aspromonte National Park

(Figure 9.4) extrapolated from the Nature Map of the Calabria Region [Aramini et al., 2023].

The analysis carried out on a regional scale made it possible to ascertain and map 79 habitats for the Aspromonte national park, divided into 6 macro-categories (Figure 9.6):

- ✓ 2. Non-sea waters (5); 3.
- ✓ Scrubs and grasslands (22);
- ✓ 4. Forests (24);
- ✓ 5. Marshes formations (3);
- ✓ 6. Rupees and gravel (2);
- ✓ 8. Crops and built-up areas (20).

The largest areas are occupied by the habitats of macrocategory 4 "Forests" (65% of the area of the Aspromonte national park) among these beech forests with 22.6%, with 17.5%. The habitats of macrocategory 3 "Shrubs and prairies", which are those with the greatest diversity of types, occupy 22% of the area, including the Italian hilly and mountain broom bushes (7.7%) and the *Cytisus infestus* scrub (5.2%) "Agricultural land and artificial landscapes"; among these the habitat that occupies a greater area are the Olive groves over 3.1% of the area. Many habitats have limited surface areas, but they are no less important for the conservation of biodiversity as the habitat "Boschi ripariali a *Platanus orientalis*" (0.3%) or "*Quercus Petraea* oak forests of southern Italy" (0.1%) and the "Forests of *Ilex aquifolium*" with an even lower percentage.

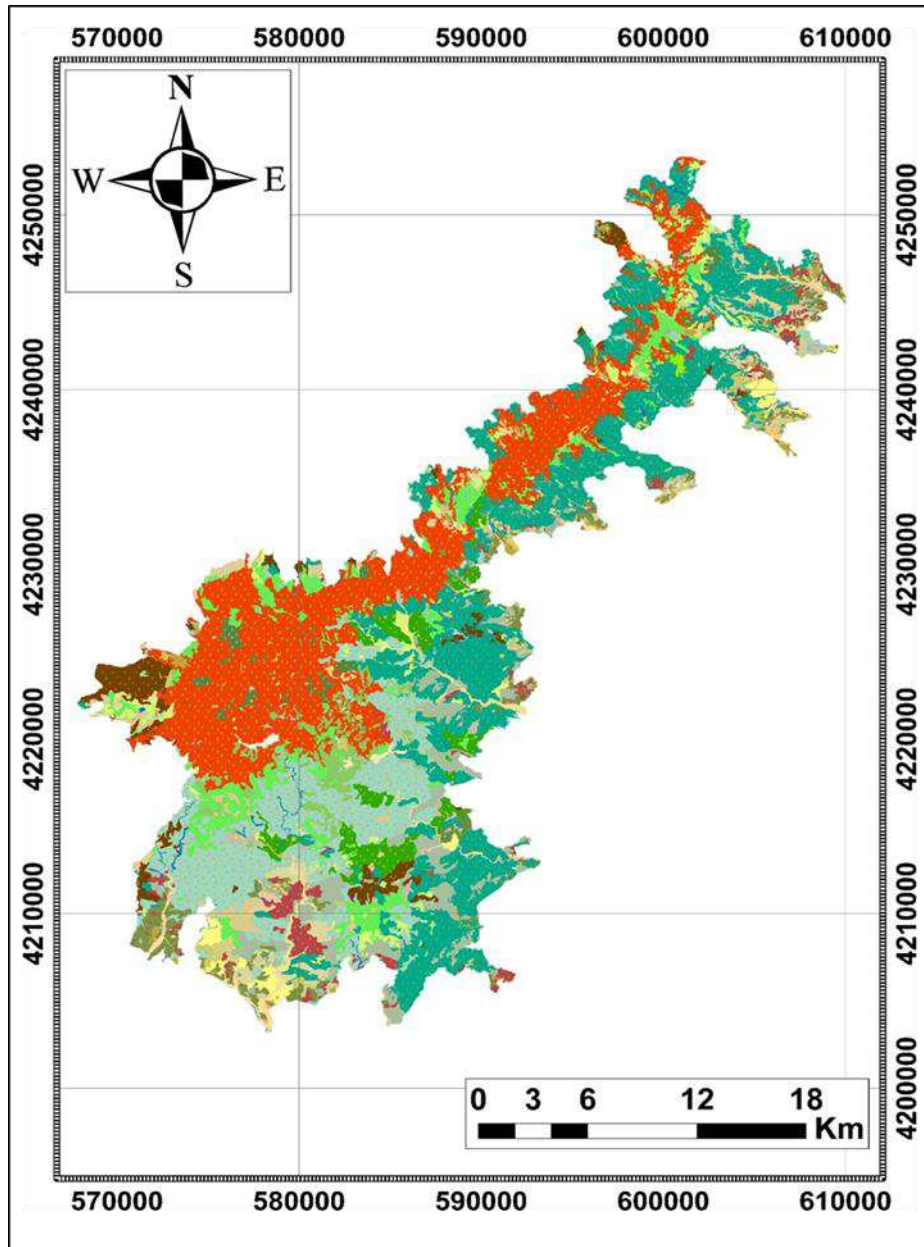


Figure 9.4. Nature map of Aspromonte National Park.

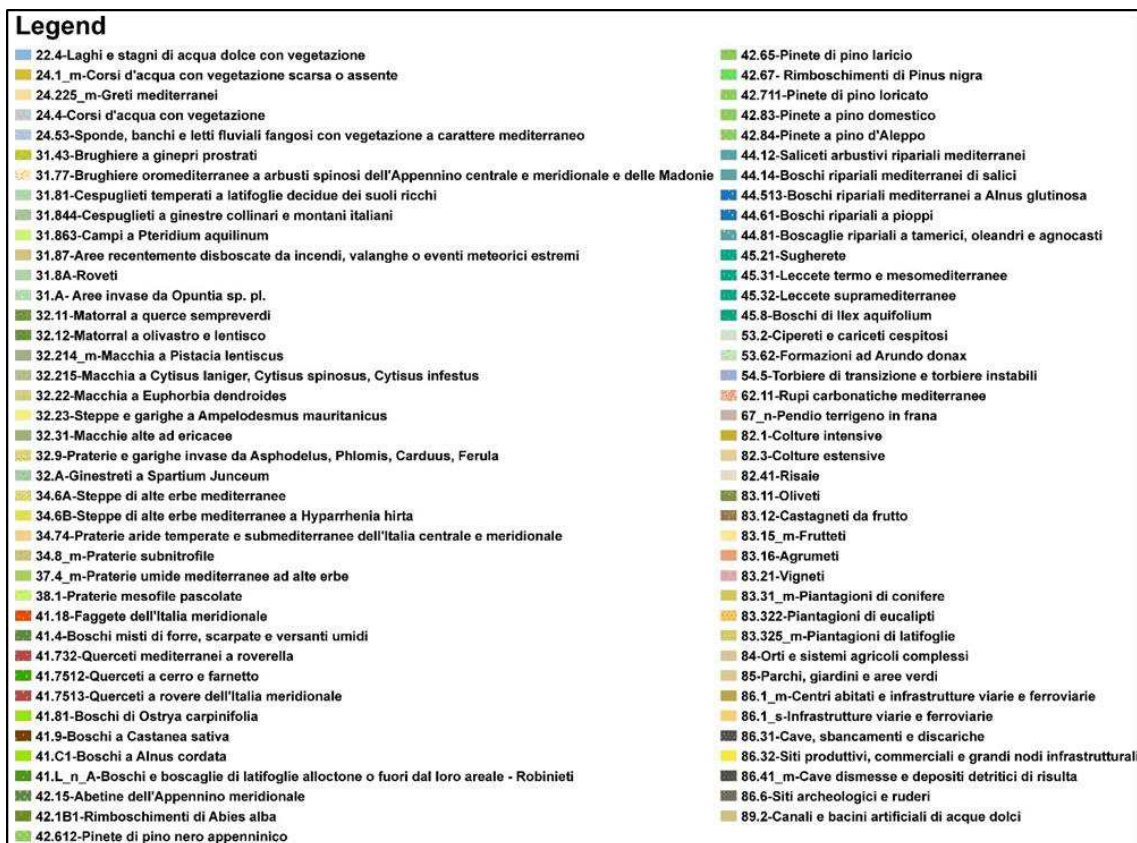


Figure 9.5. Map legend of the nature map of the Aspromonte National Park.

