GYPWORLD
A GLOBAL INICIATIVE TO UNDERSTAND GYPSUM ECOSYSTEM ECOLOGY

UNIVERSITÀ DEGLI STUDI DI REGGIO CALABRIA
Mediterranea

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AGRARIA

# BOOK OF ABSTRACTS
## and FIELD TRIP GUIDE

## 2nd INTERNATIONAL WORKSHOP
# GYPWORLD
1-4 APRIL 2019 - REGGIO CALABRIA (ITALY)

**GYPWORLD: A Global initiative to understand gypsum ecosystem ecology**
**Book of abstracts and Field trip guide**

**II International Workshop**
Reggio Calabria (Italy) 1-4 april, 2019.
Mediterranea University of Reggio Calabria, Italy.

Book of abstracts and Field trip guide: Key speakers, Oral presentations and Poster presentations

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GYPWORLD

A GLOBAL INICIATIVE TO UNDERSTAND GYPSUM ECOSYSTEM ECOLOGY

### II GYPWORLD WORKSHOP
### Reggio Calabria, 1-4- april 2019

# PROGRAM

*Monday, 1st April 2019*

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|---|---|
| **9:00-17:00** | **GYPWORLD Project Mid-term Review Meeting** |

*Tuesday, 2nd April 2019*

| | |
|---|---|
| **9:00-9:30** | **Welcome** |
| 9:30-10:15 | *Key speaker.* Rebecca E. Drenovsky (Oberlin College, USA): Chihuahuan Desert gypsum endemics: patterns of adaptation in relation to phylogeny and distribution extent |
| **10:15-11:00** | **Oral session I** |
| 10:15-10:30 | José Ignacio Querejeta et al.: Gypsophyles use water from deeper soil layers than gypsovags during drought in a semiarid gypsum shrubland community: is deep rooting a key functional trait of gypsum specialists? |
| 10:30-10:45 | Luca Di Nuzzo et al.: Analysis of the taxonomic and functional diversity of lichens in an environmental gradient in Spain |
| 10:45-11:00 | Roberto López-Rubio et al.: Three-year maintained drought reduces diversity in gypsum annual plant communities |
| 11:30-12:15 | *Key speaker.* Juan Herrero (Agencia Estatal Consejo Superior de Investigaciones): Why gypsum makes soils so special for life |
| **12:15-13:00** | **Oral session II:** |
| 12:15-12:30 | Helga Ochoterena et al.: Looking for gypsum floras: a novel method based on geographic information systems and plant collections |
| 12:30-12:45 | Francisco J. Pérez-García et al.: Where to look for gypsophily phenomena? Towards a global mapping of the world gypsum outcrops |
| 12:45-13:00 | Fabian Martínez-Hernández et al.: Gypsum outcrops in Utah: an important habitat for plant conservation |
| **14:30-15:00** | **Poster session** |
| 15:00-15:45 | *Key speaker.* Adrián Escudero (Universidad Rey Juan Carlos, SPAIN): Living on gyspsum soils: a challenge for plants and an opportunity for ecologists |
| 15:45-16:30 | *Key speaker.* Mehdi Abedi (Tarbiat Modares University, IRAN): Functional ecology of arid lands: microhabitats explain vegetation and lichens compositions |
| 16:30-16:45 | Carmelo M. Musarella et al.: Which habitat for Sicilian gypsophytes? |

*Wednesday, 3rd April 2019*

| | |
|---|---|
| 9:00-9:45 | *Key speaker.* Mike Lyons (Department of Biodiversity, Conservation and Attractions, AUSTRALIA): The gypsum flora and plant communities of Western Australia |
| 9:45-10:30 | *Key speaker.* Aran Luzuriaga (Universidad Rey Juan Carlos, SPAIN): Species coexistence in gypsum habitats of Spain |

| | |
|---|---|
| **10:30-12:30** | **Oral session III** |
| 10:30-10:45 | Sergio Muriel et al.: Do gypsophilic lichens exist? Towards a worldwide checklist of lichens living in gypsum soils |
| 10:45-11:00 | Pablo Tejero et al.: Tracking gypsophily across the phylogeny: 3 study cases. |
| 11:30-11:45 | Ana Foronda et al.: Gypsophyte shrubs enhance the survival and growth of perennial grasses in gypsum plant communities of the Middle Ebro Valley |
| 11:45-12:00 | Rocío Chaves et al.: Neighbourhood matters! Plant survival and fitness is favoured in experimentally manipulated communities with high phylogenetic diversity |
| 12:00-12:15 | Andreu Cera et al.: Evaluating the presence of fungi associated with plant roots of gypsum environments |
| 12:15-12:30 | Hossein Akhani: Diversity of the genus Heliotropium s.l. in SW Asia growing in xerophytic, psammophytic and gypsophytic communities |
| **12:30-13.00** | **Working session GYPWORLD WP 1 & 2** |
| **13:00-13:30** | **Working session GYPWORLD WP 3 & 4** |
| 13:30-13:45 | Closure |
| 15:00 | Departure to Santa Ninfa (TP) - Sicily |
| 19:10-20:00 | Giuliana Madonia, Salvatore Pasta: Presentation of the field trip on the Sicilian gypsum. |

*Thursday, 4th April 2019*

Field trip held on “Grotta di Santa Ninfa” Nature Reserve and “Grotta di Entella” Nature Reserve

# KEY SPEAKERS

# Chihuahuan Desert gypsum endemics: patterns of adaptation in relation to phylogeny and distribution extent

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Plant ecologists have long been fascinated by unique soil types and how they influence plant distribution, abundance, competition, and evolution. From these classic works, we know that soil chemistry can have profound effects on plant ecology and evolution. We also know that these systems can be biodiversity hotspots. Unlike other unusual soils, such as serpentine and limestone, we know significantly less about gypsum soils, despite their global distribution. Furthermore, much of what we know about these substrates comes from the Spanish flora. Using the Chihuahuan Desert of North America as our study system, we compared the physiological ecology of widely and narrowly distributed gypsophiles and their non-endemic congeners or confamilials growing on and off gypsum soils, respectively. In our work, we addressed two broad questions: (1) are there global patterns in the mechanisms supporting gypsum adaptation; and (2) what are the roles of phylogeny, lineage age, and distribution extent on these patterns? Overall, we found that leaf accumulation and assimilation of S and Ca (e.g., as gypsum) in older, widely distributed gypsophilic lineages is a potential mechanism supporting life on gypsum and that phylogeny was important for understanding patterns in foliar mineral nutrition. We extended this work to include data from Spanish taxa, and found that these general patterns held. Furthermore, certain taxonomic groups revealed unique leaf chemical signatures, particularly among members of the Brassicaceae, which were rich in leaf N and S. We propose these patterns are related to glucosinolate accumulation, and we provide some field data to support this hypothesis. We also have some data from whole plants, suggesting exclusion of excess Ca and S may support the growth of younger, narrowly distributed gypsophiles. Together, these data point to generalized patterns in adaptation to gypsum across study systems, with unique adaptations associated with wide and narrow gypsophiles. Overall, we propose that phylogenetic patterns may be key to unraveling these various adaptation mechanisms.

**Keywords**: Brassicaceae; pre-adaptation; glucosinolates; defense compounds; phylogeny; lineage age

# Why gypsum makes soils so special for life

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Gypsum ($CaSO_4{\bullet}2H_2O$) is a widely recognized mineral that has been continuously used since ancient times for many applications. This old knowledge of gypsum contrasts with the wrong or confusing statements that can be found throughout literature. The oral presentation reviews this subject and the historical reasons related in the past with the difficulties of communication between researchers, including the access and comparison of methods and results. The advent of the observations under polarizing microscopes and later under scanning electron microscopes was crucial for understanding the genesis and behavior of gypseous soils. The list of references provided at the end of this abstract includes those mentioned in the oral presentation.

The attribution of salinity to the presence of gypsum in the soils has been an erroneous affirmation supported by the simultaneous occurrence of gypsum with halite and other soluble salts in lacustrine sediments or other environments. The role of gypsum for plants' life in soils is antagonistic with sodium salts as shown by (1) or (2). In fact, gypseous soils irrigated with good quality water have been productive for hundreds of years in Spain (3) in spite of the apparition of sink holes, the nutrient imbalances, and the attack to concrete and other materials. Examples of confusing statements happen in some scientific journals of high impact (4) or even in articles devoted to gypsiferous soils (5). These kinds of statements contribute to the disregard of the reasons that make gypsum soils the support of ecosystems distinctly contrasting with those at the conterminous "normal" soils.

A basic error is to refer $CaSO_4$ as gypsum, with absence of the two water molecules in the formula. Many methods for preparation of soil samples—or other materials— prescribe an initial drying at temperatures that eliminate part or all of the constitutional water of gypsum (Fig. 1). The lability of gypsum against heating makes all further lab determinations on these heated samples incorrect, as the results are referred to a false weight of soil. As a rule of thumb, the 40ºC temperature must not be surpassed in any step of the preparation or analysis of samples of gypseous materials.

Another point that needs attention is the concept of particle-size classes. The fragility of the gypsum crystals makes the particle sizes largely artifactual after the routine grinding before the analyses. Moreover, the usual methods of determination of particle sizes based on dispersion and sedimentation is arguable due to (i) the flocculation induced by the dissolution of gypsum, (ii) the departure of the typical lenticular shape of gypsum particles from the assumption made when applying the Stokes' law, or (iii) the specific viscosity of the solution saturated in sulfate and calcium. The unsoundness of these determinations has been recognized by the USDA when stating terms in-lieu of texture for the soils with > 40% gypsum (6). The feel appraisal of the texture in the field seems much sounder. On the other hand, the determination of particle-size classes is often oriented to depict the hydric behavior of the soil, as it is a key soil property for plants' life in the arid regions where most gypseous soils occur. For this purpose the determination of the curves of water retention at different suction potentials can be recommended. This method gives eloquent measurements (7) by an easy procedure available in many labs using the ceramic plates.

The lability of gypsum against heating, however, allows easy and unsophisticated methods for the gypsum content determination in soils and similar materials. The thermogravimetric method of (8) refined by (9) is adequate for gypsum contents > 2% and non-smectitic soils. A method also satisfactory for low contents was developed by (10) based on the gypsum/basanite phase change. Both Artieda's and Lebron's methods only need common labware and equipment and few, if any, chemicals. Direct and rapid determinations on samples with few preparation, e.g. in the field within plastic bags, are possible with much more expensive instrumentation (11). The mentioned methods have been discussed and compared by (12,13).

A research subject for plant physiologists is how living organisms interact with the gypsum particles they are in direct contact with. This approach ought to consider not only the physiology of the organisms, but also the specific conditions and phenomena at the surface of the crystals like those studied by (14) or by (15), among others.

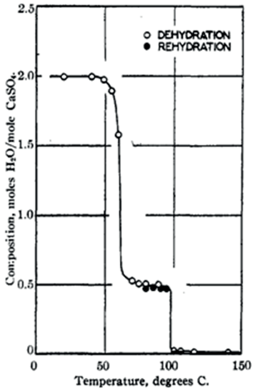

Fig. 1. Calcium sulfate hydration phases against temperature (Weiser et al., 1936).

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# Living on gyspsum soils: a challenge for plants and an opportunity for ecologists

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Probably one of the most important type of plant edaphisms and, unfortunately, one of the less studied, is the "gypsophily" or the ability for growing on gypsum soils. Although the reasons for this scarce knowledge are complex, the fact that gypsum soils are confined to drylands into Subtropics and Mediterranean climate-type regions, far of the wealthiest regions is not of low-concern. Surprisingly, gypsum soils extend on vast regions around the world from Australia to America and with countries in Africa where they covered more than the 70 % of their surface such as Ethiopia and give support for millions.

