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## **Patterns of seed germination in Mediterranean mountains: study on 37 endemic or rare species from Sierra Nevada, SE Spain**

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# Patterns of seed germination in Mediterranean mountains: study on 37 endemic or rare species from Sierra Nevada, SE Spain

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## Abstract

LORITE, J., M. RUIZ-GIRELA & J. CASTRO (2007). Patterns of seed germination in Mediterranean mountains: study on 37 endemic or rare species from Sierra Nevada, SE Spain. *Candollea* 62: 5-16. In English, English and French abstracts.

The study of seed germination of endangered flora species is vital for conservation strategies. In this context, performed germination experiments were performed with a set of 37 endemic, rare or often endangered, taxa of the Sierra Nevada high mountain (SE Spain), an area that constitutes a hotspot of diversity in the Mediterranean region. Seed germination varied depending on the species, from 0% to ca. 95%. A group of 10 species belonging to 9 families showed a low or null germination percentage. Dormancy in these species is likely to be complex and to involve some kind of physiological ground. A second group of species showed a germination percentage between 5 and 20%, most of these belonging to families producing hard-coated seeds (e.g. *Papilionaceae*, *Geraniaceae*). Treatments to promote their germination were thus easy to apply. A large fraction of taxa had a germination percentage above 20%, often above 50%. The germination percentage did not correlate positively with the speed of germination (estimated as the  $T_{50}$ ) or with altitude, but correlated negatively

## Résumé

LORITE, J., M. RUIZ-GIRELA & J. CASTRO (2007). Modèles de germination de graines dans les montagnes méditerranéennes: étude de 37 espèces endémiques ou rares de la Sierra Nevada, SE Espagne. *Candollea* 62: 5-16. En anglais, résumés anglais et français.

L'étude de la germination des graines d'espèces en danger est fondamentale pour mettre en place des stratégies de conservation. Dans ce contexte, des expériences de germination ont été menées sur 37 taxons endémiques, rares ou souvent en danger, en provenance des hautes montagnes de la Sierra Nevada (SE de l'Espagne), une aire géographique qui constitue un «hotspot» de diversité dans la région méditerranéenne. La germination des graines a varié selon l'espèce de 0% à 95%. Un groupe de 10 espèces appartenant à 9 familles ont montré un pourcentage de germination bas ou nul. La dormance de ces espèces est complexe et dépend de mécanismes physiologiques. Un second groupe d'espèces a montré un pourcentage de germination entre 5 et 20%, la plupart de ces espèces appartenant à des familles produisant des graines à côtes rugueuses (ex. *Papilionaceae*, *Geraniaceae*). Les traitements pour promouvoir leur germination ont été faciles à appliquer. Une grande partie de ces taxons ont présenté un pourcentage de germination au dessus de 20%, souvent au dessus de 50%. La corrélation du

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(although weakly) with diaspore mass. Families such as *Compositae*, *Cruciferae*, *Geraniaceae*, *Labiatae* and *Papilionaceae* are identified as families where seed germination may not imply major problems. *Aquilegia vulgaris* subsp. *nevadensis*, *Arenaria nevadensis*, *Carex camposii*, *Gentiana lutea*, *Linaria glacialis*, *Narcissus nevadensis*, *Nardus stricta*, *Odontites granatensis*, *Papaver lapeyrouisianum* and *Sorbus hybrida* need studies of dormancy breakage to establish guidelines to optimize management of the scant seed material. As a whole, the results contrast with the generalized idea of a high level of dormancy in alpine species.

### Key-words

Sierra Nevada National Park – Seed germination – Endemic species – Rare species – Threatened flora – Plant conservation – Mediterranean high mountain

pourcentage de germination n'a pas été trouvé positive avec la vitesse de germination (estimée comme le  $T_{50}$ ) ou avec l'altitude. Elle a été trouvée négative (faiblement) avec la masse de la diaspore. Les familles comme les *Compositae*, *Cruciferae*, *Geraniaceae*, *Labiatae* et *Papilionaceae* ont été identifiées comme les familles où les germinations de graine ne présentent pas de problèmes majeurs. Des espèces comme *Aquilegia vulgaris* subsp. *nevadensis*, *Arenaria nevadensis*, *Carex camposii*, *Gentiana lutea*, *Linaria glacialis*, *Narcissus nevadensis*, *Nardus stricta*, *Odontites granatensis*, *Papaver lapeyrouisianum* et *Sorbus hybrida* ont besoin d'études sur la rupture de dormance pour permettre la mise en place de directives visant à optimiser la gestion de stock peu abondant de graines. Ces résultats contrastent avec l'idée que les espèces alpines ont une dormance élevée.

## Introduction

The knowledge of the germination capacity and germination requirements of any plant species is of interest for its management, but, in particular, the study of the germination of rare and endemic species is of paramount importance for the conservation and management of these species for several reasons. First, seed germination is the only way to preserve the genetic variability of the populations (FENNER & THOMPSON, 2005). Second, these species are in many cases under risk of extinction, so that an accurate understanding of their germination ability is critical to optimize conservation and restoration efforts (GASTON, 1994; BLANCA & al., 1998; MORENO-SÁIZ & al., 2003). However, the germination of endemic and rare species, in particular from high mountain and alpine habitats, is often scarcely known, as these species have a restricted distribution, are difficult to sample, and are, in many cases, under threat of extinction due to low population levels, which restrict the use of plant material and even make it undesirable in years of low seed production (ESCUADERO & IRIONDO, 2003). In addition, the germination of these species is in many cases subjected to complex physiological controls, given that they inhabit a type of habitat (e.g. high mountain, specific soil types) that has shaped a set of traits related to seed dormancy (KÖRNER, 1999).