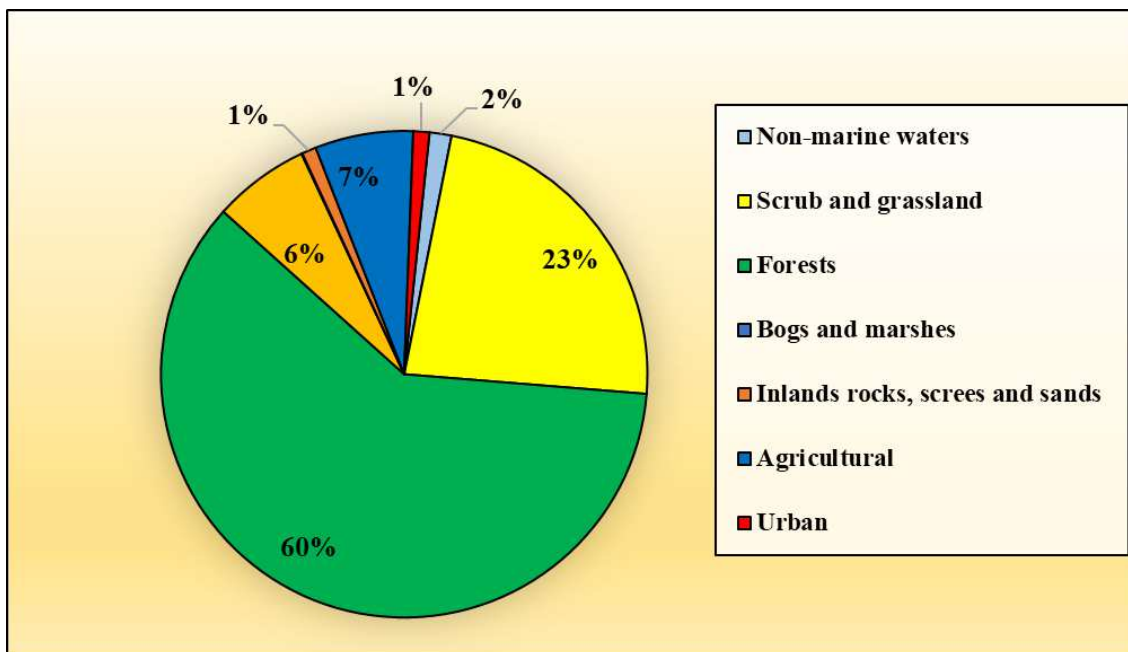


Figure 9.6. Percentage of area occupied by different macro-categories

Figure 9.7 shows the map of the directive habitats present in the Aspromonte

National Park, with an area of 62.8%. The largest areas are occupied by habitat 9210\* and 9340.

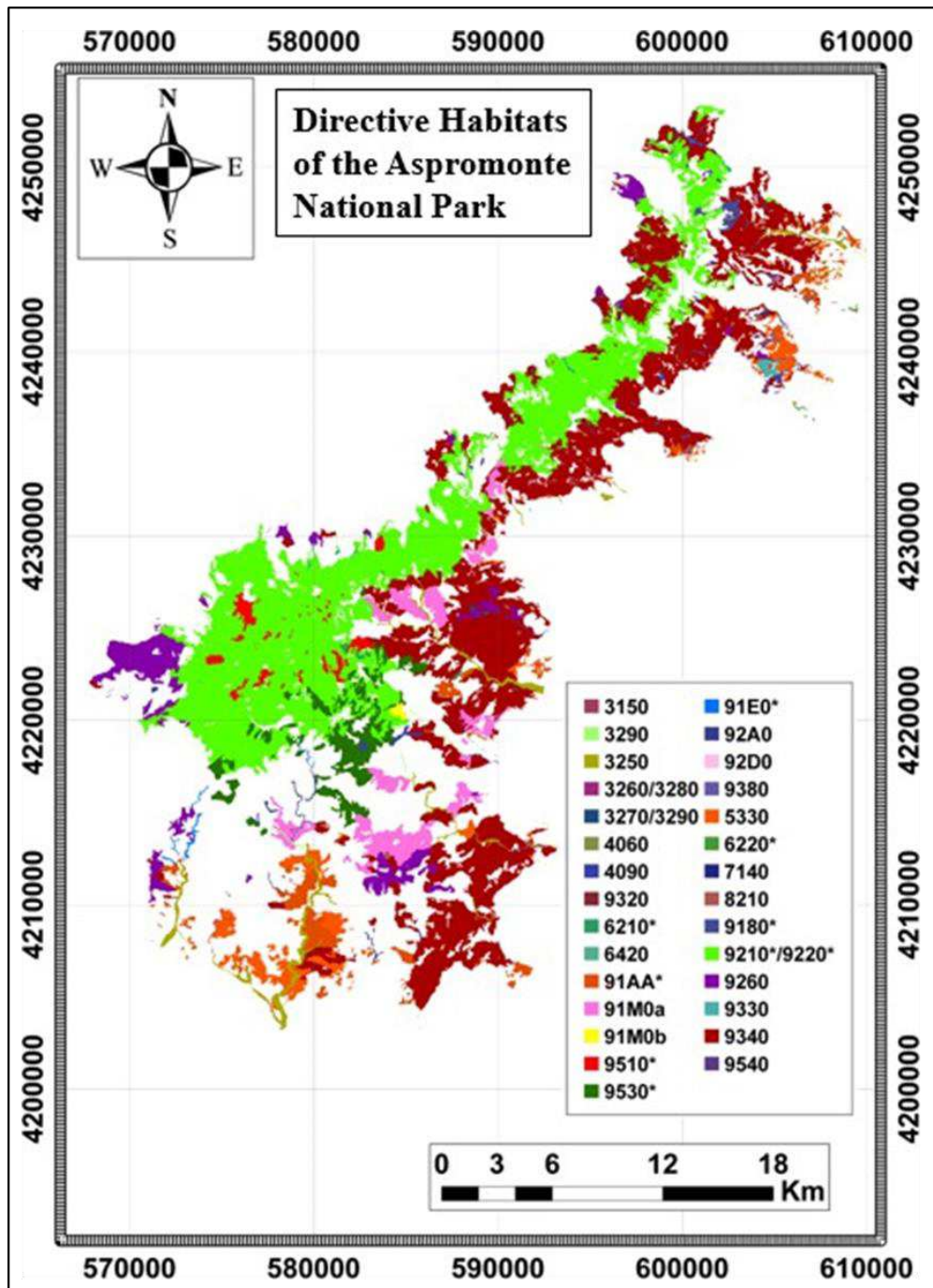


Figure 9.7. Area of occupied Directive habitats in Aspromonte National Park.

The comparison of the geodatabases, relating to the vegetation map of 2023 and 2002, allowed the data shown in Figure 9.8 to be processed. From the graph it can

be seen that the forest vegetation that characterizes the Aspromonte National Park has had an increase except for habitat 9530\*, and 91Mob. The analysis shows that the area of habitat 9530\* decreased by 1.7% due to a destructive fire, which in August 2021 affected a large area of the Aspromonte National Park. While the 91Mobe 9180\* habitat underwent a reduction of 0.2% and 0.1% of the surface compared to 2001. The habitats that showed a greater increase of 2.6%, 1.4% and 0.7 compared to 2001 were habitats 9340 and 91AA\* and 9220\*/9210\*.

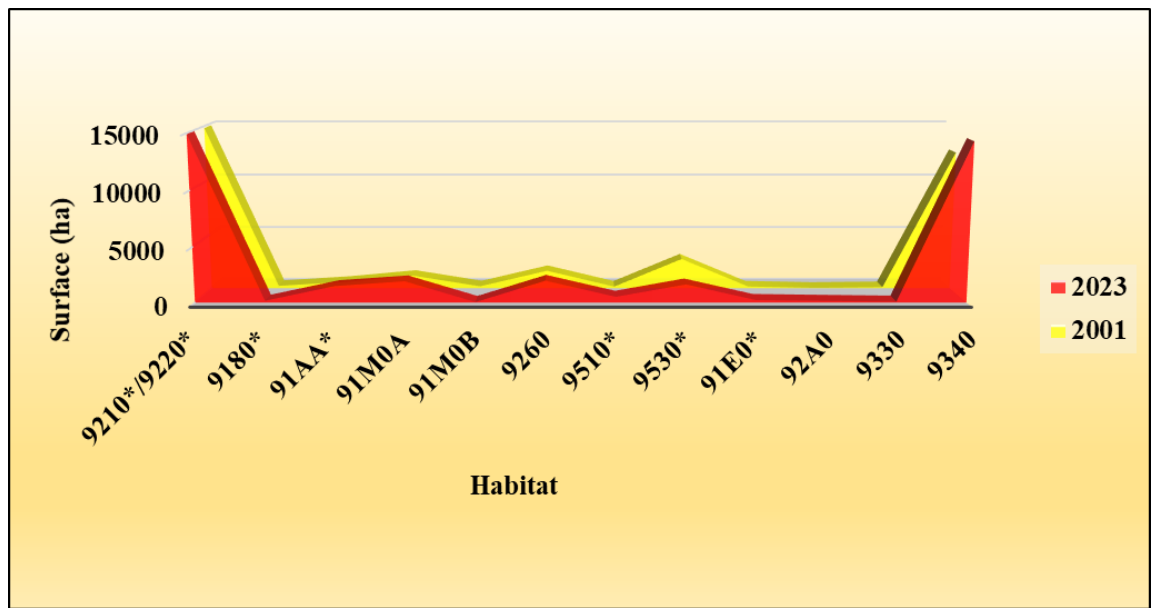


Figure 9.8: Diachronic analysis of forest vegetation areas occupied between 2001 and 2023.

### 9.3.2. Landscape metrics

The fragmentation analysis took several parameters into account. Table 1 shows the 2001 and 2023 fragmentation index values calculated for each forest habitat in the Aspromonte National Park.

Table 9.1. Values of fragmentation indices and total surface of habitat type. (**NP** - Number of patches; **AREA\_AM** - Weighted average patch size area; **PD** - Patch density)

Class	NP		PD		AREA_MN	
	2001	2023	2001	2023	2001	2023
9340	378	328	0.5856	5082	33.3075	43.582

9260	131	68	0.203	0.10	12.5734	29.167
				54		1
9210*/9220*	193	147	0.299	2277	76.8063	102.29
						93
9180*	13	26	0.0201	0.04	17.0562	6.4919
				03		
92A0	63	55	0.0976	0.08	0.6113	2.7553
				52		
91E0*	96	115	0.1487	0.17	1.6607	2.017
				82		
91AA*	99	192	0.1534	0.29	6.1769	7.407
				75		
9330	2	3	0.0031	0.00	49.405	26.726
				46		7
91Moa	47	39	0.0728	0.06	25.2785	49.859
				04		2
9530*	58	65	0.0899	0.10	47.3817	22.256
				07		8
9510*	10	31	0.0155	0.04	15.583	17.018
				8		4
91Mob	16	3	0.0248	0.00	11.3956	18.706
				46		7

### Number of patches (NP)

The number of patches (NP) varies considerably between the different habitat types (Figure 9.9). The highest values of this parameter in 2023 compared to 2001 were found in the habitat *Quercus pubescens* (91AA\*), which is undoubtedly the most fragmented habitat. Habitats 9530\*, 91E0\*, 9510\*, 9180\* and 91MOB also have more patches than in 2001.