Fortunately, during the last twenty years we have assisted to a boom in the research on this topic with most of the work done in the context of the gypsum soils of the Mediterranean Basin, but also with outstanding efforts and contributions from colleagues from north America and other regions. Although the list of milestones is large, the ability of some of these plants for "drinking" water from the crystallographic water during the summer and drought season is really outstanding.

Here, we want to give a semblance of the state of art in the topic and mainly to describe the opportunity for ecologists, evolutive biologists and other researchers to use these very specialized systems as models for testing critical questions in their fields. For instance, recent works are shedding light on a very ancient and long standing questions in Evolution, are the hyper specialized plants evolutive dead ends or not? If not, how do these plants face the oncoming new climate scenarios? In parallel, the stressful conditions they face give also the opportunity to evaluate and even experimentally test some relevant questions related to community ecology such as the role of plant to plant interactions in the assembly of plant communities or the existence of diffuse positive networks almost plants to give opportunity to rare species.

We want to enjoy the possibility for discussing new venues and some paradigmatic ideas on the gypsohpily with all of you.

# Functional ecology of arid lands: microhabitats explain vegetation and lichens compositions

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Gypsum ecosystem is rarely investigated in Iran and only few studies reported flora or soil condition of agriculture lands. Considering gypsum habitats located in the arid lands therefore our knowledge in the arid lands could help for better understanding gypsum ecosystems. Arid lands include different habitats such as steppes, shrublands, hayperarid, saline soil, calcareous and gypsum habitats which plant species have different functional adaptation to survive in these harsh conditions. In this paper some aspect of plant species adaptation and vegetation and lichen compositions in response to environmental conditions in Iran is presented. In most arid and semi-arid regions, vegetation is distributed sporadically and on the soil surface between vegetation, biological soil crusts (BSCs) are present. The role played by dominant species in the structure and function of plant communities has been explicitly considered in the context of the ecosystem engineer concept or in the nurse effect concept, which proves that dominant species may act as promoters of plant diversity via plant to plant positive interactions. In this context, it is critical to unveil how dominant plant perennial species may affect the diversity of other biological guilds living there, such as lichens or annual plants. Microhabitats are the key part of vegetation patterns in these ecosystems with special conditions in soil moisture, soil temperature and fertility. In addition, species mainly have ionome and chemical adaptation to survive in soils with high amount of soil elements like saline, gypsum and calcareous soils.

Different habitats were selected to show functional adaptation of arid lands in Iran. We selected Almeh-Gharatikan site to as mountain steppes in Golestan National Park. In this area we first compared different shrub patches in two substrates and then effects of *Juniperus excelsa* shrubs on microhabitats conditions were studied. In addition, we studied the *Onobrychis cornuta* cushions in two exposures with different burning, shrub death treatments. 20 cushions and its open plots were selected in each treatment. The two corner and center position of each cushion were also analysed in this study. In second study we selected Artemisia steppes as the dominant steppes in Iran. Different sites were selected to study Artemisia steppes including Mirzabailo and Soolegerd in Golestan National park. We studied the effect grazing in Soolegerd sites in 3 grazing sites on biotic interactions and functional diversity and microclimatic conditions. In third research to study the role of BSCs in arid lands we selected Artemisia steppes including different cyanobacteria, lichens and moss crusts and its effect on microhabitats modification in Golestan National park. We also studied the interaction of *Artemisia sieberi* patch with lichens and moss and plant species. We evaluated the role of microhabitats on conservation aspect using soil seed bank studies. We germinated soil seed bank from different microhabitats in greenhouse and then measured seed bank richness and seed bank diversity. For biotic interactions we calculated RII. Soil moisture measured by TDR and soil temperature by thermometer and soil properties were measured in first soil 10 cm in different treatments. We also study the vegetation patches in hyperarid of Iran in Lut desert.

In mountainous steppes fire reduced the high competition in Onobrychis cushions and adversely shrub death increased the competition. Cushion position also play important role showing more competition in the center of cushions which competitive role of shrub reduced in the border of cushions. Cushions had lower daily tempreture flactuation and higher moisture and also soil C and N than open patches. *Juniperus excelsa* patches are more fertile and also had higher richness than open plots. The rocky substrate and also southern exposure showed more facilitation.

Our results showed that domestic animals grazing have significant effect on RII. The highest facilitation was observed in intermediate grazing and in other side, for high grazing and low grazing sites competition was considerable. Artemisia patches also showed lower moisture and higher daily temperature fluctuations. Artemisia patches in general showed competitive effect on understory species which may related to its alellopathic effects.

Moisture content in Artemisia with moss was more than Artemisia without moss in winter and in the spring was inverse. Lichens had lowest daily temperature fluctuations and highest soil moisture content than moss and cyanobacteria. Artemisia had highest soil seed bank richness and among BSCs, lichens had the highest soil seed density. Organic carbon content in moss was higher than lichen and cyanobacteria and the amount of nitrogen in lichen was higher than moss and cyanobacteria.

In hyperarids the conditions are more complicated with high temperature, wind erosion and drought. Lut desert is warmest point in the world which have extreme conditions. Rare species can survive in this harsh conditions again create patches. However, to tolerate this conditions create small hills using sands deposited by wind which called Nebkas which can create small microhabitats to keep moisture and modify temperatures as small islands. These experience could be applied for gypsum ecosystems in Iran to better understanding the mechanism of species adaptation in gypsum soil.

**Keywords**: Functional traits, Golestan National Park, grazing, fire, patch.

**Acknowledgement**: I would like to thanks Golestan National Park and Tarbiat Modares University and also Khadijeh Bahalkeh, Negar Ahmadian, Vria Hosseini, Zahra Farahani and Atefeh Ghorbanalizadeh for their help and contribution.

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# The gypsum flora and plant communities of Western Australia

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Gypsum substrates in Western Australia are associated with many of the vast array of naturally saline wetlands found in both the transitional rainfall zone of the SW botanical province and arid zone. Additional deposits are found in a limited number of coastal Holocene saline lagoons (barred basins) in lower rainfall areas. Inland gypsum deposits formed as a result of increasing aridity during the late Quaternary. Aeolian deposition of evaporites produced lunette (parabolic) dunes on the downwind side of salt lakes, with the composition of dune soils reflecting the prevailing hydrological conditions and broader climate at the time of their formation. These processes produced a complex mosaic of substrates, including near pure gypsum, gypsiferous clays, pelleted clays and sands.

Developing a definitive list of the gypsum flora of Western Australia is problematic given the paucity of species records with corresponding substrate gypsum content data. Herbarium collection data, with often subjective habitat descriptions, and the few systematic studies (1, 2), along with expert field knowledge have formed the basis of available checklists of the Western Australian (and Australian) gypsum flora (3, 4). Revision of these data found that the number of gypsophiles and gypsoclines in Western Australia has been overestimated, with many taxa better regarded as gypsovags, displaying broad distributions in saline and calcareous environments. Despite these limitations, approximately 35 taxa can be regarded as gypsophiles in Australia, with approx. 20 taxa occurring in Western Australia. An additional 55 Australian taxa are gypsoclines, with 40 occurring in Western Australia.

Within Western Australia many gypsum loving plants have restricted distributions and are listed as 'Conservation taxa' (e.g. Figs. 1, 2). Threats to gypsum plants and the plant communities they occur within include the potential cumulative impacts of small scale gypsum mining.

Fig. 1. *Frankenia* sp. Southern gypsum

Fig. 2. *Angianthus globuliformis*

**Acknowledgements**: Thanks to Anne Rick (Coates) for the use of her datasets and sharing her detailed knowledge of the gypsum flora of the SW of Western Australia. Julia Percy-Bower completed database searches for records of gypsum flora within the collections of the Western Australian herbarium. Bart Huntley undertook the GIS analysis of gypsum deposit occurrences and herbarium collection data.

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# Species coexistence in gypsum habitats of Spain

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Gypsum outcrops are widespread restrictive soils in arid zones throughout the world. In spite of the harsh environmental conditions, these habitats are home to a very large number of species, many of them endemic and threatened. However, very little is known about the mechanisms promoting species coexistence in such stressful environments. Exploring plant assemblages from a functional viewpoint allows us to identify the causal rules associated with community assembly. This functional perspective relies on the prevalence of niche specialization and functional differences among species. Plant trait-based ecology is providing new insights into old questions of community ecology. Species local assemblies are considered the result of the hierarchical contribution of three environmental filters: a) dispersion, b) abiotic, and c) biotic factors. Gypsum habitats are highly suitable systems to test the relative contribution of abiotic and biotic filters on the assembly of plant communities because both of them are particularly active here.

In this talk, we will present the most outstanding results dealing with the mechanisms promoting species coexistence in gypsum outcrops of central Spain. We demonstrated that gypsum soil was a crucial determinant of annual plant species assembly that is subsequently modulated by climate and lately by biotic interactions with perennial plants and Biological Soil Crusts (BSCs) at fine spatial scales (1, 2). Furthermore, we found that gypsum soils were not an “all or nothing” filter in the arrangement of realized annual plant communities; gypsum acted as a probabilistic abiotic filter (*sensu* Shipley 2010) since most species were able to establish in gypsum and the surrounding calcareous substrate. At finer spatial scales, *Stipa* tussocks expanded niche space in calcareous but not in gypsum soils, demonstrating the intense control of gypsum soils on plant communities. Subsequently, the BSCs restricted the range of soil affinity values of the co-occurring species, suggesting that this component of semiarid systems is decisively shaping species assemblies as well. We found that winter freezing events acted as a primary abiotic constraint on annual plant assemblies (3). In addition, *Stipa* tussocks facilitated the establishment of less freezing resistant species by ameliorating the winter freezing conditions compared with open/bare areas. We provided the first evidences of a direct filtering of BSCs on seed bank dynamics (4). These results highlight the role of BSCs as a spatial niche-partitioning component and their potential contribution to annual species coexistence and to the high diversity levels observed in these communities. In Peralta et al (minor rev in J Ecology) we demonstrated the importance of rain timing and amount in shaping annual plant communities, and we identified germination filters as the main processes determining community assembly. Our results suggest phenotypic integration of functional traits that allow resistance to drought along the life cycle. We identified two roles for BSCs: 1) a biotic filter that prevented germination and establishment of certain species 2) a buffer against water shortage in later stages. Even annual plant communities behave as highly tolerant to water shortage, we found that extreme droughts can filter the species assembly, especially combined with BSC perturbations, that consequently yield a simplified and a less diverse community.

The Intergovernmental Panel on Climate Change predicts that these habitats will be greatly affected because of intensified dryness and Global Change drivers such as habitat fragmentation (IPCC 2014; Escudero et al. 2015). We showed that soil seed banks in gypsum systems determined perennial plant communities, but, interestingly, seed bank features were not determined by the time elapsed since disturbance (5, 6). We found that the early persistent seed bank led to a recovery of gypsum habitats after a relatively short time. We demonstrated that the effects of habitat fragmentation on diversity of annual plant communities not only occurred at the landscape scale but also at fine spatial scales where plants coexist (7). Surprisingly, we found evidences that greater isolation among fragments did not necessarily decrease the species density per area; indeed, we found greater species densities in fragments that are more isolated. These results are particularly relevant since these habitats are extremely threatened.

