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Aridity level, rainfall pattern and soil features as key factors in germination strategies in salt-affected plant communities

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In arid environments, particularly in halophytic habitats, germination ecophysiology is strongly affected by environmental factors, primarily water availability, which is influenced by quantity and seasonal distribution of precipitation and soil properties.

The aim of this paper was to demonstrate that water availability is essential for the control of germination and the response of seedlings growing in saline areas. With this approach, we compared the germination strategies in two *Halocnemum* populations with contrasting rainfall regimes and soil aridity. The germination behavior and radicle growth under various temperature regimes, light conditions and salinity levels were evaluated.

Differences were found for all parameters between the populations. Seeds from the drier Mediterranean population exhibited common opportunistic behavior and germinated in a wide range of conditions, whereas germination in the Temperate population preferred conditions with light and was restricted to alternating temperatures, adaptations to temporary waterlogged environments. This restriction was eliminated when seeds were previously exposed to high salt concentrations, which confirmed an osmopriming effect.

Based on our results, the development of global conservation plans for species with large distributions is not recommended. Successful management plans for threatened habitats should consider single populations and the reproductive strategies that developed in response to local environmental conditions.

1. Introduction

Understanding the relationships between vegetation structure and function and environmental factors is fundamental for developing suitable conservation and management strategies for natural habitats. Among these environmental factors, soils and local seasonal variations in climatic parameters determine the different growth and plant development stages (Jafarian et al., 2011).

The effects of different annual quantities of rain and seasonal rain patterns on seedling emergence and establishment in arid and semiarid ecosystems, which determine structure and function, are well established (Miranda et al., 2009, 2011; Veenendaal et al., 1996). The importance of soil moisture potential for the success of reproductive stages is also acknowledged, particularly in drought environments (Hillel, 2012).

Halophyte communities are particularly dependent on water availability, and in particular, germination strategies are expected to adapt to water availability (Espinar et al., 2005). Donohue et al. (2010) established that germination behavior was one of the earliest phenotypes expressed by plants, which has consequences for the evolution of postgermination traits, ecological niches and geographic ranges.

Halophytic habitats are distributed in a wide variety of landscapes, from coastal areas to mountain valleys, are exposed to a wide variety of climatic conditions, from Mediterranean desertic to Temperate xeric, and are vastly different in size, from only a few square meters to a few square kilometers. These habitats are dependent primarily on edaphic factors, topography, the saline

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water table and salt water flooding. Halophytic vegetation is characterized by simple structure and uniformity of species composition depending on salt tolerance and adaptation strategies. Variations in annual rainfall quantity and distribution cause significant seasonal changes in salt concentrations, which allows plants with different salt tolerances to grow together.

The natural vegetation in salt-affected environments faces two major challenges: (i) high salt concentrations in soil, which restrain the germination phase and the early seedling stages; and (ii) difficult water absorption, which affects primarily adult plants. The germination and establishment phases are also affected by variations in surface salinity, available soil water, temperature and soil crust strength of saline sites (Malcolm et al., 2003), among other factors such as life form, habitat and competitive ability. To explain plant distribution, the success of these phases should be the first factor considered.

The salt tolerance of plants living in halophytic communities depends on a range of adaptations, which include many aspects of plant physiology, such as ion compartmentalization, osmolyte production, osmotic adjustment, selective transport and uptake of ions, enzymatic and nonenzymatic antioxidant response, salt inclusion/excretion and genetic control (Flowers and Colmer, 2008; Lokhande and Suprasanna, 2012). The seed germination strategies and plant salt tolerances in halophytes are determined by these factors, which vary considerably among different species, e.g., *Salicornia herbacea* germinates even at 1.7 M, whereas germination in *Spergularia marina* is significantly reduced at 0.17 M NaCl (Khan and Gul, 2008).

One characteristic of this vegetation type is the dominance of *Amaranthaceae* perennial shrub species with high salt tolerances. Among them, the species of *Halocnemum* M. Bieb., are distributed widely from southern Europe and North Africa to Mongolia in Asia (Nilhan et al., 2008), primarily in areas with a Mediterranean macrobioclimate, xeric or desertic, and with a dry, arid or semiarid ombrotype (P typically 40–300 mm) at altitudes of 0–2000 m asl. In the regions of North Africa and West and Central Asia that have arid climates, the species have more extensive stands and grow primarily in salt deserts, salt lakes and inland depressions (Qu et al., 2008; Schmidt and Uppenbrink, 2009), where the primary source of salt is continental. Nevertheless, the occidental populations of the Mediterranean basin in southwestern Europe are scarce, with only three localities in Spain and four in Italy (Biondi, 1992). According to IUCN categories, these populations are "Vulnerable" in Italy and "Critically Endangered" in Spain.