The habitats of *Fagus sylvatica* (9210\*/9220\*) and *Quercus ilex* (9340) show lower values than in 2001.

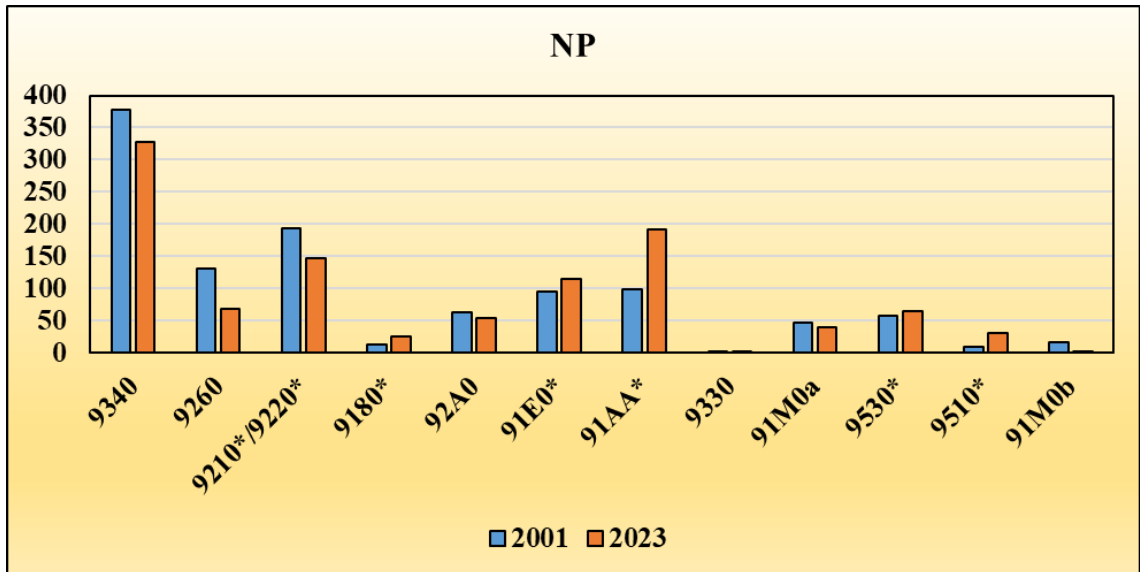


Figure 9.9. Number of patches (NP) for each habitat type.

#### Mean area (AREA-MN)

The average area of the different habitat types (Figure 9.10), shows in 2023, minimum values for habitat 9530\* (sub-Mediterranean pine forests with endemic black pine), 91AA\* (Eastern white oak woods) 9180\* (*Tilio-Acerion* forests of slopes, screes and ravines), while maximum values for habitats 9210\*/9220\* (Apennine beech forests with *Taxus* and *Ilex*/Apennine beech forests with *Abies alba* and beech forests with *Abies nebrodensis*), 9340 (*Quercus ilex* and *Quercus rotundifolia* forests) and 9260 (*Castanea sativa* woods).

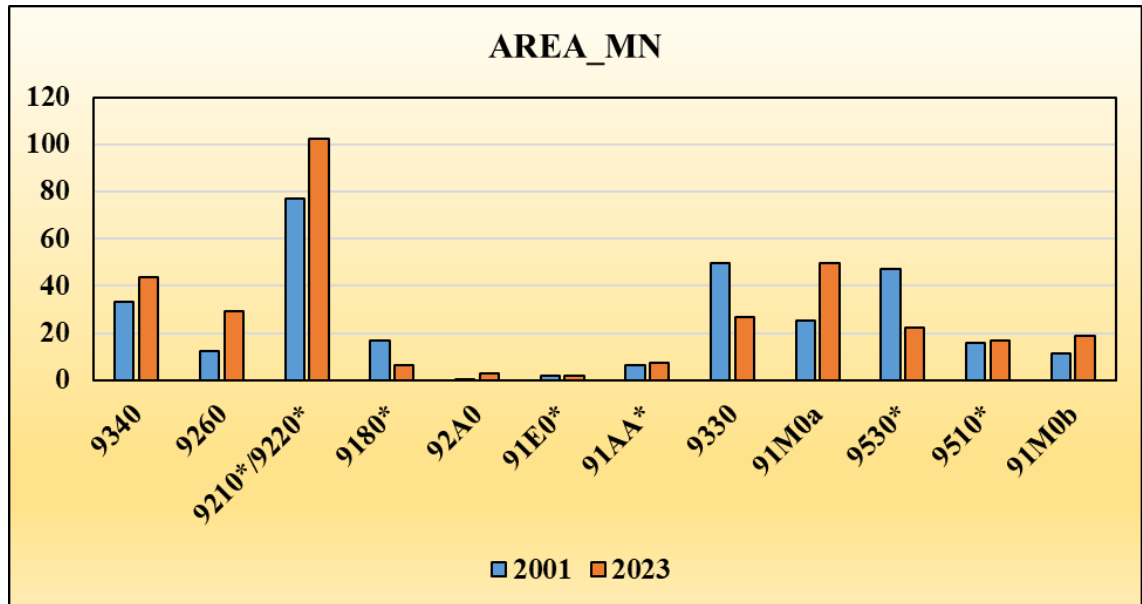


Figure 9.10. Mean area (AREA MN) of each habitat type

#### Patch density (PD)

The highest patch density (Figure 9.11) in 2023 are found in habitats 9530\* (sub-Mediterranean pine forests with endemic black pine), 91AA\* (eastern white oak forests) and in habitats 91E0\* (alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior*), 9510\* (*Abies alba* of the southern Apennines) and 91M0b (Pannonian-Balkan cherry forests with *Quercus petraea* (Matt) Liebl. subsp. *austrotyrrhenica* Brullo, Guarino & Siracusa), while low values are found in 9210\*/9220\* (Apennine beech woods with *Taxus* and *Ilex*/Apennine beech), 9340 (*Quercus ilex* and *Quercus rotundifolia* woods) and 9260 (*Castanea sativa* woods).

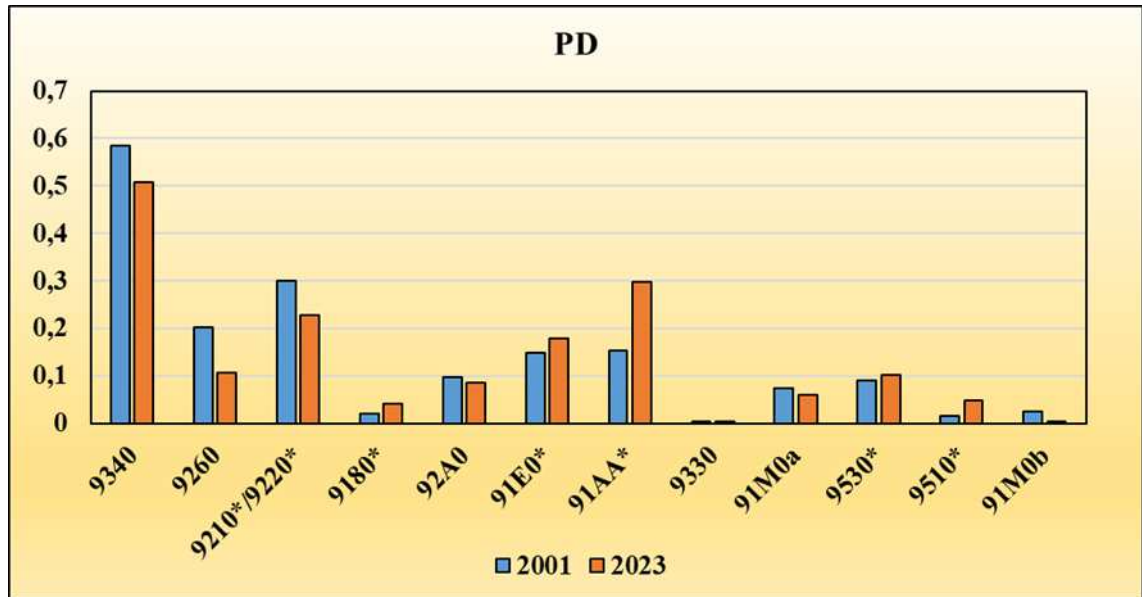


Figure 9.11. Patch density (PD) for each type of habitat.

#### 9.4. Discussion

The analysis carried out in this study shows that the use of the Nature Map is an important tool for knowing and representing the typology and distribution of the ecosystems and habitats present in the Aspromonte National Park.

From the nature map of the Aspromonte National Park it was possible to extrapolate the area occupied by the directive habitats (63%), showing a high naturalness. Among these habitats 9210\*, 9220\* and 9340 occupy a larger area according to Spampinato et al.2008).

The analysis allowed us to detect the presence of a new habitat of directive 9380 (Forests of *Ilex aquifolium*), high and shrubby phytocenosis dominated by *Ilex aquifolium*, whose presence is linked to the destruction of the tree plan (Biondi et al 2009).

The landscape model significantly influences landscape processes and features (McGarigal and McComb 1995). The results showed a slight increase in surface area and less fragmentation for beech and holm oak habitats compared to 2001,

this may be linked to the fact that these habitats fall in areas A and B where the anthropogenic impact is limited.