To conclude, climatic fluctuations and biotic determinants emerge as sources of niche differentiation in time and space. This variability creates a temporal and spatial heterogeneity at fine scales that finally promotes species coexistence and the high diversity levels observed in gypsum semiarid systems of Spain.

Fig.1. *Campanula fastigiata* growing on Biological Soil Crust

Fig. 2. Typical gypsum landscapes of central Spain.

Fig. 3. Irrigation treatment

**Acknowledgements**: AGORA Project. Ref.– CGL2016–77417–P.

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# ORAL COMMUNICATIONS

# Gypsophyles use water from deeper soil layers than gypsovags during drought in a semiarid gypsum shrubland community: is deep rooting a key functional trait of gypsum specialists?

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We hypothesized that gypsum specialist species and gypsovag (non-specialist) species coexisting in semiarid gypsum ecosystems would differ significantly in key plant functional traits related to water and nutrient use strategies, including foliar stoichiometry, stomatal regulation and water source utilization patterns. To test this hypothesis, we evaluated the isotopic ($\delta^{13}C$, $\delta^{15}N$, $\delta^{18}O$) and elemental composition of leaves and the isotopic composition of stem water ($\delta^{2}H$, $\delta^{18}O$) in a target pool of 12 coexisting plant species (11 shrubs and 1 perennial tussock grass) growing on gypsum outcrops in semiarid southeastern Spain. Our target species included 4 gypsum specialists (*Ononis tridentata, Heliathemum squamatum, Teucrium libanitis, Herniaria fruticosa*) and 8 gypsovags (*Anthyllis cytisoides, Stipa tenacissima, Helianthemum syriacum, Dorycnium pentaphyllum, Rosmarinus officinalis, Thymus vulgaris, Thymus moroderi, Fumana ericoides*). We found consistent differences in the oxygen isotopic composition and the degree of evaporative isotopic enrichment (d-*excess*) of stem water between the two groups, indicating that gypsum specialists are capable of extracting and using water stored in deeper soil layers than their gypsovag neighbours during the summer dry season when the upper soil layer is dry. Gypsum specialists generally showed lower foliar $\delta^{18}O$ values (suggesting higher cumulative transpiration rates), higher leaf $\delta^{15}N$ (consistent with uptake of N from deeper soil layers), higher foliar concentrations of Ca, Mg, S, and Sr and lower foliar concentrations of K and Fe than their gypsovag neighbours. However, these differences between functional groups were less consistent than those found for water extraction depths. Overall, these data suggest that root ability to penetrate through hard, gypsum-rich subsoil layers and tolerate the high concentrations of S and Ca in these layers may represent a key functional trait of gypsum specialists that allows them to gain access to deeper, less fluctuating and more reliable moisture sources during prolonged drought periods.

**Keywords**: stable isotopes, leaf stoichiometry, functional traits, plant water sources, plant water use strategies.

# Analysis of the taxonomic and functional diversity of lichens in an environmental gradient in Spain

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Lichens are among the most important organisms in gypsum soils (Fig. 1), greatly contributing at diversity and biomass of this environment. In the Iberian Peninsula, drivers shaping lichen communities are quite well-known (1, 2). Nevertheless, main drivers that influence the functional traits in these communities are poorly investigated. The aim of this work is to analyze the changes on taxonomic and functional diversity of gypsum lichen communities along an environmental gradient in Spain. For this purpose, we plan to sample these communities along a broad environmental gradient in Spain. Until now, 17 plots (Fig. 2) were sampled. Within each plot we established ten 50x50 cm quadrats and we recorded the coverage of all lichen species present. We calculated species richness and Shannon Diversity Index and characterized every lichen species by a set of functional traits (e.g. growth form, thallus color) to calculate the community weighted mean (CWM). We also measured two quantitative functional traits, specific thallus mass (STM) and water holding capacity (WHC) for several lichen species. Climatic variables were retrieved at plot level from WorldClim database (3) and those that presented high correlation were discarded. To analyze the influence of the climatic variables on the communities and on their CWM, Linear Models were performed. A total of 70 lichen taxa were identified. We found that species diversity indices responded to changes in temperature and precipitation. Regarding community functional structure, species presented similar strategies for this type of environment, such as a flattened morphology (crustose and squamulose) and traits that help to deflect the high irradiance (pruina and thallus color). While temperature and precipitation variables influenced squamulose lichens, crustose species seemed to respond only to precipitation variables. Other traits as thallus color or presence of pruina were not related with climatic variables. We also compared the intra- and interspecific variation of WHC and STM for several species in the gradient.

Fig. 1. Lichens in gypsum soil

Fig. 2. Sampling sites

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# Three-year maintained drought reduces diversity in gypsum annual plant communities

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Variability in rain amount and timing are the main source of niche differentiation promoting species coexistence and high diversity values in Mediterranean annual plant communities. Consequently, predicted changes in rain patterns under climate change scenarios will very likely affect annual species assembly processes. Here we present the preliminary results (three years data) of a field experiment devoted to determine the effect of a 50% rain reduction on annual communities. Rain reduction followed the experimental design of International Drought Experiment (https://wp.natsci.colostate.edu/droughtnet/activities/international-drought-experiment/), whose goal is to determine how and why terrestrial ecosystems may differ in their sensitivity to extreme drought.

Rain shelters were stablished in summer 2015, covering seven 3x3 m plots in a gypsum area in the Tajus valley in Central Spain. Annual plants were annually recorded at the flowering peak in four 25x25 cm subplots bellow each rain shelters and in control plots. To identify processes affected by drought every species was characterized by measuring functional traits related to the leaf economics spectrum (specific leaf area [SLA] and leaf dry matter content [LDMC]), reproduction trade-offs (seed mass and reproductive ratio), resource uptake (root:shoot dry mass ratio) and resource distribution (plan size). Then the communities were described in terms of their taxonomic (species composition, Simpson diversity and evenness) and functional structure (community weight means, CWM, and RaoQ). Results showed an important effect of year but also a clear signal of drought in species composition and especially in the functional structure of the community. The subsequent reduction in terms of taxonomic and functional diversity evidenced a functional convergence of the community towards more stress-resistant designs and, therefore, great resistance to drought.

# Looking for gypsum floras: a novel method based on geographic information systems and plant collections

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Reliable information about the plant species growing on gypsum soils is the starting point for many questions on their ecology and evolution. Nevertheless, to know whether a species grows on gypsum or not is not an easy task: to date, we rely on the knowledge of experts to make this decision.

Looking for a more objective way to assemble the gypsum flora of the world we suggest a method using geographic information systems and plant collections (1). This method uses Landsat 7 (2) and Landsat 8 (3) imagery to detect gypsum (Fig. 1), combining it with information obtained from reliable databases of plant species.

We present a study case for the Cuatro Ciénegas municipality (CCM) in the state of Coahuila, Mexico. This region is characterized by a complex mosaic of soils with different gypsum contents. These gypsum outcrops host a species-rich gypsophilic flora that has mostly been described only in the last 50 years, lacking a checklist for the vascular plant species currently known to occur there.

We use databases both personal and for herbarium specimens to map georeferenced specimens on top of putative gypsum outcrops identified through the Landsat interfaces.

Our results demonstrate that the method is powerful, that CCM has an outstanding number of potential gypsum outcrops, many of which are botanically unexplored (Fig. 2). We found 298 species in 187 genera and 60 families of vascular plants growing on potential gypsum outcrops in CCM. The method we propose is a starting point that needs to be corroborated with other tools and extensive field work.

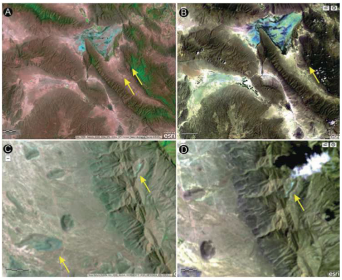

Fig. 1. General aspect of the same area using similar scales and different Landsat imagery. A and B) General view around the Cuatro Ciénegas Basin (CCB). C and D) Close up of a small potential gypsum outcrop highlighted in the corresponding area with a yellow arrow. Landsat 7 imagery, with channels 7, 4, and 3 (A and C) vs. Landsat 8 imagery (layer 6.1), with channels 7, 6, and 4 (B and D)

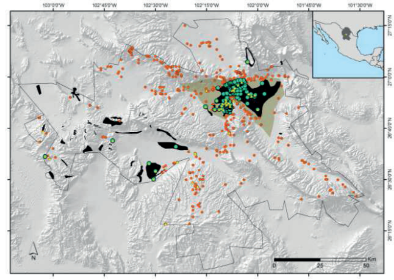

Fig. 2. Collecting efforts in the Cuatro Ciénegas municipality (CCM). In the map of Mexico at top right, the state of Coahuila is highlighted in dark gray and CCM is indicated in yellow. Orange dots correspond to general herbarium collections without indication of gypsum; green dots correspond to collections that intersected with a polygon; yellow triangles indicate collections that have an explicit reference to gypsum on the label. Cuatro Ciénegas basin (CCB) is indicated in olive-green and the potential gypsum outcrops are indicated in black

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# Where to look for gypsophily phenomena? Towards a global mapping of the world gypsum outcrops

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Biodiversity has a spatial basis, this is the reason why a geographical basis at a detailed scale is absolutely essential for this study. In the case of the study of gypsophily (i.e., the link between plants and gypsum soils) at a global scale, a cartography of gypsum outcrops worldwide is essential. In order to compile information on gypsum outcrops, the most important sources are geological and edaphological cartographies, although these have limitations. In the case of Spanish gypsum, areas the geological cartography did not collected one third of the outcrops detected through the gypsophilous flora and vegetation. In fact, the use of indicator plants and botanical prospecting is a classic methodology when locating mineral deposits since Cannon used this methodology for Uranium in the Colorado Plateau in 1957.The opposite can also be useful, so that a third source of information to locate and delimit gypsum deposits are the data on mining, natural resources and "economic geology". In many countries, this is the main and even the unique source of information. All these information sources can be contrasted with satellite images, for the delimitation of gypsum outcrops (Fig. 1). Based on these information sources, a map of gypsum outcrops of the world was elaborated. The cartography generated in this way will be useful for the management and conservation of the gypsum flora, for the study of the spatial patterns of the gypsophytes and the study of gypsophily in general, as well as for identifying areas not sufficiently prospected from both the botanical and biological point of view.

Preliminary results show that the extent of gypsum outcrops covers much more and includes many more countries than previous cartographies had collected. In spite of this, the preliminary character of the offered cartography is undeniable and, as with the gypsophilous global species checklist, only the involvement of a greater number of local and regional experts will make it possible to have a more or less accurate gypsum mapping areas.