Currently, society assumes that natural areas have ecological, educational and scientific value, and demands the implementation of priority conservation actions. For these purposes, management and conservation plans for protected areas are required. Thus, knowledge of how species function is essential, particularly of reproductive processes, to identify the factors that pose a recognizable threat and to facilitate the conservation of biodiversity in natural habitats. Among the priority conservation areas, salt-affected environments, generally in arid areas, are one of the most threatened and exploited ecosystems in the world and are recognized to provide of a wide range of ecosystem services (Barbier, 2012).

The EU Habitats Directive explicitly recognizes the rarity and small area occupied by halophytic perennial vegetation habitats, among which the *Halocnemum* communities are included. Annex I of the Directive includes this vegetation type in Habitat Code 1420: "Mediterranean and thermo-Atlantic halophilous scrubs (*Sarcocornietea fruticosae*)". Unfortunately, despite reductions on the Mediterranean coasts, which impose a severe risk of extinction, these saline environments are not considered priority habitats.

As an additional consideration, a wide morphological variation of *Halocnemum* plants was observed in the Mediterranean basin, which led to taxonomic research that attributed the typical Mediterranean populations to *Halocnemum cruciatum* (Forssk.) Tod. (Bacchetta et al., 2012), whereas the populations of Tyrrhenian and North Adriatic coasts were assigned to *Halocnemum strobilaceum* (Pall.) M. Bieb. (Biondi et al., 2013). Furthermore, a new species, *Halocnemum yurdakulolii* (Yaprak and Kadereit, 2008), was described in Turkey.

The communities characterized by *Halocnemum* species are low in diversity, are often monotypic and normally grow in inland salt depressions and littoral marshes with high salinity. The establishment of these plant communities depends on soil salinity and plant competition. Typically, *Halocnemum* dominate lower marshes subject to periodic flooding, where the species inhabit muddy and dry salt flats. These habitats are primarily related to geomorphologic structures such as actual and ancient river deltas, coastal lagoons and salt lakes (Pérez–Lahiguera et al., 2009).

For seed germination and seedling growth, Qu et al. (2008) highlighted the importance of the different adaptation strategies of various ecotypes of *H. strobilaceum* that occurred under distinct environmental conditions. The study of specific germination adaptations is the key to develop specific, effective management and conservation plans and to help evaluate the effects of current threats, particularly future changes in temperature and water supply caused by climate change (Walck et al., 2011). Information on these saline habitats and baselines for plant functioning is critical for the decisions on future actions for sustainable conservation and management.

This study focused on the comparison of species germination responses and on the adaptive strategies related with ecological conditions, particularly water availability and seasonal rainfall distribution. Thus, our main aim was to demonstrate the potential effects of rainfall patterns on the germination strategies that developed to achieve high reproductive effectiveness in salt-affected habitats from arid and semiarid territories.

With this approach, two populations of the genus *Halocnemum*, which live in two different climate regimes, were examined in the present study. The first population was *H. strobilaceum*, located in Italy at the northern limit of the European distribution for this species, with a Temperate macrobioclimate and direct influence of the sea, in a temporarily flooded coastal zone by the sea or by the Reno River. Compared with the usual growth conditions for the species of the genus, this population grows in more humid conditions. The second population was *H. cruciatum*, located in a Spanish inland semiarid salt marsh with a typical Mediterranean macrobioclimate.

The different adaptive strategies of seed germination behavior (germination percentage, rate and recovery response) and radicle growth under various salinity levels, temperature and light conditions and their relation to the ecological conditions for these two populations were compared.

2. Materials and methods

The seeds were collected during natural dispersal in two protected areas (Fig. 1): the Po Delta Regional Park in the Emilia-Romagna region in the State Natural Reserve Sacca di Bellocchio (Ravenna, Italy) and the El Hondo Nature Park (Crevillente, Spain). The seeds were cleaned and stored in paper bags in a controlled environment (20 °C and 40–50 % RH) until germination tests.

2.1. Field site description

The State Natural Reserve Sacca di Bellocchio is a brackish area with 258 ha of halophytic vegetation on the northern Adriatic Sea