According to other studies (Wieser et al., 2019; Bryn et al 2008) the rate of increase at higher altitudes may be connected to the abandonment of traditional land use management.

In this research, the results obtained from the landscape analysis show that in 2023 compared to 2001, the g1AA\*, 9530\*, 91Eo\* habitats have a smaller surface area, a greater number of patches, and a higher density, thus showing a high fragmentation. In the case of habitat 9530\*, this fragmentation is closely linked to the high severity of fires that has been recorded in Aspromonte National Park [Bombino et al 2023; Bombino et al 2024]. The habitat area of *Quercus petraea* (91Mob) is currently small and very fragmented compared to 2001, this is caused by intensive grazing and recurrent fires that have affected the Aspromonte National Park area, blocking the evolution of vegetation in accordance with Aramini et al., 2023.

According to literature (Mercurio et al., 2022, Aramini et al., 2023, the fragmentation of Mediterranean oak trees that in the past occupied vast and continuous areas, is linked to fires, illegal logging and grazing.

This confirms in agreement with other studies (Jiménez-Olivencia et al., 2021) that at lower altitudes the transformation of land cover is linked to anthropogenic pressure, causing greater degradation through fragmentation and homogenization of the landscape.

## **9.5. Conclusion**

The comparison between the vegetation cartography for the years 2001 and 2023 allows a diachronic reconstruction of the evolution of forest habitats within the Aspromonte National Park, highlighting their changes. In 2001, pine forests and oak trees occupied a large part of the surface. Currently, these habitats occupy

significantly reduced areas as a result of fires, grazing, the expansion of cultivated areas and the construction of artificial plants set up with exotic species.

The diachronic analysis of vegetation clearly highlights not only the transformations, but also the evolutionary dynamics and potential of vegetation. From it can be derived guidelines for the planning and management of the protected area, and conservation measures for fragmented habitats and for those that occupy very low areas with high naturalistic value because they risk becoming extinct in consideration of their rarity.

According to several studies (Global Forest Watch, 2020; Venter et al., 2016) it is particularly important to take into account the areas surrounding protected areas as there is a high rate of deforestation in nearby unprotected areas.

To this end, in relation to our results, it is essential to promote the creation of buffer zones in the Mediterranean belt since, by performing the function of protective barriers, they contribute to the conservation of biodiversity through the reduction of anthropogenic action. In addition, they favour the increase of connectivity for animal and plant organisms and reduce the chemical and physical effects deriving from natural events (Perelló et al., 2012, UNESCO 2009, de Almeida-Rocha et al., 2021).

## General Conclusions

Habitats have undergone numerous and significant changes due to environmental processes and anthropogenic impact that have led to fragmentation causing the disappearance of species and communities, and the loss of connectivity.

The study of the conservation status and interpretation of Habitats, as well as the ecosystem, is relevant for the application of current agricultural and environmental policies (Common Agricultural Policy, Rural Development Programme, Habitats Directive) which must achieve the primary objective of biodiversity conservation.

The use of Nature Map of the Calabria region has been fundamental for the identification of the various habitats, and for the conservation of biodiversity.

In this research study, the main objective was to assess the conservation status of the habitats present in the Calabria Region.

From our results, it can be understood that the analysis of habitat vegetation through diversity indices, and environmental analysis through GIS are suitable for identifying the conservation status of habitats. Ecological indicators, such as those used in this thesis, can therefore be suitable for defining models and processes of change, and a useful tool for identifying areas that show a high degree of naturalness.

In relation to the objectives we had set ourselves, most of them were achieved as: Reporting of new habitats added to the cells of the EEA reference grid 10 km × 10 km, the system used to represent the distribution of habitats on a European scale.

New methodologies and more detailed and more objective indicators on the state of conservation of directive habitats (43/92).

Cognitive framework to build models for estimating the conservation status, allowing to outline a more detailed picture of the prospects of habitat and species maintenance.

Quantification of the parameters that can significantly influence the classification of ecological status.

Synthetic and extensive environmental framework with cartographic and assessment data on habitats. (Ex: impacts of climate change on habitats and species, spread of alien species, studies and projects habitat loss following fires).

Interpretation of the habitats in which the monumental trees registered for the Calabria Region fall. Identification and design of ecological networks for the connection of Natura 2000 Network Sites.

Reconstruction of connectivity, and identification of areas of high naturalness, and those with greater resistance also present outside the Natura 2000 network sites.

Connectivity development can be used to optimize the conservation of the Natura 2000 Network. If practical theories are applied to the new paths identified, these sites could cover more important areas for the conservation of biodiversity and more connected habitats, essential for the conservation of biological evolutionary processes through the dispersion and migration of animal and plant species.

Assessing biodiversity and understanding the ecological characteristics of habitats makes it possible to interpret evolutionary dynamics and predict future scenarios due to climate change.

The results obtained in this thesis have provided an important contribution to the topic, which, as a whole, can be a valuable support for the implementation of a conservation strategy compatible with the integrated management of ecosystems to ensure the long-term maintenance of biodiversity, and can be used as a guide for different regions.



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S1. phytosociological table (2270\*)

Relevé number	1	2	3
Cell ID	: 10kmE486N173	: 10kmE486N174	: 10kmE486N175
Latitude	38°30'37.38"	38°30'42.10"	38°30'39.10"
Longitude	16°15'29.86"	16°15'32.37"	16°15'30.39"
Date	21/07/2005	04/06/2016	21/07/2005
Area (m2)	20	50	20
Altitude (m a.s.l.)	1148	1142	1146
Apect (°)			
Slope (°)			
Cover (%)	100	100	100
Tree layer height (m)	.	.	.
Shrub layer height (m)	.	.	.
Herb layer height (m)	1	1	1
Tree layer cover (%)	.	.	.
Shrub layer cover (%)	.	.	.
Herb layer cover (%)	100	100	100
Charact. of Dactylorhizo-Juncetum effusi			
Juncus effusus L. subsp. effusus	3	1	5
Charact. of Dactylorhizo-Juncion striati, Holoschoenetalia vulgaris, Molinio - Arrhenatheretea	.	.	.
^Epipactis palustris (L.) Crantz	-	3	-
Carex leporina L.	+	-	-
Dactylorhiza maculata (L.) Soó subsp. saccifera (Brongn.) Diklić	1	1	1
^Hypericum tetrapterum Fr.	2	3	2
Cirsium creticum (Lam.) d'Urv. subsp. triumfettii (Lacaita) K. Werner	1	-	2
^Prunella vulgaris L. subsp. vulgaris	1	-	1
Juncus articulatus L. subsp. articulatus	+	2	+
Potentilla erecta (L.) Raeusch.	1	-	-
Other species	.	.	.
Mentha aquatica L. subsp. aquatica	2	1	2
Epilobium palustre L.	2	1	1
Geranium versicolor L.	1	-	-
Carex distans L.	-	3	-
Carex echinata Murray	1	5	-
Chaerophyllum hirsutum L.	-	-	1

<i>Equiseto palustre</i> L.	2	-	1
<i>Galium palustre</i> L. subsp. <i>elongatum</i> (C.Presl) Arcang.	-	-	1
<i>Holcus mollis</i> L. subsp. <i>mollis</i>	3	-	3
<i>Lycopus europaeus</i> L.	-	-	1
<i>Lysimachia nemorum</i> L.	+	1	+
<i>Potamogeton polygonifolius</i> Pourr.	-	2	1.

## S2. Phytosociological table (6420). Chapter 2

Relevé number	1	2
Cell ID	10kmE483N172	10kmE488N171
Latitude	38°24'24.69"	38°19'41.01"
Longitude	15°52'9.40"	16°25'45.07"
Date	27/03/2022	03/05/2022
Area (m2)	100	
Altitude (m a.s.l.)	-	-
Cover (%)	100	100
Average vegetation height (m)	12	
Tree layer height (m)	12	10
Shrub layer height (m)	-	-
Herb layer height (m)	0,4	0,4
Tree layer cover (%)	80%	95%
Shrub layer cover (%)	-	-
Herb layer cover (%)	40%	20%
Charact. of Pistacio- Rhamnetalia alaterni, Quercetea ilicis		
^ <i>Pinus pinea</i> L.	4	5
^ <i>Asparagus albus</i> L.	1	-
Other species		
<i>Allium triquetrum</i> L.	1	-
<i>Carduus pycnocephalus</i> L.	+	-
<i>Cynodon dactylon</i> (L.) Pers.	1	-
<i>Daucus carota</i> L.	+	-
<i>Fumaria bastardii</i> Boreau	+	-
<i>Hordeum murinum</i> L.	-	+
<i>Lagurus ovatus</i> L. subsp. <i>ovatus</i>	+	+
<i>Lolium rigidum</i> Gaudin	-	+
<i>Chenopodium album</i> L.	-	+
<i>Plantago lagopus</i> L.	-	+

<i>Sonchus bulbosus</i> (L.) N.Kilian & Greuter subsp. <i>Bulbosus</i>	+	-
<i>Stellaria media</i> (L.) Vill.	+	-
<i>Urtica membranacea</i> Poir.	+	-
<i>Vicia dasycarpa</i> Ten.	+	-