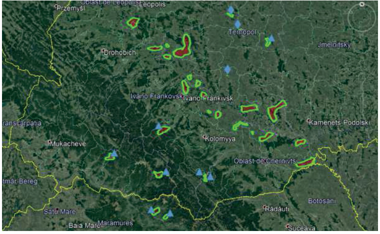

Fig. 1. SW Ukraine and N Romania gypsum outcrops and the occurrence of gypsophites *Gypsophila fastigiata* (diamonds) and *Sedum antiquum* (triangles)

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# Gypsum outcrops in Utah: an important habitat for plant conservation

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Great progress has been made in understanding the ecology, assembly and evolution of gypsophile floras worldwide. In North America important gypsum deposits appear in the southwest. These habitats are facing the same conservation problems reported worldwide. Utah State is known to have important gypsum deposits, hosting them several endemic and/or rare species. The information available about the gypsophytes is scattered across the literature, and in many ways scarce and imprecise. In this work we aim: i) to compile the information about plant species living on gypsum in Utah and ii) to explore the spatial distribution and conservation status of the flora. Both to call attention to this overlooked habitat.In order to compile the occurrences of gypsophiles and gipsovagues in Utah, we have used the Intermountain Region Herbaria Network and GBIF for gypsophiles, as well as the existing floras for the area (e.g. 1, 2).For the spatial analysis of the distribution of this flora, the concepts of richness and rarity were used, as well as the MARXAN program for the selection of reserves. In this case the OGUs (Operational Geographical Units) were grids of 10 km. In total, gypsum flora was recorded in 207 OGUs. After the bibliographic review we have compiled 88 taxa living exclusively or preferentially on gypsum, 30gypsophiles. Many species demand conservation efforts urgently (22 taxa), however 12 of them remain unlisted in red list of endangered species. The main threat factors are: off-road vehicles (16 taxa), quarrying (11 taxa), grazing and/or trampling (9 taxa) and infrastructure construction (6 taxa). The spatial analysis revealed as the richest areas those located to the SW of the state, especially the area of St. George (fig. 1). The grids with greater richness was 7 gypsophytes. The rarity partially repeated that pattern. St. George (figure 2) also reflected the highest values. The analysis with MARXAN selected 14 OGUs for the best solution, while 3 grids were always selected after 10000 iterations (Summed Solution). In both cases, the previously mentioned territories were among those solutions. This work revealed that gypsophytes are partially protected in Utah.

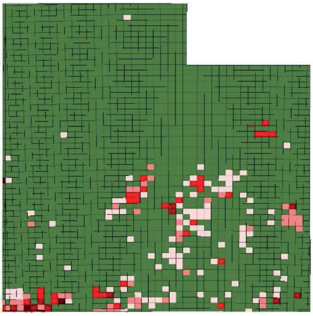

Fig. 1. Rarity in the Utah OGUs considered

Fig. 2. White Dome Nature Preserve (Utah)

**Acknowledgements:** This work was supported by GYPWORLD project.

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## Which habitat for Sicilian gypsophytes?

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Many authors highlighted the relationship between gypsum bedrock and vegetation, as many plant species grow exclusively or preferentially on such peculiar substrates (1, 2).

In a previous study, we analysed the gypsum flora of Italy and elaborate a checklist of Italian gypsophilous flora, through a structured group communication process of Italian botanical experts who have joined to select focal plant species connected to gypsum substrates (3).

In this study, we evaluate the role of gypsophytes in the gypsum vegetation. The study concerns Sicily where most of the gypsum outcrops of Italy are present. The vegetation surveys were carried out with the phytosociological approach.

As in other territories the Sicilian gypsum outcrops constitute ecological "islands" (3), characterized by peculiar edaphic and microclimatic conditions, immersed in an environmental matrix of the "gessoso-solfifera" substrates such as marls, clays and various types of limestone.

Three categories of plants in relation to the preference for the substrate are individuated: gypsophite (narrow and wide), gypsovag and accidental, according to the previous study (4). The contribution of each group to plant communities biodiversity was evaluated with the Shannon index.

The study showed that the plant communities structured by gypsophyte are: ephemeral therophytic vegetation with *Chaenorhinum rupestre*, *Sedum* rock communities whit *Sedum gypsicola* subsp. *trinacriae* and *Petrosedum ochroleucum* subsp. *mediterraneum*, chasmophytic cliffs vegetation with *Brassica villosa* subsp. *tineoi* and the bryophyte community with *Tortula revolvens,* typical of gypsum substrates from various European territories (5).

Gypsophytes play an important role in structuring communities grows directly on gypsum or on thin layers of lithosol, poor-nutrient in low productive environments. In plant communities growing on soils developed from gypsum, the role of gypsophytes is less relevant.

This is probably due to Mediterranean sub-humid bioclimate of Sicilian gypsum outcrops that cause a prevalent flow-down movement of water in the soil profile and give rise to relatively fertile soils, which properties are controlled by the vegetation type rather than by soil gypsum conditions (1).

The strict gypsum plant communities allow us to recognize and characterizing the gypsum habitat in Sicily as it was predicted in the European red list of habitats (6).

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# Do gypsophilic lichens exist? Towards a worldwide checklist of lichens living in gypsum soils

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Lichens are one of the dominant life-forms in arid ecosystems, including gypsum soils. They participate in several processes and the functioning of these ecosystems. However, despite of their importance and singularity, lichens from gypsum soils are not well studied. In addition, the affinity for the gypsum substrate is not well studied. Based on these premises we ask the following questions: do gypsophilic lichens exist? In that case, which are these species? Are they different species between different gypsum areas?

In order to solve these questions, we have compiled a worldwide checklist of lichens growing on gypsum areas and soils. For that purpose, we have searched in several bibliographic data bases using different key words. As a result, we have checked a total of 283 articles in which we have found information about 26 countries. The checklist includes 5392 specimens, belonging to 381 species from gypsum soils (98 epiphytic species were excluded). Spain and Germany, with 179 and 106 species, are the countries with more species. Other countries with a relatively high number of species are Italy, Poland, United States (74, 59, 46 species respectively). It is important to note the low or absent number of species found in southern hemisphere countries (i.e. Argentina, Australia, Chile, and South Africa). We also compare and discuss the geographical affinities of the studied species.

We have further analysed the species specificity for the gypsum substrate. To do this we have employed and compared two methods. Based on them we propose different categories for the specificity for gypsum content in lichens.

# Tracking gypsophily across the phylogeny: 3 study cases

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To gain an evolutionary understanding of plant gypsophily, is essential to incorporate phylogeny in the analyses. Here we present an overview of three different approaches that we are currently undertaking to tackle this issue. (I) we have selected 5 Iberian genera with gysophite or gypsovag species in which a fairly complete and reliable phylogeny is published (*Ononis*, *Helianthemum*, *Chaenorrhinum*, *Reseda* and *Teucrium*). In each of these 5 lineages we plan to explore the events of gypsophily and to evaluate the existence of preadaptations along the clades in terms of ionome. (II) Within the *Ononis tridentata-fruticosa-rotundifolia* clade, we intend to carry out Hyb-Seq taking the leaf and soil chemical composition into account. Among other biogegraphic and phylogenetic inferences, we are particularly interested on the comparison of the ionome of *O. fruticosa* populations growing in and out gypsum. (III)We plan to reconstruct the phylogeny of the genus *Frankenia* based on HybSeq, which comprises a relevant amount of halophyte, gypso-halophyte and gypsum species, particularly in Australia. This worldwide distributed genus is crucial for the understanding of chemical adaptations of gypso-halophytes, a poorly described functional group, but requires a taxonomic and phylogenetic clarification before further analysis. Approaches II and III will use the Angiosperms-353 kit (myBaits), which will allow integrating the results in further studies beyond our current particular purposes.

# Gypsophyte shrubs enhance the survival and growth of perennial grasses in gypsum plant communities of the Middle Ebro Valley

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Facilitation is a key process for maintaining plant diversity in semi-arid gypsum plant communities, where plant establishment is critical due to the harsh climatic and substrate conditions (1). In these harsh environments, gypsophytes (well-adapted to gypsum) can have a positive role in plant communities by providing favorable microhabitats for less adapted species and thus promoting plant establishment under their canopies (2). In a previous observational study based on plant spatial associations, the gypsophyte shrubs *Gypsophila struthium* and *Ononis tridentata* were found to accumulate species-rich vegetation patches in gypsum plant communities of the Middle Ebro Valley, suggesting a facilitative role of these shrubs on plant establishment (3). Since together with biotic interactions, other abiotic and biotic factors can influence the spatial pattern of the community (4), field experiments are needed to corroborate the underlying mechanisms that generate the observed spatial patterns. We aimed to assess experimentally the potential positive effect of *G. struthium* and *O. tridentata* on the establishment and development of two dominant perennial grasses in gypsum plant communities of the Middle Ebro Valley (*Stipa lagascae* and *Lygeum spartum*). For comparison purposes, we also assessed the potential facilitative effect of other dominant shrubs in the community (*Helianthemum squamatum* and *Thymus vulgaris*). Specifically, we sowed one seed and we planted one juvenile individual per grass species under the canopy of 50 adult individuals of each shrub, and in 50 points in open areas (Fig. 1). We assessed seed germination and seedling survival, growth and vigour (Fig. 2). After 3 years, we found that both perennial grasses survived more and better (*i.e.*, taller and more vigorously) under the canopy of *G. struthium* and *O. tridentata* than under the canopy of *H. squamatum* and *T. vulgaris* and in open areas. However, no significant effects were found for seed germination. The experiment corroborated that these gypsophyte shrubs have a positive role on the establishment of other species under their canopies, thus resulting in species-rich patches under canopy.

Fig. 1. Plantation of a juvenile of *S. lagascae* under the canopy of *T. vulgaris*

Fig. 2. Measurements of the height of the planted grasses

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# Neighbourhood matters! Plant survival and fitness is favoured in experimentally manipulated communities with high phylogenetic diversity

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Annual plant communities in Mediterranean gypsum-soil systems are recognised to have high species richness. However, the mechanisms promoting species coexistence in such stressful environments are not well-known. In recent decades, analyses of the phylogenetic patterns of communities has emerged as an interesting approach to understand processes underling species assemblage. However, there is a great controversy in the literature about the ecological soundness of this approach. Some studies support that high values of phylogenetic diversity may promote plant productivity and ecosystem stability, probably because phylogenetically distant species are less prone to compete for the same resources and are more likely to benefit from facilitative interactions, thus promoting niche complementarity. However, all previous studies are based on observational approaches that avoid concluding cause-effect relationships. In this study, we aimed to experimentally test this idea by creating annual plant assemblages with contrasting phylogenetic diversities and evaluating plant-level responses to environmental stress in a common garden experiment. Does phylogenetic structure of the plant community determine individual response to drought, the main environmental filter in our system? Four taxonomic combinations of annual species were established. Thus, we created two high phylogenetic diversity scenarios (Phylogenetic Species Variability, PSV= 0.8) and two with low phylogenetic diversity (PSV= 0.3). Each species combination was subjected to two water availability treatments, control (simulating natural rainfall) and drought (33 % of natural rainfall). Each experimental scenario was replicated 10 to 16 times (n= 110). We registered survival of each plant (n= 7700) every 2 weeks, and flower phenology every week. After fruit ripening, we collected every plant and every fruit (n= 24720). Results show that plants that coexist in high phylogenetically diverse communities were more prone to survive and have higher fitness than those coexisting with phylogenetically closer species. For the first time, we have demonstrated that phylogenetic patterns are indeed excellent proxies not only to understand species assembly but also to delve into community functioning.

**Keywords**: phylogenetic diversity, annual plants, coexistence, community assembly.

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Figure 1. Photograph of the experiment and example of a community

# Evaluating the presence of fungi associated with plant roots of gypsum environments

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Arbuscular mycorrhizal fungi (AMF) are critical components of terrestrial ecosystems. This symbiosis benefits plant growth in extreme soils (i.e. metal-contaminated, serpentine, saline), but little is known about the ubiquity and function of AMF in plants that grow in gypsum soils, both specialist (gypsophiles) and tolerants (gypsovags). We can determinate AMF colonization by presence of mycorrhizal arbuscules in roots. Previous studies indicate that gypsovags have more colonization of AMF than gypsophiles. However, the seasonality in the root colonization by fungi has not been studied in these systems, even though important differences in fungal root colonization have been reported for other semiarid environments. We quantified the presence of mycorrhizal arbuscules (AC), vesicles (VC), and fungal hyphae (FC) in the roots of three species of gypsophiles (*Helianthemum squamatum*, *Lepidium subulatum* and *Gypsophila struthium*), and two species of gypsovags (*Matthiola fruticulosa* and *Helianthemum syriacum*) growing in a gypsum outcrop in autumn and spring. Also we determinated soil variables such contents of gypsum, soluble nitrate, soluble ammonium, total nitrogen, assimilable phosphorus and organic matter. The fungal colonization was not significant between gypsovags and gypsophiles. However, all plants showed more fungal colonization in spring than autumn, when nitrates are lower. Our results indicate that the fungal root colonization of plants living on gypsum soils shows seasonal changes, been greater in spring.

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# Diversity of the genus *Heliotropium* s.l. in SW Asia growing in xerophytic, psammophytic and gypsophytic communities

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The genus *Heliotropium* belongs to family Boraginaceae (Boraginales). It is widespread in arid and semi-arid belts of the Old and New World. Based on recent molecular phylogenies a separate lineage of the genus representing $C_4$ species is segregated as *Euploca*. *Heliotropium* s.l. species are important elements of xerophytic, pasmmophytic and gypsophytic communities of SW Asia. From 66 known species in SW Asia 36 species occurring in Iran as the richest country with 17 endemic species. 54% of the species are annuals distributed in mountain and low-mountain areas, whereas the perennial species with 40% occur in deserts and very dry habitats plus a few species showing multiform as annual, biennial and perennial. The $C_4$ lineage belonging to *Euploca* consists of only 2-3 species occurring in area with Saharo-Sindian and Somalia-Masaei phytochoria. The majoring of endemic species are Irano-Turanian and most of them are annuals often with limited distribution. The undulating hills with gypsum and marl soil seems to be important drivers for the diversification of the genus in foothills of Alborz and Zagros Mountains. From 12 species growing in gypsum habitats in Iran, 4 species (*H. denticulatum, H. esfandiarii, H. khayamii* and *H.* spec. nov.) are restricted in gypsum and marl habitats. In this work, the preliminary molecular phylogenetic studies of SW Asian species using three nuclear and plastid markers will be presented and phytogeographical importance of distribution patterns of the genus will be discussed.

# Geomorphological setting of the Rocca di Entella and Santa Ninfa gypsum areas

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Sicily hosts the most complete and extended Messinian evaporites successions of the Mediterranean Basin. These rocks occur extensively in central and southern Sicily, narrow but significant outcrops are present also in the western, northern, north-eastern and south-eastern part of the island. The Sicilian evaporites belong to the Gessoso-Solfifero Group; they are composed of a succession of evaporitic limestone, gypsum, and salt (mainly halite and K- and Mg-salts) with intercalations of clays, marls and carbonates. Generally, evaporites lie above Upper Messinian diatomites (Tripoli Fm.) or above Upper Tortonian-Lower Messinian silico-clastic deposits and are overlain by Pliocene marly-limestone (Trubi Fm.). The evaporite successions were involved in the Plio-Pleistocene tectonic phases that generated south-trending fold-and-thrust belts. Due to their high solubility, the Sicilian evaporites (mainly gypsum) are affected by karst processes responsible for the origin of a large variety of surface landforms and subterranean caves (1, 2).

The Rocca di Entella and Santa Ninfa areas are two small gypsum karst areas located in western Sicily, within the Belice Valley. Both were designated as nature reserves by the Sicilian Regional Government in order to preserve their peculiar surface landforms and caves(3).

The Rocca di Entella is an isolated hill (556 m a.s.l.) consisting mainly of banded primary selenite gypsum, separated by thin carbonate layer, which lies on Lower Messinian-Upper Tortonian clayey-marly rocks. This is bordered by scarps up to 120 m high, and steep slopes affected by gravitative processes. The geomorphological setting is influenced by the lithological and structural features and by Quaternary tectonic uplifting. High-angle faults brought into lateral contacts rocks with different erodibility (gypsum and the underlying clayey-marly rocks) favouring differential erosion and producing inverted relief (4). Karst is quite widespread and displays many surficial and subterranean landforms. The first are mainly small-scale forms (karren) and solution dolines which occur on the summit area of the hill. As regards the underground landforms, the most developed cave is the Grotta di Entella, which is the reason for the establishment of a nature reserve by the Sicilian Regional Government.

The Santa Ninfa area, located some kilometres west from the Rocca di Entella, is characterized by a gypsum plateau gently sloping southward and bordered to the north by an elongated NE-SW scarp. This plateau is articulated in different aligned gypsum relief with an altitude ranging from 663 m to about 500 m a.s.l. Messinian gypsum rocks lie on Upper Tortonian-Lower Messinian silico-clastic deposits and are overlain by Pliocene marly-limestone of the Trubi Formation. The gypsum shows different facies as: selenite gypsum, resedimented gypsum (gypsum-rudite, gypsarenite, gypsum-siltite) and microcrystalline gypsum (alabastrine).

The geomorphological setting is mainly influenced by karst processes whichfavoured the development of about 40 subterranean caves and a large variety of surface landforms, such as: small sculptures in rock (karren), solution dolines and karst valleys. In the northern part of the plateau the dolines occupy the whole area, forming a mesh polygonal system, typical of tropical regions (5). The karst valleys are generally blind valleys that may be entirely cut in gypsum, or they may be cut in clayey-marly rocks and end blindly at a gypsum threshold. The most significant is the Bivierevalley which feed the Grotta di Santa Ninfa cave. This latter represents the most important cave of the karst area, both for its size and for its morphological and speleogenetic features.

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# Ecological and floristic outline of the plant communities growing on the gypsum outcrops of the Sicilian Gessoso-Solfifera Formation

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Notwithstanding the remarkable surface of Sicily characterized by outcropping gypsum, the dedicated literature on this substrate is still poor (1-3). A first synthesis on the vegetation units occurring on such substrates at a regional scale was recently published (4 and references therein). Several contributions to the flora and the vegetation of the two sites that we will be visiting, i.e. the nature reserves of 'Grotta di Santa Ninfa' and 'Rocca di Entella' (W Sicily) are available (5-8). Most of gypsum outcrops coincide with the inner part of the island, subject to strong human pressure since millennia and nowadays almost devoid of tree cover and prone to frequent burning and overgrazing. Hence, it is hard to reconstruct the past vegetation patterns and to identify the current dynamic series. Currently the most mature plant communities are represented by small sized forest areas dominated by *Quercus virgiliana* and/or *Quercus ilex*, which may be framed into *Quercetea*, *Quercetalia* and *Quercion ilicis*. More frequent are the sclerophyllous scrub communities referred to *Quercetalia calliprini*, with *Pistacia lentiscus*, *Asparagus albus*, *Euphorbia dendroides*, *Anagyris foetida*, *Chamaerops humilis*, *Prasium majus*, *Teucrium fruticans* and *Artemisia arborescens* playing a major role. Much more common are the garrigues dominated by subshrubs belonging to Lamiaceae, like *Thymbra capitata*, *Rosmarinus officinalis* and *Micromeria fruticulosa* or the mosaic-like perennial grasslands, mostly dominated by *Hyparrhenia hirta* or *Ampelodesmos mauritanicus*. Since 2016 an international research project led by the universities of Reggio Calabria (Italy) and Almería (Spain) is aimed at identifying the Italian vascular plant species and assemblages linked to gypsum substrates. As for Sicily, the preliminary results (9) pointed out that only four species occurring on the island, i.e. *Chaenorhinum rupestre*, *Festuca gypsophila*, *Sedum gypsicola* subsp. *trinacriae* and *Petrosedum ochroleucum* subsp. *mediterraneum,* are strictly linked to gypsum outcrops, while four more (e.g. *Brassica villosa* subsp. *tineoi*, *Diplotaxis harra* subsp. *crassifolia*, *Erysimum metlesicsii*, *Gypsophila arrostii* subsp. *arrostii*) clearly prefer it. Many other plants frequently found on gypsum (e.g. *Astragalus caprinus* subsp. *huetii*, *Athamanta sicula*, *Cachrys sicula*, *Matthiola fruticulosa*, *Sedum* spp., *Silene fruticosa*, *Teucrium aureum, Thapsia meoides*, etc.) are able to colonize also the other rock outcrops of the Gessoso-Solfifera Formation, such as limestones and marls. Many of these plants belong to genera which occur not only on gypsum, but also on other 'hostile' substrates such as serpetinites or dolomias (e.g. *Erysimum*, *Fumana*, *Helianthemum*, *Matthiola* and *Micromeria*), and probably have developed edaphic stress-tolerance to avoid competition on 'easier' substrates.

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# POSTERS

# Leaf morphological traits comparisons between Gypsophile and Gypsovag species from Iran

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Some plants have ability to survive in substrates with limiting conditions. Gypsum soils have special physical and chemical properties that hamper the survival of plants in these ecosystems. At the same time, gypsum soil are home to many rare, narrow endemic and endangered plant species. Depending on their adaptation to gypsum soils, plants can be classified as gypsophiles and gypsovags. Several adaptive mechanisms have been suggested for gypsum plant specialist, mainly related to plant biochemistry. However, little information is available on standard leaf morphological traits, especially in gypsum plants from Iran.
We measured leaf thickness, leaf length, leaf fresh mass, leaf dry mass, specific leaf area and leaf dry matter content in 10 gypsovag and 11 gypsophiles species growing in four different sites in Semnan, Iran, in May 2018.
Our results showed that the leaf thickness, leaf length, leaf fresh mass, leaf dry mass and leaf dry matter content were higher in gypsovags but the specific leaf area (SLA) was higher in gypsophiles. The lower SLA of gypsovags may be related to higher growth rate and leaf turnover of gypsophiles, while the higher leaf thickness of gypsovags may indicate they use thicker leaves to compensate the absence of leaf chemical adaptations. More study cases are needed to have more solid conclusions on the functional adjustments of gypsum species.

**Keywords**: Functional traits, Gypsum ecosystem, Leaf dry matter content, Specific leaf area.

# Study of water uptake mechanisms in plants living in gypsum

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Gypsum has water in its crystalline structure ($CASO_4 \cdot 2H_2O$) and depending on the temperature, pressure or presence of solutes this water can be naturally lost. Crystallization water represents 20.8% of the total weight of gypsum and previous studies show that it constitutes a source of water for organisms living in this substrate, especially under drought conditions. However, the mechanisms displayed by plants to gain access to crystalline water remain unexplored. Similarly, the ecological implications that this new source of water can have for the structure of the communities and their ecophysiology is unknown.
Here we present a set of experiments being currently undertaken to shed light on these issues.