### S3. Phytosociological table (2250\*). Chapter 2

Relevé number	1
Cell ID	10kmE486N178
Latitude	38,917158
Longitude	16,220564
Date	25/05/2022
Area (m2)	10
Altitude (m a.s.l.)	5
Apect (°)	-
Slope (°)	-
Cover (%)	100
Tree layer height (m)	-
Shrub layer height (m)	3
Herb layer height (m)	0.1
Tree layer cover (%)	-
Shrub layer cover (%)	100
Herb layer cover (%)	5
Charact. Associazione <i>Pistacia lentiscus</i> - <i>Juniperetum macrocarpae</i>	
<i>Juniperus macrocarpa</i> Sm.	2
<i>Pistacia lentiscus</i> L.	4
Char. Alleanza e Ordine (Eleo - Ceratonion , <i>Pistacio lentisci</i> - <i>Rhamnetalia alaterni</i> )	
<i>Asparagus albus</i> L.	+
<i>Rhamnus alaternus</i> L. subsp. <i>alaternus</i>	1
Char. Classe ( <i>Quercetea ilicis</i> )	
<i>Phillyrea latifolia</i> L.	2
<i>Rubia peregrina</i> L.	+
Other species	
<i>Lagurus ovatus</i> L.	+
<i>Pittosporum tobira</i> (Thunb.) W.T. Aiton	1
<i>Acacia saligna</i> (Labill.) H.L.Wendl.	2
<i>Tamarix africana</i> Poir.	2
<i>Nerium oleander</i> L. subsp. <i>oleander</i>	1

Helichrysum italicum (Roth) G.Don	+
Lobularia maritima (L.) Desv.	+

#### S4. Phytosociological table (g1AA\*). Chapter 2

Relevé number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Cell ID	10k m E48 6 N17 7	10k m E48 7 N17 8	10k m E48 3 N17 5	10k m E48 8 N17 6	10k m E48 4 N17 3	10k m E48 8N 174	10k m E48 8N 174	10k m E48 8N 174	10k m E48 7N 173	10k m E48 7N 173	10k m E48 8N 172	10k m E48 6N 169	10k m E48 5N 169	10k m E48 5N 179
Latitude	38, 84 112 2	38, 95 626 1	38, 67 845 3	38, 71 673 3	38,5 52 583	38,5 6 151 7	38,5 7 609 2	38,5 7 716 9	38, 45 173 9	38, 45 122 2	38,3 8 914 4	38,1 5 608 6	38,1 3 591 4	38,1 3 481 4
Longitude	16. 29 095 8"	16, 41 338 1	15, 91 798 9	16, 41 509 2	15,9 31 75	16,4 4 086 4	16,4 4 614 7	16,4 4 527 5	16,3 4 891 1	16,3 4 902 8	16,3 9 79	16,1 2 877 8	16,0 5 066 9	16,0 4 768 6
Date	26/ 05/ 202 2	02/ 06/ 202 2	02/ 06/ 202 2	04/ 10/ 202 2	28/ 03/ 202 2	15/0 7 /20 04	24/ 06 /20 06	24/ 06 /20 06	20/ 07 /20 06	20/ 07 /20 06	03/0 5 /20 22	20/ 04 /20 22	29/ 05 /20 02	29/ 05 /20 02
Area (m2)	200	300	100	400	100	200	200	200	100	100	100	200	200	400
Altitude (m a.s.l.)	130	393	89	485	116	117 6	100 7	102 1	672	662	65	45	205	308
Apect (°)	O	SE	.	SO	SE	SE	NO	SO	E	E	O	E- SE	N	NE
Slope (°)	20	40	.	20	20	20	10	10	60	50	9	40	50	30
Cover (%)	100	80	100	90	90	100	100	100	100	100	100	90	100	100
Tree layer height (m)	9	13	8	16	13	20	15	15	14	14	12	14	15	12
Shrub layer height (m)	4	2	2	3	5	3	2	2	3	3	6	2	3	4
Herb layer height (m)	0.2	0.8	0.8	0.8	0.6	0.6	0.7	0.7	0.7	0.7	0.5	0.5	0.8	0.8
Tree layer cover (%)	90	70	70	70	80	95	90	90	90	95	85	75	95	80
Shrub layer cover (%)	40	40	90	50	20	60	30	20	60	70	40	40	80	90

Herb layer cover (%)	10	40	20	60	40	70	70	80	50	50	50	70	40	60
Quercus pubescens Willd. subsp. Pubescens (Tree)	4	3	4	4	4		2	1	4	5	4	4	4	2
Quercus pubescens Willd. subsp. Pubescens (Shrub)	2	1		2	2						+			
Quercus pubescens Willd. subsp. Pubescens (Herb)				+								+	2	+
Charact. taxa of Erico-Quercion ilicis														
Quercus congesta C.Presl (Tree)						4	4	4					2	
Quercus congesta C.Presl (Herb)							+	1						
Quercus dalechampii Ten.						2		2						
Quercus amplifolia Guss.										2				
Cytisus villosus Pourr.			+			+	3	+	1	3			2	
Silene							+							



m Aiton														
Charact. and taxa Quercetalia ilicis, Quercetea ilicis														
Smilax aspera L.	3				1						2		2	
Quercus ilex L. subsp. Ilex (Tree)	2					2	2	3	3	2		1	3	
Quercus ilex L. subsp. Ilex (Shrub)														+
Quercus ilex L. subsp. Ilex (Herb)							+							
Viburnum tinus L. subsp. tinus	2										3			
Fraxinus ornus L. subsp. Ornus (Tree)	1								2	2				
Fraxinus ornus L. subsp. Ornus (Shrub)									1	2	+		+	+
Fraxinus ornus L. subsp. Ornus (Herb)				+					1					
Asparagus acutifolius L.	+		1		1				+	+		+	2	+
Rubia	+	+		1	1					2	2	2	3	1

peregrina L.														
Rosa sempervirens L.	+	2	1	1		1		1				2	2	1
Myrtus communis L.			1											
Lonicera implexa Aiton subsp. implexa			+										+	
Cytisus infestus (C.Presl) Guss.		1							+					
Quercus suber L. (Tree)		1												
Quercus suber L. (Shrub)		+												
Asplenium onopteris L.	+	+	+	+	+				1	1	+	+	+	+
Daphne gnidium L.		+												
Carex flacca Schreb.	+	+		+								1		
Olea europaea L. (T		+			1								+	
Olea europaea L. (Shurb)														
Arisarum vulgare O.Targ.Toz z. subsp.Vulga re					+						+	+	+	
Carex distachya Desf.									+	+			+	+



australis (Tree)														
Celtis australis L. subsp. Australis (Herb)														+
Transg. Quercu - Fagetea														
Castanea sativa Mill. (Tree)				2										
Castanea sativa Mill. (Shrub)				1										
Quercus petraea (Matt.) Liebl. subsp. austrotyrrh enica Brullo, Guarino & Siracusa						3								
Brachypodi um sylvaticum (Huds.) P.Beauv. subsp. sylvaticum		1		1		2	2	1	1	+		1	3	
Quercus frainetto Dieci.						2								
Euphorbia meuselii Geltman						2	1	+						
Acer opalus Mill. subsp. obtusatum (Waldst. &							1							

Kit. ex Willd.) Gams														
Fagus sylvatica L. subsp. sylvatica						1								
Ostrya carpinifolia Scop.						1								
Festuca heterophylla Lam.						1								
Daphne laureola L.						+	1	+						
Aremonia agrimonoides (L.) DC. subsp. agrimonoides						+	+							
Galium rotundifolium L. subsp. rotundifolium						+	+							
Vinca major L. subsp. major				1					1	3				
Hedera helix L. subsp. helix				2						1				
Hedera helix L. subsp. Helix (Shrub)														
Ilex aquifolium L.							1	+						
Sorbus torminalis (L.) Crantz								1						
Scutellaria								1					1	





(L.) D.Gut.Larr., Santos- Vicente, Anderb., E.Rico & M.M.Mart. Ort.		+											
Rumex bucephalop horus L.		+											
Medicago coronata (L.) Bartal.		+											
Polypodiu m cambricum L.		+											
Crepis leontodont oides All.		+					+	+					+
Glebionis coronaria (L.) Spach		+											
Stellaria media (L.) Vill.		+											
Rhamnus cathartica L.		+											
Agrimonia eupatoria L. subsp. eupatoria		+											
Silene latifolia Poir.		+											
Hieracium morum L.		+											
Sorbus domestica L.			1				+	+					+
Ampelodes			1		1							2	









Oenanthe pimpinelloi des L.															+
Anogramm a leptophylla (L.) Link															+
Geranium rotundifolium L.															+
Arum italicum Mill. subsp. italicum															+
Smyrniaceae perfoliatum L. subsp. rotundifolium (Mill.) Bonnier & Layens															+
Rhagiaceae stellatus (L.) Gaertn.															+

### S5. Phytosociological table (g1Eo\*). Chapter 2

Relevé number	1	2	3	4	5	6	7	8	9	10	11
Cell ID	10km	10k	10k	10k	10k	10k	10k	10k	10k	10k	10k
	E4	mE	mE	mE	mE	mE	mE	mE	mE	mE	mE
	86N1	488	488	488	487	488	487	487	488	488	482
	78	N1	N1	N1	N1	N1	N1	N1	N1	N1	N1
	74	74	78	77	77	75	76	74	74	70	
Latitude	38,97	38,5	38,5	38,9	38,8	38,8	38,6	38,7	38,5	38,5	38,2
	59	88	88	75	29	29	99	77	94	94	59
	17	022	147	397	164	097	014	242	142	478	411
Longitude	16,25	16,3	16,3	16,4	16,4	16,4	16,3	16,3	16,3	16,3	15,7
	84	93	92	27	04	05	24	46	99	99	63
	31	328	011	989	547	75	903	686	9	725	797
Date	25/05/	22/0	22/0	09/0	20/1	20/1	07/0	20/0	15/0	24/0	30/0
	2	7/	7/	4/	0/	0/	9/	7/	7/	6/	4/
	022	2019	2019	2022	2015	2015	202	202	200	200	200