- The gypsophite *Helianthemum squamatum* (Fig 1) is being cultivated in pots with natural gypsum soil and soil where the crystalline water has been labeled with deuterium. Half of the pots of each soil type have been sterilized with γ-radiation and subsequently watered with a filtrate incorporating a natural soil bacteria inoculum, so as to produce fungus-free soil. We plan to over-impose a drought treatment to half of these plants and measure the differences in water uptake and in gypsum crystalline water use. This will inform on the role of fungi for crystalline water uptake.
- *H. squamatum* and its sister gypsovag species *Helianthemum* syriacum (Fig 2) are being cultivated in rhizotrons with fungus-free soil and natural soil (following γ-sterilization and addition of a bacteria filtrate) where changes in the pH of the rhizosphere will be monitored (Fig 3). This will indicate the ability of these plants to modify gypsum soil pH.
- We have designed mini-rhizotrons (Fig 4) compatible with crystallographic measurements and are cultivating *H. squamatum* in them. Plants will be subjected to drought and different analyses (Raman spectrometry, gas-exchange, XR-D, tomography) will be carried out at the plant and root-soil interface to detect changes in the thermodynamic phases of gypsum and gypsum dissolution processes mediated by root activity.
- Finally, to detect differences in the use of crystalline water among plants growing in the same community, we carried out a field survey of the xylem sap of 20 dominant species of the gypsum community in Alfajarín, Zaragoza both in spring and summer, and characterized the isotopic composition water table and soil water along three 1 m depth soil profiles.

Fig. 1. *H. squamatum*

Fig 2. *H. syriacum*

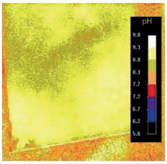

Fig. 3. Monitoring image

Fig. 4. Minirhizotron

# Biogeochemical analysis of *Dittrichia viscosa* (L.) Greuter in different habitats of the SE of Spain and its potential use as a bioindicator species

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*Dittrichia viscosa* is a perennial herb, diffused in the Mediterranean region, which has spread to other continents (America and Australia) as an invasive species. Although its primary habitats are gravel riverbeds, sands and coasts, it is common in secondary habitats as roadsides and oldfields. Currently, it is considered an expanding species due to both its remarkable pioneer character and the anthropic disturbance increases. Its capability to colonize new environments has been well documented, what has been justified by its high phenotypic plasticity, stress tolerance and resistance to chemical contamination. It is particularly profuse in the South and East of Spain, in coastal and pre-coastal areas, but also penetrates inland. Growing on all types of substrates, from serpentines to saline soils, it can be abundant on gypsum as one of the few plant species able to colonize bare soils in abandoned quarries. Due to its distribution and abundance, *D. viscosa* has potential biotechnological applications, such as its promising use for phytoremediation in mining affected semiarid soils, since it is an efficient bioaccumulator of trace metals (1, 2). This ability, together with its ubiquitous character, makes it to be considered as an indicator species, which could be also used as a sentinel species to detect contamination in large areas of the Mediterranean Basin and other parts of the world.

Taking these characteristics into account, from the stoichiometric perspective (mineral composition), species samples from four populations in the urban area of Almeria city and two other populations from special soils (gypsum and saline soils) were studied. In total, 31 chemical elements were analysed, in addition to C and N, in roots, stems and leaves.

The outcomes showed important variations in the mineral composition of this plant, especially on gypsum and saline soils. This species presented relatively high Na contents on every sampled environment, although it cannot be considered a halophile species. Something similar happened with K. Nevertheless, it can be considered a bioindicator species for pollution caused by B and Mo.

**Keywords**: Phytoremediation, sentinel plant, indicator, gypsum quarry, gypsophily, serpentine.

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# Important Plant Areas (IPAs) for the conservation of the Iberian gypsophilous flora: a metaheuristic approach

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Gypsum outcrops are very rich and rare from the floristic point of view, which is why they are listed as Priority Habitats by the EU. Although this habitat is widely distributed throughout the Iberian Peninsula, the threatening factors that conflict with its conservation must not be ignored, such as mining, agriculture, inappropriate reforestation and urban development and infrastructure. To try to reduce these threats it is necessary to have accurate information about the distribution of this habitat and its species.

For this we have developed a database with the distribution of 74 gypsophytes (species restricted to gypsum outcrops) according to the latest checklist of Iberian gypsophytes updated (1, 2). For each gypsophyte, chorological information has been collected in UTM 10x10 grids so that the database has 33,292 records distributed by all the Iberian gypsum outcrops. With respect to previous approaches, 61 grids and 9309 new records of species have been added.

To prepare the selection of reserves, the MARXAN program was used and a series of UTM were selected throughout Spain, making sure that all the taxa were at least in a grid. For example the *Hedysarum boveanum* subsp. *palentinum* in Duero, *Ononis tridentata* subsp. *crassifolia* in La Malahá or *Teucrium lepicephalum* in Alicante. In the same way, grids with a high number of taxa are selected in the center of Spain (Madrid, Guadalajara), in the Iberian southeast with Almeriensian endemisms such as *Teucrium turredanum* and *Helianthemum alypoides* and grids in the Ebro that collect taxa such as *Euphorbia minuta* subsp. *moleroi* or *Senecio auricula* subsp. *sicoricus*. In the Best Solution (Fig. 1), 4 grids were selected in the Betica province and 3 in Murcian-Almeriensian and the other 9 in the Ibero-Levantine Mediterranean territories.

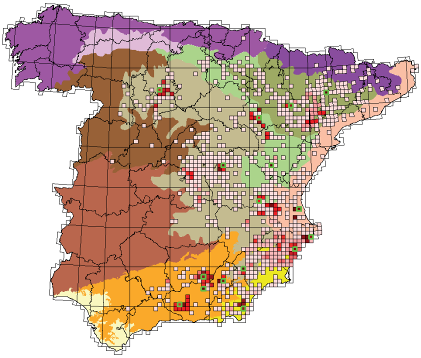

Fig. 1. Best Solution

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# Disentangling the contribution of deterministic vs. stochastic processes to plant community assemblage: an experimental field manipulative proposal in gypsum steppes

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Assembly of plant communities is explained as a conceptual gradient defined by two opposing postulates: the deterministic approach (1), which interprets the community as a constrained combination of species strongly defined by environmental filters, and the stochastic view (2), which interprets the community as an open, randomly coinciding combination of species, subordinated to ecological-drift processes. Although both approaches have received much attention, assemblage theory has grown mainly on the basis of observational studies due to the difficulty of manipulating entire communities.

In this study we show the design of a novel field experiment in a semi-arid gypsum system, aimed to evaluate the relative contribution of both stochastic processes (i.e., arrival of propagules) and abiotic (water availability) and biotic (presence of perennials and biological soil crust) environmental filtering to the assemblage of annual species. The experiment consists of (i) two scenarios of presence of propagules (seedless soil from gypsum quarry vs. homogenized natural soil with complete seed bank); (ii) five scenarios of biotic filters (presence of complete *Macrochloa tenacissima* plants or only with the above- or the underground part, presence of biological soil crust, and bare soil); (iii) two scenarios of water availability (natural precipitation vs. experimentally duplicated). The result is a complete factorial design with 20 experimental treatments 10-fold replicated (i.e., 200 50cm x 50cm plots). The experiment will be run for the next three years, during which species assembly rules should manifest. We hypothesize that changes in the intensity of the environmental filters may promote or inhibit the expression of stochastic processes in the assembly of species.

Figure 1. Photograph of the experimental plots

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2) H. A. Gleason (1926) Bull. Torrey. Bot. Club, 53, 7-26

# Microbiomes associated to the ground surface under the canopy of *Gypsophila struthium* Loefl. in natural and perturbed edaphic environments

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The singularity of the Iberian gypsum outcrops is recognized attending to the flora that characterizes it, which is widely known. However, little is known about the communities of microorganisms present in these special soils. These communities have become a focus of interest both in unaltered ecosystems and those subjected to ecological restoration, which have been characterized to evaluate their ecological functionality and to estimate the success of the restoration process. Therefore, in this study we have proposed to characterize the microbial communities (fungi and bacteria) present on the surface of different types of gypsum environments in *Karst de yesos de Sorbas*, Spain.

Two abandoned quarries (Q1 and Q3), one restored (R), two undisturbed environments rich in gypsum (K, selenitic, and S, farinaceous gypsum), and a third that also presented clays (O, where the dominant gypsophyte was *Ononis tridentata* L.) were selected. In each of these environments, samples were taken both in bare soil (BS) and under the canopy of the species *Gypsophila struthium* (GS). A metabarcoding approach was used to profile bacterial and fungal compositions, using primer pairs for 16S rDNA and ITS2 region respectively.

Diversity indices in both microbial communities were higher in GS than in BS, so canopy favors an increase of such diversity. Although values in R obtained were slightly lower than the rest, it is evident a favorable recovery. In bacterial community significant differences were found in phyla Actinobacteria and Chloroflexi between O and R, and in phyla Bacteroidetes, Proteobacteria (higher in GS), and Cyanobacteria (higher in BS) between BS or GS. The higher presence of Cyanobacteria on BS (particularly in R) denotes a fundamental role of this phylum in the enrichment of the soils of the perturbed environments (Q1, Q3 and R). Other outstanding phyla was Actinobacteria, which shows a strong presence in arid environments, and of relevance in the O environment, which suggests an important role in favoring the regeneration of canopy cover. Another interesting phylum was Bacteroidetes, more frequent in GS, given its copiotrophic nature and sensitivity to altered soils, being able to be an indicator of the evolution of the restoration. In fungal community, the main phyla were Ascomycota and Basidiomycota. Significant differences were observed only between BS and GS in classes Dithiodeomycetes and Agaricomycetes, being higher in GS, given that the majority of representatives of these groups are endophytes or saprophytes, or conform mycorrhizal associations.

The results presented here could improve the understanding of the soil biological process in gypsum soils and its recovery.

**Keywords:** bacterial and fungal communities, *G. struthium*, gypsum outcrops, metagenome, quarry restoration, unaltered environment.

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# FIELD TRIP GUIDE

# Basic information and brief description of the field trip held on “Grotta di Santa Ninfa” Nature Reserve and “Grotta di Entella” Nature Reserve during the II GYPWORLD Workshop 2019

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## The “Grotta di Santa Ninfa”

The “Grotta di Santa Ninfa” Nature Reserve has been instituted in 1995 by the Regional Department of Territory and Environment, and it is managed by Legambiente Sicilia, an Italian environmental association. The protected area is made up of two zones with a different bonding regime: 1) the Reserve Area “A”, consisting of the entire development of the Cave; 2) the Pre-reservation Zone “B” comprising the “blind” Biviere Valley, for a total area of 140 hectares.

Since 2000, the entire territory of the nature reserve has become part of the Sites of Community Importance of the European Community, pursuant to Directives 92/43 EEC. The site ITA010022 “Complesso dei monti di Santa Ninfa – Gibellina e Grotta di Santa Ninfa” http://natura2000.eea.europa.eu/Natura2000/SDF.aspx?site=ITA010022 extends for about 870 hectares on gypsum hills in the municipalities of Santa Ninfa and Gibellina, in the province of Trapani. It is a karstic plateau of considerable naturalistic-environmental and geological-geomorphological importance. The configuration of the natural landscape is defined by the articulated morphology of the Gibellina and Santa Ninfa Mountains (Fig. 1,3).

In 2008 Legambiente Sicilia provided for the drafting of the Management Plan of SIC, that since 2015 has been designated as a Special Conservation Zone (SAC) of the Mediterranean biogeographical region.

Moreover, since 2015 the "Grotta di Santa Ninfa" Nature Reserve has been included among the Geosites, with national scientific interest.

Figure 1. Landscape of "Grotta di Santa Ninfa" Nature Reserve

In the northern plateau, the highest relief is represented by Mt. Finestrelle (663 m), separated by a valley (Valle Sorgo) from Rocca delle Penne (673 m) (the highest relief of the ridge).

Since the nineteenth century, several geological, geomorphological and speleological studies have been carried out in the area of the "Gypsum complexes of Santa Ninfa" (Baldacci, 1886; Spataro, 1891; Marinelli, 1899, 1917; Gemmellaro, 1915). However, there is little or no naturalistic research before the establishment of the "Grotta di Santa Ninfa" nature reserve in 1996. In recent years, Legambiente Sicilia, which manages the Nature Reserve "Grotta di Santa Ninfa", has promoted research and study activities (Casamento & Palmeri, 2001; Casamento, 2001).

## Floristic and Vegetation information

The first works of great phytogeographic interest were written in the nineteenth century by Gussone (1828-1832, 1843-1845) and by Lojacono-Pojero, 1888-1909).

Besides the oldest botanical works that have interested the area, it is also useful to mention: Bartolo & Brullo (1986), Bernhardt (1986a-1988), Bernhardt & Hurka (1989), Brullo & Spampinato (1986, 1991), Raimondo *et al.* (1994), Minissale (1995), Bolliger (1999). Pasta & La Mantia (2001a-b) instead produced a first important monographic contribution to the knowledge of vascular flora, vegetation and local habitats.

Actually, according to the last Management Plan of “Complessi gessosi Santa Ninfa” - SIC ITA 010022 “Complesso dei Monti di Santa Ninfa, Gibellina e Grotta di Santa Ninfa”, in this site there are 506 plant species, of which 41% are Mediterranean species s.l.. Regarding the life forms, 43,7% are therophytes, while the hemicryptophytes represent the 24% of the total. Several species (90) in the SIC represent a floristic emergencies.

The truly rare species within the SIC are: *Ambrosina bassii*, *Astragalus huetii*, *Ophrys garganica*, *O. oxyrrhynchos*, *Brassica rupestris* subsp. *rupestris*, *Brassica villosa* subsp. *bivoniana*, *Calendula suffruticosa* Vahl subsp. *fulgida*, *Capnophyllum peregrinum*, *Catananche lutea*, *Crepis bursifolia*, *Cymbalaria pubescens*, *Daucus muricatus*, *Diplotaxis crassifolia*, *Echinaria capitata* subsp. *todaroana*, *Helictotrichon cincinnatum*, *Jacobaea lycopifolia*, *Lomelosia cretica*, *Nepeta apuleii*, *Orchis anthropophora*, *Orchis longicornu*, *Rumex thyrsoides*, *Salvia viridis*, *Scorzonera cana*, *Thymus spinulosus, Vicia narbonensis*.

In the SCI area, several alien species have been counted and now they are definitively spontaneous or subspontalized and several casual or completely naturalized adventitious: *Oxalis pes-caprae*, *Symphyotrichum squamatum*, *Conyza bonariensis*, *Ailanthus altissima*, *Eucalyptus* sp., *Arundo donax*, *Agave americana*, *Myoporum tenuifolium*, *Lantana camara*.

## SINTAXONOMIC SCHEME

- CHARETEA FRAGILIS Fukarek ex Krausch 1964
  - CHARETALIA HISPIDAE Sauer ex Krausch 1964
    - CHARION FRAGILIS (Krause ex Krause et Lang 1977) Krause 1981
      - *Charetum vulgaris* Corillion 1957
- PHRAGMITO-MAGNOCARICETEA Klika in Klika et Novák 1941
  - PHRAGMITETALIA W. Koch 1926 em. Pignatti 1954
    - PHRAGMITION COMMUNIS W. Koch 1926
      - *Phragmitetum communis* (W. Koch 1926) Schmale 1939
      - *Typhetum angustifoliae* (Allorge 1921) Pignatti 1953
      - *Helosciadetum nodiflori* Br.-Bl. (1931) 1952
    - AGROSTIO-ELYTRIGION ATHERICAE Brullo et Siracusa 2000?
      - Comm. of *Festuca arundinacea* e *Phalaris coerulescens*
- MOLINIO-ARRHENATHERETEA R. Tx. 1937
  - PLANTAGINETALIA MAJORIS R. Tx. et Preising in R. Tx. 1950
    - MENTHO-JUNCION INFLEXI De Foucault 1984
      - Comm. of *Pulicaria dysentherica* e *Mentha suaveolens*
- ASPLENIETEA TRICHOMANIS (Br.-Bl. in Meier et Br.-Bl. 1934) Oberdorfer 1977
  - ASPLENIETALIA GLANDULOSI Br.-Bl. et Meier 1934
    - DIANTHION RUPICOLAE Brullo et Marcenò 1979b
      - *Diplotaxio crassifoliae-Brassicetum tinei* Brullo et Marcenò 1979
      - Comm. of *Brassica rupestris* subsp. *rupestris*
- PARIETARIETEA Oberdorfer 1977
  - TORTULO-CYMBALARIETALIA Segal 1969

    - PARIETARION JUDAICAE Segal 1969
      - *Capparidetum rupestris* O. de Bolòs et Molinier 1958
    - CYMBALARIO-ASPLENION Segal 1969
      - Comm. of *Parietaria judaica* e *Athamanta sicula*
- ANOMODONTO-POLYPODIETEA Rivas-Martínez 1975
  - ANOMODONTO-POLYPODIETALIA O. de Bolòs et Vives in O. de Bolòs 1957
    - POLYPODION SERRATI Br.-Bl. in Br.-Bl., Roussine et Nègre 1952
      - *Selaginello denticulatae-Cymbalarietum pubescentis* Brullo, Marcenò et Siracusa 2004
    - BARTRAMIO-POLYPODION CAMBRICI O. de Bolòs et Vives in O. de Bolòs 1957
      - Comm. of *Sedum dasyphyllum, Ceterach officinarum* e *Umbilicus horizontalis*
    - SELAGINELLO DENTICULATAE-ANOGRAMMION LEPTOPHYLLAE Rivas-Martínez, Fernández-González et Loidi 1999
      - *Anogrammo leptophyllae-Selaginelletum denticulatae* Molinier 1937
  - CHEILANTHETALIA MARANTO-MADERENSIS Saenz et Rivas-Martínez 1979
    - PHAGNALO SAXATILIS-CHEILANTHION MADERENSIS Loisel 1970 corr. Perez et Al. 1989
      - Comm. of *Cheilanthes maderensis*
- PAPAVERETEA RHOEADIS Brullo, Scelsi et Spampinato 2001
  - PAPAVERETALIA RHOEADIS Hüppe et Hofmeister ex Theurillat et Al. 1995
    - RIDOLFION SEGETI Nègre ex El Antri in Rivas-Martínez, Fernández-González et Loidi 1999
      - *Capnophyllo peregrini-Medicaginetum ciliaris* Di Martino et Raimondo 1976
- ONOPORDETEA ACANTHII Br.-Bl. 1964
  - CARTHAMETALIA LANATI Brullo in Brullo et Marcenò 1985
    - ONOPORDION ILLYRICI Oberdorfer 1954
      - *Carlino siculae-Feruletum communis* Gianguzzi, Ilardi e Raimondo 1996
      - Comm. of *Dipsacus fullonum*
- POLYGONO-POËTEA ANNUAE Rivas-Martínez 1975
  - POLYGONO ARENASTRI-POËTALIA ANNUAE R. Tx. in Géhu, Richard et R. Tx. 1972
    - POLYCARPION TETRAPHYLLI Rivas- Martínez 1975
      - *Trisetario aureae-Crepidetum bursifoliae* Brullo 1980
- STELLARIETEA MEDIAE R. Tx. Lohmeyer et Preising ex von Rochow 1951
  - POLYGONO-CHENOPODIETALIA ALBI R. Tx. et Lohmeyer in R. Tx. 1950 em. J. Tx. 1966
    - FUMARION WIRTGENII-AGRARIAE Brullo in Brullo et Marcenò 1985a
  - SOLANO NIGRI-POLYGONETALIA CONVOLVULI (Sissingh in Westhoff, Dijk et Passchier 1946) O. de Bolòs 1962
    - DIPLOTAXION ERUCOIDIS Br.-Bl. in Br.-Bl., Gajewski, Wraber et Walas 1936
      - *Chrozophoro tinctoriae-Kickxietum integrifoliae* Brullo et Marcenò 1980
  - THERO-BROMETALIA (Rivas-Goday et Rivas-Martínez ex Esteve 1973) O. de Bolòs 1975
    - HORDEION LEPORINI Br.-Bl. in Br.-Bl., Gajewski, Wraber et Walas 1936 corr. O. Bolòs 1962
    - ECHIO-GALACTITION TOMENTOSAE O. de Bolòs et Molinier 1969
      - Comm. of *Dactylis hispanica* e *Elaeoselinum asclepium*
    - FEDIO GRACILIFLORAE-CONVOLVULION CUPANIANI Brullo et Spampinato 1986
- GALIO-URTICETEA Passarge ex Kopecký 1969
  - URTICO-SCROPHULARIETALIA PEREGRINAE Brullo in Brullo et Marcenò 1985
    - ALLION TRIQUETRI O. de Bolòs 1967
      - *Acantho mollis-Smyrnietum olusatri* Brullo et Marcenò 1985a
  - CONVOLVULETALIA SEPIUM R. Tx. 1950
    - SENECIONION FLUVIATILIS R. Tx. 1950?
      - Comm. of *Arundo donax*
- GERANIO-CARDAMINETEA HIRSUTAE (Rivas-Martínez, Fernandez-Gonzalez et Loidi 1999) Rivas-Martínez et Al. 2001
  - GERANIO PURPUREI-CARDAMINETALIA HIRSUTAE Brullo in Brullo et Marcenò 1985a
    - VALANTIO-GALION MURALIS Brullo in Brullo et Marcenò 1985a
- STIPO-TRACHYNIETEA DISTACHYAE Brullo in Brullo, Scelsi et Spampinato 2001
  - STIPO-TRACHYNIETALIA DISTACHYAE Rivas-Martínez 1978
    - TRACHYNION DISTACHYAE Rivas-Martínez 1978