							2	2	4	6	4
Area (m2)	200	100	100	100	100	100	200	200	100	200	100
Altitude (m a.s.l.)	248	1004	1014	607	358	346	666	731	997	1001	41
Apect (°)	-	-	-	SE	-	-	O	NO	-	-	-
Slope (°)	-	-	-	2	-	-	5	15	-	-	-
Cover (%)	100	100	100	100	90	90	95	100	70	100	90
Tree layer height (m)	14			26	15	15	18	18	15	16	-
Shrub layer height (m)	4			8	3	3	5	3	-	3	10
Herb layer height (m)	1			1	1	1	0.9	0.7	1	1	0.7
Tree layer cover (%)	85	95	95	70	90	90	90	95	70	90	-
Shrub layer cover (%)	80	10	5	20	10	40	30	10	-	60	80
Herb layer cover (%)	50	80	100	90	80	70	70	80	50	70	20
Diagnostic taxa of Angelico sylvestris- Alnetum glutinosae											
^Angelica sylvestris L. subsp. sylvestris	-	-	4		1		1				
Charact. taxa of Osmundo regalis - alnion glutinosae											
Hypericum hircinum L.					1	1					2
Osmunda regalis L.					3				3		
Athyrium filix-femina (L.) Roth							2	2		1	
Pteridium aquilinum (L.) Kuhn subsp. aquilinum							+	+			
Ilex aquifolium L. (arbust)	-	+	-								
Polystichum setiferum (Forssk.) T.Moore ex Woyn.					1	1		2			
Charact. taxa of Populion and Populetalia albae											
^Alnus glutinosa (L.) Gaertn. (Tree)	3	5	5	4	5	5	4	5	4	5	
^Alnus glutinosa (L.) Gaertn. (Shrub)				2				1			4
^Angelica sylvestris L. subsp. sylvestris	-	-	4								
^Lysimachia nemorum L.	-	3	1				+				
^Populus nigra L.	2	-	-								
^Salix alba L.	2	-	-		+						
^Carex pendula Huds.	+	-	1	1	2	3	1				
^Chaerophyllum hirsutum L.	-	+	-								
^Sambucus nigra L. (Shrub)	-	+	-	2	1	2	2	2		1	
^Sambucus nigra L. (Herb)								1			
^Solanum dulcamara L.									+	1	
Charact. taxa of Salici purpureae- Populetea nigrae											
Carex remota L.	-	2	3		3	1		2	2	2	1

Other species										
Catalpa bignonioides Walter	+	-	-							
Convolvulus sepium L.	1	-	-							
Lactuca sativa L. subsp. serriola (L.) Galasso, Banfi, Bartolucci & Ardenghi	+	-	-							
Anethum foeniculum L.	+	-	-							
Robinia pseudoacacia L. (Tree)	2	-	-			1				
Robinia pseudoacacia L. (Shurb)	2	-	-							2
Amorpha fruticosa L.	2	-	-							
Ailanthus altissima (Mill.) Swingle	1	-	-							
Nerium oleander L. subsp. oleander	+	-	-							
Rubus ulmifolius Schott	2	-	-	2						4
Bidens pilosa L.	+	-	-							
Solanum nigrum L.	+	-	-							
Juncus acutus L. subsp. acutus	+	-	-							
Ranunculus repens L.	-	3	2							
Poa palustris L. subsp. palustris	2	-	-							
Rubus hirtus Waldst. & Kit. group	-	1	2	+		3	3		1	
Crataegus monogyna Jacq.	-	1	-			1			2	
Dryopteris filix-mas (L.) Schott	-	+	3							
Prunella vulgaris L. subsp. vulgaris	-	+	1							
Mentha longifolia (L.) L.	-	+	-							
Arisarum vulgare O.Targ.Tozz. subsp. vulgare	-	+	-							
Cirsium palustre (L.) Scop.	-	+	-							
Cynosurus cristatus L.	-	+	-							
Euonymus europaeus L.	-	+	-	+						
Helosciadium nodiflorum (L.) W.D.J.Koch subsp. nodiflorum	-	+	-							
Oenanthe pimpinelloides L.	-	+	-							+
Persicaria decipiens (R.Br.) K.L.Wilson	-	+	-							
Potentilla reptans L.	-	+	-					1		
Primula vulgaris Huds. subsp. vulgaris	-	+	-							
Ranunculus flammula L.	-	+	-							+
Rumex sanguineus L.	-	-	1			2				
Cardamine sp.	-	-	+							+
Geum urbanum L.	-	-	+							
Symphytum tuberosum L. subsp. angustifolium (A.Kern.) Nyman				+						
Rumex scutatus L.				1						
Cardamine chelidonia L.				1						
Anemone apennina L.				2						



Thalictrum aquilegiifolium L. subsp. aquilegiifolium										1		
Malus sylvestris (L.) Mill.											2	
Stellaria nemorum L.											2	
Prunella laciniata (L.) L.											2	
Arisarum proboscideum (L.) Savi											2	
Poa sylvicola Guss.											2	
Acer pseudoplatanus L.											+	
Dactylorhiza maculata (L.) Soó subsp. saccifera (Brongn.) Diklić											1	
Thalictrum sp.											1	
Galium aparine L.											1	
Equisetum palustre L.											+	
Acanthus mollis L. subsp. mollis												+
Convolvulus silvaticus Kit.												1
Arundo donax L.												1
Salix tyrrhenica Brullo, Scelsi & Spamp.												2

## S6. Phytosociological table (g2A0). Chapter 2

Relevé number	1
Cell ID	10kmE486N178
Latitude	38,97015
Longitude	16,258033
Date	26/05/2022
Area (m2)	200
Altitude (m a.s.l.)	210
Apect (°)	-
Slope (°)	-
Cover (%)	100
Tree layer height (m)	16
Shrub layer height (m)	3
Herb layer height (m)	0.6
Tree layer cover (%)	90
Shrub layer cover (%)	50
Herb layer cover (%)	20
Charact. and diff. taxa of Populion albae, Populetales albae, Salici purpureae-Populetea nigrae	
^Salix alba L.	3
^Alnus glutinosa (L.) Gaertn.	2

^Populus alba L.	2
^Convolvulus sepium L.	1
^Sambucus nigra L.	2
^Urtica dioica L.	1
^Carex pendula Huds.	+
^Arum italicum Mill. subsp. italicum	+
^Equisetum telmateia Ehrh.	+
Other species	
Avena fatua L.	+
Lolium perenne L.	+
Sonchus asper (L.) Hill	+
Phleum pratense L. subsp. pratense	+
Robinia pseudoacacia L. (A)	1
Theligionum cynocrambe L.	+
Fumaria officinalis L.	+
Oxalis pes-caprae L.	+
Helianthus tuberosus L.	1
Arundo donax L.	1
Ailanthus altissima (Mill.) Swingle	1
Nerium oleander L. subsp. oleander	2
Stellaria media (L.) Vill.	+
Rubus ulmifolius Schott	3
Ervum tetraspermum L.	+
Geranium robertianum L.	+
Equisetum ramosissimum Desf.	+
Parietaria judaica L.	1

### S7. Phytosociological table (9330). Chapter 2

Relevé number	1	2	3
Cell ID	10kmE485N1 78	10kmE487N175	10kmE489N1 75
Latitude	38,953347	38,683064	38,638206
Longitude	16,179847	16,292239	16,510347
Date	25/05/2022	07/09/2022	04/10/2022
Area (m2)	200	200	400
Altitude (m a.s.l.)	75	400	366
Apect (°)	S-SE	NO	N
Slope (°)	5	50	30
Cover (%)	100	95	100
Tree layer height (m)	12	12	14
Shrub layer height (m)	2.5	4	2.5

Herb layer height (m)	0.4	0.7	0.6
Tree layer cover (%)	75	95	100
Shrub layer cover (%)	50	30	50
Herb layer cover (%)	40	40	30
Charact. taxa of Helleboro Quercetum suberis.			
Helleborus viridis L. subsp. bocconeii (Ten.) Peruzzi	.	+	.
Lathyrus venetus (Mill.) Wohlf.	.	+	.
Charact. of var. Myrtus communis dell' HelleboroQuercetum suberis.			
Myrtus communis L.	2	2	+
Pistacia lentiscus L.	1	.	.
Charact. of var. Myrtus communis dell' HelleboroQuercetum suberis.			
Char. Alleanza ( Erico - Quercion ilicis)	.	.	.
Quercus suber L. (Tree)	5	5	4
Quercus suber L. (Shrub)	2	.	1
Quercus suber L. (Herb)	1	+	+
Erica arborea L.	.	3	2
Drymochloa drymeja (Mert. & WDJKoch) Holub subsp. exaltata (C.Presl) Foggi & Signorini	.	1	2
Arbutus unedo L.	.	.	1
Cytisus villosus Pourr.	.	+	+
Char. Ordine e Classe ( Quercetalia ilicis, Quercetea ilicis)			
Crataegus laevigata (Poir.) DC.	2	.	.
Rubia peregrina L.	2	2	1
Quercus ilex L. subsp. Ilex (Tree)	-	2	3
Quercus ilex L. subsp. Ilex (Shrub)	-	1	.
Quercus ilex L. subsp. Ilex (Herb)	.	+	1
Quercus pubescens Willd. subsp. Pubescens (Tree)	2	2	.
Quercus pubescens Willd. subsp. Pubescens (Shrub)	.	.	1
Quercus pubescens Willd. subsp. Pubescens (Herb)	.	.	.
Smilax aspera L.	2	1	2
Fraxinus ornus L. subsp. Ornus (Tree)	.	.	2
Fraxinus ornus L. subsp. Ornus (Shrub)	.	2	1
Fraxinus ornus L. subsp. Ornus (Herb)	.	+	1
Rosa sempervirens L.	2	2	1
Phillyrea latifolia L.	.	.	1
Ruscus aculeatus L.	.	.	1
Asparagus acutifolius L.	+	1	.
Carex flacca Schreb.	+	.	.
Carex distachya Desf.	+	.	.

<i>Daphne gnidium</i> L.	+	.	.
<i>Asplenium onopteris</i> L.	.	1	+
<i>Cyclamen hederifolium</i> Aiton	.	+	+
<i>Dioscorea communis</i> (L.) Caddick & Wilkin	.	+	.
Other species	.	.	.
<i>Gladiolus italicus</i> Mill.	+	.	.
<i>Urospermum picroides</i> (L.) Scop. ex F.W.Schmidt	+	.	.
<i>Oenanthe pimpinelloides</i> L.	+	.	.
<i>Brachypodium rupestre</i> (Host) Roem. & Schult.	+	.	.
<i>Rubus ulmifolius</i> Schott	+	.	.
<i>Pteridium aquilinum</i> (L.) Kuhn subsp. <i>aquilinum</i>	+	.	.
<i>Ranunculus lanuginosus</i> L.	+	.	.
<i>Epipactis helleborine</i> (L.) Crantz	+	.	.
<i>Ampelodesmos mauritanicus</i> (Poir.) T.Durand & Schinz	.	2	.
<i>Aegonychon purpurocaeruleum</i> (L.) Holub	.	1	.
<i>Sorbus domestica</i> L.	.	1	.
<i>Crataegus monogyna</i> Jacq.	.	1	.
<i>Vinca major</i> L. subsp. <i>major</i>	.	1	.
<i>Clematis vitalba</i> L.	.	1	.
<i>Prunus spinosa</i> L. subsp. <i>spinosa</i>	.	+	.
<i>Castanea sativa</i> Mill.	.	+	.

## S8. Phytosociological table (2110,2150). Chapter 2

Relevé number	1	2
Cell ID	10kmE488N171	10kmE488N171
Latitude	38,953347	38,683064
Longitude	16,179847	16,292239
Date	03/05/2022	03/05/2022
Area (m2)	50	50
Altitude (m a.s.l.)	6	4
Apect (°)	0	0
Slope (°)		
Cover (%)	70	80
Tree layer height (m)		
Shrub layer height (m)		
Herb layer height (m)	0,5	0,5
Tree layer cover (%)		
Shrub layer cover (%)		
Herb layer cover (%)	70	80
Charact. Associazione <i>Cypero mucronati</i> - <i>Agropyretum juncei</i>		
^ <i>Thinopyrum junceum</i> (L.) Á.Löve	1	4

Char. Alleanza Ordine e Classe ( Ammophilon, Ammophiletalia, Ammophiletea)		
Medicago marina L.	4	1
Lotus creticus L.	3	3
Achillea maritima (L.) Ehrend. & Y.P.Guo subsp. maritima		+
Eryngium maritimum L.	+	+
Other species		
Reseda alba L. subsp. Alba		+
Silene niceensis All.	2	2
Tragopogon dubius Scop.	+	
Tribulus terrestris L.		+
Xanthium strumarium L.	+	
Festuca bromoides L.		1
Matthiola tricuspidata (L.) W.T.Aiton	2	2
Lagurus ovatus L. subsp. ovatus	+	+
Andryala integrifolia L.	+	+
Glaucium flavum Crantz	+	

### S9. Phytosociological table (8210). Chapter 2

Relevé number	1
Cell ID	10kmE488N171
Latitude	38,327394
Longitude	16,407747
Date	03/05/2022
Area (m2)	20
Altitude (m a.s.l.)	65
Apect (°)	N
Slope (°)	15
Cover (%)	60
Tree layer height (m)	
Shrub layer height (m)	2
Herb layer height (m)	0,6
Tree layer cover (%)	
Shrub layer cover (%)	20
Herb layer cover (%)	40
Charact and Diagnostic taxa of Dianthion rupicolae, Asplenietalia glandulosi	
^ Dianthus virgineus L.	3
Ptilostemon gnaphaloides (Cirillo) Soják subsp. naphaloides	2
Erucastum virgatum C.Presl subsp. Virgatum	+
Other species	
Artemisia arborescens (Vaill.) L.	+

<i>Cytisus infestus</i> (C. Presl) Guss. subsp. <i>infestus</i>	+
<i>Reichardia picroides</i> (L.) Roth	1
<i>Lotus cytisoides</i> L.	1
<i>Euphorbia dendroides</i> L.	1

S10. Phytosociological table (1430). Chapter 2

Relevé number	1
Cell ID	10kmE4,83N175
Latitude	38,665712
Longitude	15,862635
Date	03/05/2022
Area (m2)	20
Altitude (m a.s.l.)	33
Apect (°)	0
Slope (°)	40
Cover (%)	60
Tree layer height (m)	-
Shrub layer height (m)	-
Herb layer height (m)	0,5
Tree layer cover (%)	-
Shrub layer cover (%)	-
Herb layer cover (%)	80
Charact and Diagnostic taxa of (Artemision arborescentis, Salsolo- Peganetalia, Pegano-Salsoletea	
^ <i>Artemisia arborescens</i> (Vaill.) L.	3
^ <i>Anagyris foetida</i> L.	2
Other species	
<i>Lonicera implexa</i> Aiton subsp. <i>implexa</i>	2
<i>Micromeria graeca</i> (L.) Benth. ex Rchb.	2
<i>Jacobaea maritima</i> (L.) Pelsler & Meijden	2
<i>Bituminaria bituminosa</i> (L.) C.H.Stirt.	1
<i>Sisymbrium atrypurea</i> (L.) Greuter & Burdet	1
<i>Centaurium erythraea</i> Rafn	1
<i>Plantago</i> sp.	+
<i>Silene vulgaris</i> (Moench) Garcke subsp. <i>tenoreana</i> (Colla) Soldano & F.Conti	+
<i>Allium sphaerocephalon</i> L.	+

S11. Phytosociological table (91E0\*). Chapter 2

Relevé number	1
Cell ID	10kmE488N177
Latitude	38,829096
Longitude	16,405749
Date	20/10/2015
Area (m2)	100
Altitude (m a.s.l.)	346
Apect (°)	-
Slope (°)	-
Cover (%)	90
Tree layer height (m)	15
Shrub layer height (m)	3
Herb layer height (m)	1
Tree layer cover (%)	90
Shrub layer cover (%)	40
Herb layer cover (%)	70
Char. Hyperico hircini–Alnenion glutinosae	
^Hypericum hircinum L.	1
Char. Alno glutinosae-Populetea albae and Populeta albae	
^Alnus glutinosa (L.) Gaertn.	5
^Sambucus nigra L.	2
^Carex pendula Huds.	3
^Carex remota L.	1
^Polystichum setiferum (Forssk.) T.Moore ex Woyt.	1
Other species	
Hedera helix L. subsp. helix	1















































































































































































20	9340	Calabria	Reggio Calabria	San Giorgio Morgeto	Monte Campanaro	38°22'6.30"	16° 6'25.95"	10/8/2018
21	9340	Calabria	Reggio Calabria	San Luca	Fiumara Buonamico	38° 8'47.44"	16° 1'6.83"	24/7/2018
22	9340	Calabria	Reggio Calabria	Ferruzzano	Bosco di Rudina	38° 2'43.08"	16° 4'35.65"	21/6/2019
23	9340	Calabria	Vibo Valentia	Drapia	V.ne Occhi Bianchi	38°38'29.77"	15°55'57.17"	2/8/2018
24	9340	Calabria	Reggio Calabria	San Luca	Brancato	38°8'11.50"	16°2'56.17"	29/5/2002
25	9340	Calabria	Reggio Calabria	San Luca	Brancato	38°8'1.74"	16°2'50.19"	29/5/2002
26	9340	Calabria	Reggio Calabria	San Luca	Brancato	38°8'5.51"	16°2'23.87"	29/5/2002
27	9340	Calabria	Reggio Calabria	Cosoleto	Torrente Vasi	38°14'24.09"	15°53'26.88"	31/7/2018
28	9340	Calabria	Reggio Calabria	San Luca	Bosco Mancuso - Polsi	38°10'9.71"	15°58'3.73"	19/6/2013
29	91Mc	Calabria	Reggio Calabria	Stilo	S.S. 110 - Km 55,5	38°29'27.64"	16°21'52.86"	15/7/2004
30	91Mc	Calabria	Reggio Calabria	Stilo	S.S. 110 - Km 55,5	38°29'24.49"	16°21'51.48"	16/7/2004
31	91Mc	Calabria	Catanzaro	Santa Caterina dello Jonio	Tabacco	38°32'56"	16°28'45.54"	15/7/2004
32	91Mc	Calabria	Vibo Valentia	Brognaturo	Bocca d'Assi	38°34'17.82"	16°23'42.98"	16/7/2004
33	91Mc	Calabria	Reggio Calabria	Stilo	C.le Mondato	38°29'50.26"	16°21'23.59"	21/7/2005
34	91Mc	Calabria	Cosenza	San Giovanni in Fiore	Juri Vetere Soprano	39°16'56.68"	16°37'54.36"	1/8/2018
35	91Mc	Calabria	Reggio Calabria	Roghudi	Torrente Menta	38° 6'47.33"	15°54'18.36"	25/7/2018
36	91Mc	Calabria	Reggio Calabria	San Luca	Contr.a Croce di Dio sia lodato	38° 7'3.92"	15°58'9.86"	26/7/2018
37	91Mb	Calabria	Cosenza	Bocchigliero	Coppo dei cerri	39°21'39.03"	16°41'35.28"	8/8/2018
38	91Mb	Calabria	Reggio Calabria	San Luca	Serro d'Ustra	38° 7'20.47"	16° 0'43.23"	28/7/2018
39	91Mb	Calabria	Reggio Calabria	San Luca	Pietra Cappa	38°10'1.19"	16° 1'25.19"	30/7/2018
40	91Mb	Calabria	Catanzaro	Badolato	Monte S. Nicola	38°33'59.94"	16°26'18.24"	15/7/2004
41	91Mb	Calabria	Reggio Calabria	Samo	Grottelle	38°5'24.60"	16°0'35.17"	15/4/2022
42	91Ma	Calabria	Catanzaro	Petilia Policastro	Colle della Farna	39° 8'48.29"	16°43'9.20"	22/7/2018
43	91Ma	Calabria	Cosenza	Cerchiara di Calabria	Fagosa	39°55'2.10"	16°14'25.00"	11/8/2018
44	91Ma	Calabria	Catanzaro	San Pietro Apostolo	M. Trearie	38°59'29.06"	16°30'2.18"	20/7/2022
45	91Ma	Calabria						
46	91Ma	Calabria	Cosenza	Alessandria del Carretto	Monte Sparviere	39°55'20.18"	16°21'25.99"	20/7/2022
47	9330	Calabria	Reggio Calabria	Scilla	M. Scrisi	38°14'13.74"	15°42'33.96"	21/5/2018
48	9330	Calabria	Reggio Calabria	Scilla	M. Scrisi	38°14'19.67"	15°42'48.73"	21/5/2018
49	9330	Calabria						