*Thero-Sedetum caerulei* Brullo 1975 em. Brullo in Bartolo, Brullo et Marcenò 1982
STIPO-BUPLEURETALIA SEMICOMPOSITI Brullo in Brullo, Scelsi et Spampinato 2001
SEDO-CTENOPSION GYPSOPHILAE Rivas-Goday et Rivas-Martínez ex Izco 1974
Comm. of *Filago eriocephala* e *Medicago minima*
Comm. of *Sedum gypsicola* e *Sedum sediforme*
PLANTAGINI-CATAPODION MARINI Brullo 1985
Comm. of *Stipa capensis*
Comm. of *Hedysarum glomeratum*
POËTEA BULBOSAE Rivas-Goday et Rivas-Martínez in Rivas-Martínez 1978
POËTALIA BULBOSAE Rivas-Goday et Rivas-Martínez in Rivas-Goday et Ladero 1970
LEONTODONTO TUBEROSI-BELLIDION SYLVESTRIS Biondi, Filigheddu et Farris 2001
Comm. of *Charybdys pancration* e *Asphodelus ramosus*
LYGEO-STIPETEA TENACISSIMAE Rivas-Martínez 1978
HYPARRHENIETALIA HIRTAE Rivas-Martínez 1978
AVENULO-AMPELODESMION MAURITANICI Minissale 1995
*Astragalo huetii-Ampelodesmetum mauritanici* Minissale 1995 *teucrietosum flavi* n. provv.
HYPARRHENION HIRTAE Br.-Bl., P. Silva et Rozeira 1956
*Sanguisorbo verrucosae-Magydaretum pastinaceae* Bartolo, Brullo, Minissale et Spampinato 1990
BROMO-ORYZOPSION MILIACEAE O. de Bolòs 1970
*Thapsio garganicae-Feruletum communis* Brullo 1984
ARUNDION COLLINAE Brullo et al 2010
*Euphorbio ceratocarpae-Arundinetum collinae* Brullo et al 2010
Comm. of *Calendula suffruticosa* subsp. *fulgida*
CISTO-MICROMERIETEA JULIANAE Oberdorfer 1954
CISTO-ERICETALIA Horvatič 1958
CISTO-ERICION Horvatič 1958
Comm. of *Micromerio fruticosa and Coridothymum capitati*
Comm. of *Cistus creticus*
QUERCETEA ILICIS Br.-Bl. ex A. et O. de Bolòs 1950
QUERCETALIA ILICIS Br.-Bl. ex Molinier 1934 em. Rivas-Martìnez 1975
QUERCION ILICIS Br.-Bl. ex Molinier 1934 em. Rivas-Martìnez 1975 ?
Comm. of *Laurus nobilis*
PISTACIO LENTISCI-RHAMNETALIA ALATERNI Rivas-Martínez 1975
OLEO SYLVESTRIS-CERATONION SILIQUAE Br.-Bl. ex Guinochet & Drouineau 1944
*Euphorbio dendroidis-Anagyridetum foetidae* subass. *artemisietosum arborescentis* Biondi et Mossa1992
Comm. of *Chamaerops humilis*
RHAMNO-PRUNETEA Rivas Goday et Borja Carbonell ex R. Tx. 1962
PRUNETALIA SPINOSAE R. Tx. 1952
PRUNO-RUBION ULMIFOLII O. de Bolós 1954
Comm. of *Ulmus minor*
Comm. of *Rubus ulmifolius* and *Rhus coriaria*
Comm. of *Rubus ulmifolius* and *Smilax aspera*
*Rubo ulmifolii-Tametum communis* R. Tx. in R. Tx. et Oberdorfer 1958
*Rubo ulmifolii-Dorycnietum recti* Brullo, Minissale, Scelsi et Spampinato 1993
QUERCO ROBORIS-FAGETEA SYLVATICAE Br.-Bl. et Vlieger in Vlieger 1937
POPULETALIA ALBAE Br.-Bl. ex Tchou 1948
POPULION ALBAE Br.-Bl. ex Tchou 1948
*Ulmo canescentis-Salicetum pedicillatae* Brullo et Spampinato 1991

**The “Grotta di Entella”**

The “Rocca di Entella” is located in the Belìce Valley, on the border between the provinces of Palermo and Trapani, east of the Belice Sinistro river, in the territory of Contessa Entellina (Fig. 2,3). Part of its territory, since 1995, has been subjected to protection according to Law R. n. 14/88 and typologically identified, pursuant to art. 6 of the same law, as Integral Natural Reserve.

Fig. 2. West slope of the “Rocca di Entella” and the artificial lake generated by the left Belice River crossing from the "Mario Francese" Dam

The “Grotta di Entella” Nature Reserve has been entrusted in management, by the Department of Territory and Environment, to the CAI-Sicilia, regional structure of the Italian Alpine Club, environmental association present throughout Italy with about 320,000 members and whose speleological tradition is undisputed.

The "Grotta di Entella" Nature Reserve was established to "... preserve the cavity in its entirety, with meandering morphology, carved out of the Messinian's macrocrystalline plasters". The protected area is made up of two zones with a different bonding regime: 1) the Reserve Area “A”, consisting of the entire development of the Entella Cave; 2) the Pre-reservation Zone “B”, comprising a portion of the summit plateau of the Rocca di Entella and a strip of rock face that borders the Rocca to the south and west, for a total area of 20 hectares.

Since 2000, the entire territory of the "Rocca di Entella" has become part of the Sites of Community Importance of the European Community, pursuant to Directives 92/43 / EEC and 79/409 / EEC, with the name ITA020042 "Rocche di Entella" http://natura2000.eea.europa.eu/Natura2000/SDF.aspx?site=ITA020042. In 2008, the CAI Sicilia, the managing body of the reserve, on behalf of ARTA, provided for the drafting of the Management Plan of SIC / ZPS ITA020042 "Rocche di Entella". Since 2015 this SCI / ZPS has been designated as a Special Conservation Zone (SAC) of the Mediterranean biogeographical region.

Moreover, since 2015 the "Grotta di Entella" has been included among the Geosites, with national scientific interest.

The archaeological interest of the "Rocca di Entella" is also relevant. Here are the remains of the city of Entella that, with Erice and Segesta, was one of the three Sicilian cities of Elymian origin. It assumed significant importance during the wars between the Carthaginians and the Syracusans, at the time of Dionysius the Elder. In its vicinity, and due to its possession, one of the most important battles held in ancient times in Sicily, the Battle of Timoleon (342 BC), was fought. In late medieval times, it constituted, with the castle of Jato, the last bastion of defense and the liveliest center of resistance of the Saracen power against Federico II. He destroyed it in 1246.

## Floristic and Vegetation information

On the basis of this survey, 405 infrageneric entities have been registered in the territory of "Rocca di Entella"; it is primarily therophytes (50.37%), followed by hemicryptophytes (24.44%), geophytes (12.84%), camefites (5.93%), phanerophytes (3.46%) and nano-phanerophytes (2.72%). From a corological point of view the Mediterranean component stands out (endemic, steno-Mediterranean, euri-Mediterranean, Mediterranean-oriental, Mediterranean-western, etc.), whose overall incidence is around 73%. Endemism is represented by 15 entities (3.54%). Among the Sicilian endemics we should mention *Eryngium bocconei*, *Odontites rigidifolia*, *Ophrys panormitana* and *Erysimum metlesicsii*, as well as *Brassica tinei* (exclusive of gypsum internal relief) (Gianguzzi et al. 2007).

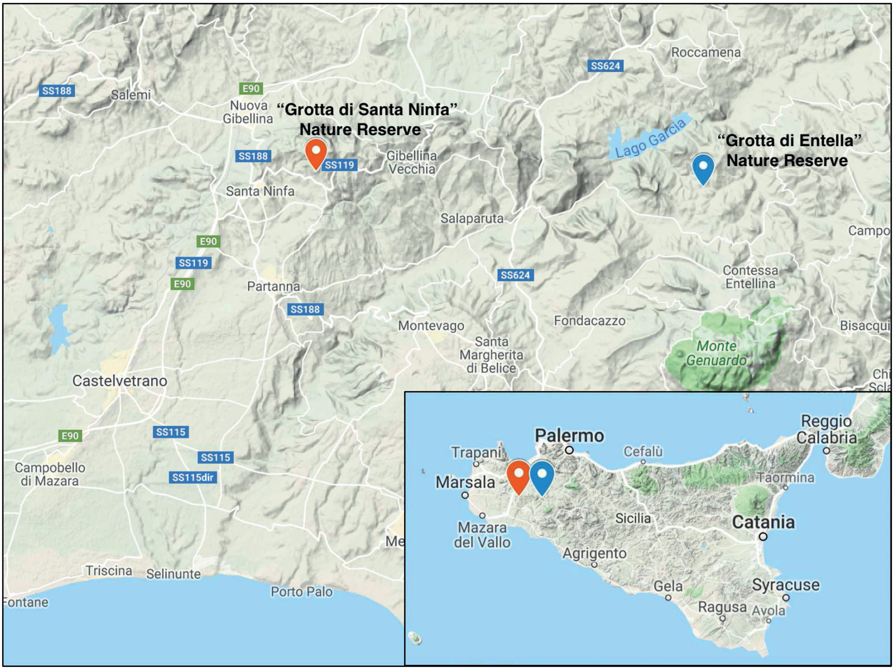

Fig. 3. Locations of "Grotta di Santa Ninfa" Nature Reserve and "Grotta di Entella" Nature Reserve

## Itinerary

**Visit to “Grotta di Santa Ninfa” Nature Reserve** (c. 8:30-12:00)
**1rst stop**: Castellaccio
Coordinates: 37°47’10.00’’ N and 12°52’57.50’’ E, 470-515 m a.s.l.
Maximum elevation range: 45 × 2 = 90 m
Highlights: karstic landscape and morphologies; gypsarenite outcrops and mosaic-like vegetation with annual and perennial grassland (Crassulaceae, *Asphodelus ramosus*, *Ferula communis*, etc.) and garrigue dominated by subshrubs, mostly Lamiaceae (e.g. *Micromeria fruticulosa*, *Thymbra capitata*); chasmophilous communities (*Athamanta sicula*, *Silene fruticosa*, *Lomelosia cretica*, *Brassica villosa* subsp. *tineoi*, ecc.) on the north-facing slopes.

**2nd stop**: Contrada Magione
Coordinates: 37°47’03.50’’ N and 12°53’52.00’’ E, 435-445 m a.s.l.
Maximum elevation range: 10 m × 2 = 20 m
Highlights: mosaic-like vegetation with annual and perennial grassland (dominated by *Ampelodesmos mauritanicus*) on lithosoils.

**3th stop**: Conca del Biviere
Coordinates: 37°47’02.00’’ N and 12°54’16.50’’ E, 465-485 m a.s.l.
Maximum elevation range: 20 m × 2 = 40 m
Highlights: karstic landscape and morphologies.

**4th stop**: Visit to the “Esplorambiente” Educational Center into the Castle of Rampinzeri. Time to have lunch and to visit the educational centre.

**Transfer and visit to “Grotta di Entella” Nature Reserve** (c. 14:30-17:30)

**1rst stop**: selenitic gypsum outcrop (geosite)
Coordinates: 37°46’17.50’’ N and 13°07’20.00’’ E, 475 m a.s.l.
Maximum elevation range: 65 m × 2 = 130 m
Highlights: karstic landscape and morphologies; macrocrystalline geminate (‘selenitic’) gypsum outcrops; moss and lichen communities and Crassulaceae assemblages (es.: *Sedum gypsicola* subsp. *trinacriae, Sedum ochroleucum* subsp. *mediterraneum* and *Sedum caeruleum*) on local gypsum outcrops intermingled with marls (‘trubi’) and limestones (‘calcari di base’).

**2nd stop**: top of Rocca d’Entella
Coordinates: 37°46’17.50’’ N and 13°07’28.00’’ E, 530 m s.l.m.
Maximum elevation range: 55 m × 2 = 110 m
Highlights: karstic landscape and morphologies; view of the archaeological site of Entella, one of the main Elymian settlements.

**3rd stop**: SW border of Rocca d’Entella
Coordinates: 37°46’22.50’’ N and 13°06’60.00’’ E, 470 m a.s.l.
Maximum elevation range: 120 m
Highlights: karstic landscape and morphologies; moss and lichen communities and Crassulaceae assemblages (es.: *Sedum gypsicola* subsp. *trinacriae*, *Sedum caeruleum* and *Phedimus stellatus*); gypsum outcrops and mosaic-like vegetation with annual and perennial grassland (Crassulaceae, *Asphodelus ramosus*, *Ferula communis*, etc.) and garrigue dominated by subshrubs, mostly Lamiaceae (e.g. *Micromeria fruticulosa*, *Thymbra capitata*); chasmophilous communities (*Erysimum metlesicsii*, *Diplotaxis harra* subsp. *crassifolia*, etc.) on the S-facing slopes.

**4th stop**
Tasting of local products offered by the Municipality of Contessa Entellina (PA).
**Departure and transfer to Reggio Calabria** (expected arrival: c. 22:00)

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