50	9330	Calabria	Reggio Calabria	Giorgio Morgeto	C.da S. Eusebio,	38°21'57.34"	16° 6'12.48"	10/6/2010
51	9330	Calabria	Reggio Calabria	Giorgio Morgeto	C.da S. Eusebio,	38°21'59.42"	16° 6'8.32"	11/6/2010
52	9330	Calabria	Reggio Calabria	Scilla	M. Scrisi	38°14'28.83"	15°42'20.49"	21/5/2018
53	9330	Calabria	Vibo Valentia	Capistrano		38°41'0.19"N	16°17'41.11"E	10/9/2022
54	9330	Calabria	Catanzaro	Gizzeria	Contrada Jacona	38°57'15.89"	16°10'47.54"	25/4/2022
55	9330	Calabria	Reggio Calabria	Giorgio Morgeto	C.da S. Eusebio,	38°21'55.30"	16° 6'14.31"	11/6/2018
56	9330	Calabria	Vibo Valentia	Pizzo	Angitola	38°45'51.47"N	16°12'59.82"E	12/4/2018
57	9330	Calabria	Catanzaro	Feroleto Antico	Pendici Baratta	38°54'27.01"	16°20'27.18"	20/4/2022
58	9330	Calabria	Catanzaro	Feroleto Antico	Pendici Baratta	38°54'46.66"	16°20'41.06"	21/4/2022
59	9330	Calabria	Catanzaro	Feroleto Antico	Pendici Baratta	38°54'20.92"N	16°21'26.45"E	22/4/2022

S14. Number of polygons crossed by the connectors for each habitat. Chapter 6

Macro-categories	Nature Map Code	Habitat Directive Code	Area (ha)	Number polig.
Agricultural	84	-	65,1	1593
Agricultural	82.1	-	55,546974	634
Agricultural	82.3	-	154,902979	2265
Agricultural	82.41	-	10,65255	5
Agricultural	83.11	-	148,381159	3325
Agricultural	83.12	-	1,157529	31
Agricultural	83.13	-	0,399515	9
Agricultural	83.15_m	-	5,139782	88

Agricultural	83.16	-	77,732654	930
Agricultural	83.21	-	5,285627	84
Bogs and marshes	54.5	7140	7,221393	10
Coastal and halophytic communities	15.5	1410	18,069607	57
Coastal and halophytic communities	15.6	1420	0,372651	4
Coastal and halophytic communities	15.72	1430	14,768794	38
Coastal and halophytic communities	16.1	1210	334,884975	579
Coastal and halophytic communities	16.21	2110/2120	166,550475	286
Coastal and halophytic communities	16.22	2230/2240/2250	237,63348	533
Coastal and halophytic communities	16.27	2250*	33,14492	126
Coastal and halophytic communities	16.28	2260	152,529302	286
Coastal and halophytic communities	16.29	2270*	353,031971	472
Coastal and halophytic communities	18.221_m	1240	73,55106	188
Forests	41.732	91AA*	1519,528751	2049
Forests	42.612	9530*	24,659481	76
Forests	42.711	95A0	22,629373	134
Forests	44.513	91E0*	261,664308	715

Forests	41.7511	91Mo	542,121147	500
Forests	41.7512	91M1	956,183038	696
Forests	41.7513	91M2	1,639922	3
Forests	41.18	9210*/9220*	2800,530515	4283
Forests	41.4	9180*	57,342156	120
Forests	41.9	9260	2117,844016	2312
Forests	41.C1	9180*	219,278204	185
Forests	42.15	9510*	54,256299	102
Forests	42.65	9530*	419,608462	953
Forests	42.83	9540	73,08024	120
Forests	42.84	9540	389,212988	388
Forests	44.12	92A0	193,7551	264
Forests	44.14	92A1	233,314568	231
Forests	44.4	91Fo	2,348802	3
Forests	44.61	92A0	1589,364675	1282
Forests	44.71	92Co	0,356561	6
Forests	44.81	92Do	157,206039	207

Forests	45.21	9330	467,659142	490
Forests	45.31	9340	2057,288004	2825
Forests	45.32	9340	1370,219054	1877
Inlands rocks, screes and sands	61.3B1	8130	5,845503	16
Inlands rocks, screes and sands	62.11	8210	35,133701	132
Inlands rocks, screes and sands	62.14	8210	28,288333	52
Non-marine waters	21_m	1150*	5,865213	11
Non-marine waters	22.1_m	3130/3140/3150	0,353574	3
Non-marine waters	22.3	3170*	30,096434	60
Non-marine waters	22.4	3150	83,024323	149
Non-marine waters	24.1_m	3290	368,326634	755
Non-marine waters	24.225_m	3250	614,300561	1004
Non-marine waters	24.4	3260/3280	333,087245	334
Non-marine waters	24.53	3270/3290	41,64447	71
Scrub and grassland	32.217	5320	1,095606	13
Scrub and grassland	36.436	6170	13,120644	157
Scrub and grassland	32.12	9320	26,310601	80

Scrub and grassland	32.13	5210	0,332014	4
Scrub and grassland	32.22	5330	46,118783	189
Scrub and grassland	32.23	5330	236,728267	751
Scrub and grassland	32.24	5330	0,055514	2
Scrub and grassland	34.6A	6220*	35,306448	83
Scrub and grassland	34.6B	6220*	46,239906	132
Scrub and grassland	34.74	6210*	39,907215	389
Scrub and grassland	34.75	62A0	8,334253	24
Scrub and grassland	35.72	6230*	2,143655	23
Scrub and grassland	36.38	6170	0,196266	12
Scrub and grassland	37.1	6430	0,475196	6
Scrub and grassland	37.31	6410	0,020582	1
Scrub and grassland	37.4_m	6420	10,488522	63
Scrub and grassland	38.1	6510	43,054371	170
Bogs and marshes	53.1	-	0,177019	2
Bogs and marshes	53.61	-	2,375517	19
Bogs and marshes	53.62	-	788,297428	1052

Coastal and halophytic communities	17.1	-	12,582281	98
Coastal and halophytic communities	19.1	-	0,820575	15
Forests	41.81	-	1,526298	30
Forests	42.1B1	-	2,385993	36
Forests	42.67	-	297,291227	913
Inlands rocks, screes and sands	62.7_n	-	146,242061	165
Inlands rocks, screes and sands	67_n	-	132,674847	302
Scrub and grassland	31.844	-	56,385749	339
Scrub and grassland	31.863	-	37,293605	527
Scrub and grassland	32.212	-	0,419306	8
Scrub and grassland	32.215	-	29,722242	491
Scrub and grassland	31.43	-	18,745472	73
Scrub and grassland	31.77	-	7,01842	44
Scrub and grassland	31.81	-	37,811069	103
Scrub and grassland	31.87	-	1,690032	17
Scrub and grassland	31.8A	-	4,937476	174
Scrub and grassland	32.11	-	111,350663	536

Scrub and grassland	32.214_m	-	49,077503	396
Scrub and grassland	32.31	-	46,901174	253
Scrub and grassland	32.9	-	11,011773	203
Scrub and grassland	32.A	-	25,819076	526
Scrub and grassland	34.8_m	-	87,92659	1005
Scrub and grassland	37.A_n	-	3,845318	70
Urban	81	-	0,288125	5
Urban	85	-	3,038539	91
Urban	83.321	-	1,529615	25
Urban	83.322	-	19,740951	250
Urban	31.A	-	0,189722	7
Urban	41.L_n_A	-	6,371144	136
Urban	41.L_n_C	-	5,248072	48
Urban	83.31_m	-	26,881325	442
Urban	83.325_m	-	171,877918	248
Urban	86.1_m	-	65,591621	1337
Urban	86.1_s	-	110,487079	2243

Urban	86.31	-	2,262933	46
Urban	86.32	-	8,682556	173
Urban	86.41_m	-	3,196912	95
Urban	86.6	-	0,14237	2
Urban	89.2	-	3,789121	111
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