In this study, we analyse the germination capacity of 37 rare (i.e. having low abundance and/or small distribution range; see GREUTER, 1991; GASTON, 1994) or endemic taxa from Sierra Nevada mountain, SE Spain. Sierra Nevada, together with the Baetic range as a whole, constitutes an important reservoir of diversity and speciation (HEYWOOD, 1995; DOMÍNGUEZ & al., 1996; MÉDAIL & QUÉZEL, 1999; THOMPSON, 2005). It also constitutes a hotspot of endemism, with 80 exclusive taxa and 125 threatened taxa (BLANCA, 2002). There is, however, very little information available on the germination capacity of the species that inhabit Sierra Nevada high mountain, which is a preliminary and necessary step to carry out recovery plans.

Because collection of large number of seeds from these taxa is undesirable in most cases, our aim was to check seed germination ability of a large number of species before treatments to break possible dormancies are used. As far as we know, most of the taxa studied here have never been tested for germination. There are few exceptions, such as *Allium schoenoprasum* L. (SPECHT & KELLER, 1997), *Astragalus granatensis* Steud. (ANGOSTO & MATILLA, 1993), or very closely related taxa such as *Hippocrepis comosa* L. (HENNENBERG & BRUELHEIDE, 2003) or *Primula elatior* subsp. *elatior* (L.) L. (JACQUEMYN & al., 2001). In any case, we include these species in the study because they are threatened in Sierra Nevada and, in addition, the germination capacity may differ greatly among populations (e.g. ALBERT & al., 2002; CERABOLINI & al., 2004; GIMÉNEZ-BENAVIDES & al., 2005; FENNER & THOMPSON, 2005).

Three questions were posed here: 1) what is the percentage and speed of germination of untreated seeds of these taxa? 2) is there any relationship between seed germination and traits related either to the seeds (seed mass) or to the habitat (altitude)? 3) which guidelines can be drawn to optimize the use of seeds of these species?

## Material and Methods

### Study area

Sierra Nevada is a mountain of 2100 km<sup>2</sup> located in SE Spain (37°N 3°W). It has complex orography, bedrock and soil composition (e.g. areas of dolomitic soils), and reaches a height of 3482 m. Sierra Nevada marks the southernmost limit of the influence of the Quaternary glaciations in Europe, when it was covered with glaciers only in areas above 2500 m (approx.) while large areas of it remained free of permanent ice (GÓMEZ & al., 2001). All this contributed to make of Sierra Nevada a refuge for many plant species during the glacial ages (BLANCA & al., 1998) and, in addition, to harbour isolated populations that have evolved under particular conditions (e.g. soil type or isolated summit areas) which have contributed to speciation and to a high level of endemism (BLONDEL & ARONSON, 1999; PEÑAS & al., 2005; THOMPSON, 2005). In fact, the area above 2000 m contains about 100 endemic or rare taxa of which 32 are included in this study. Many of these species are threatened by different factors (BLANCA & al., 1998; BAÑARES & al., 2003; see Table 1 for details), with 38 taxa included on the regional protection list (25 taxa with populations above 2000 m; LORITE & al., 2006). Today the distribution areas of the species included in this study lie within National and/or Natural parks. Climatic conditions in the localities of seed collection differ depending on the altitude (localities ranging from 1230 to 3300 m; Table 2). However, most of the species are distributed above ca. 1800 m, which marks the timberline and the start of the orophilous area in Sierra Nevada. Overall, the climate is typically alpine (with mediterranean character), with mean temperatures below 0°C during winter months and snow cover that can persist up to 8 months in the highest localities (occasionally up to 10 months in small, protected areas). GÓMEZ (2002) has reported detailed description of climatic conditions in Sierra Nevada mountain.

### Seed-germination experiments

Ripe fruits of each species studied (see Table 1 for a list of taxa and other relevant characteristics) were collected from natural populations from Sierra Nevada during the summers 2000 to 2003, depending on the species (see Table 2 for

**Table 1.** – Data about life form, distribution and habitat of the 37 taxa from Sierra Nevada high mountain used in this study (Biotype: **Ph** = Phanerophyte, **Ch** = Chamaephyte, **Hc** = Hemicryptophyte, **Ge** = Geophyte, **Th** = Therophyte):

Distribution for endemism (**SN** = Endemic of Sierra Nevada, **BM** = Endemic Baetic Mountains (Sierra Nevada and other nearby mountains such as Sierra de los Filabres, Sierra de Baza, or Sierra de Gádor)).

Threatened categories (according CABEZUDO & al., 2005; following IUCN categories; IUCN, 2001) (**CR** = Critically endangered, **EN** = Endangered, **VU** = Vulnerable, **NT** = Near threatened, **—** = No threatened. **(\*)** = less than 2000 reproductive individuals in Sierra Nevada (from BLANCA, 2002)).

| Taxon                                                                                | Biotype | Distribution                                               | Habitat                                      | Altitudinal range [m] | Threatened |
|--------------------------------------------------------------------------------------|---------|------------------------------------------------------------|----------------------------------------------|-----------------------|------------|
| <i>Allium schoenoprasum</i> L.                                                       | Ge      | Holarctic                                                  | Clearings of cushions scrubs                 | 1800-2300             | VU         |
| <i>Anthyllis tejedensis</i> Boiss.                                                   | Ch      | Baetic mountains and North Africa<br>(Morocco and Algeria) | Dolomitic sandy areas                        | 1000-2000             | —          |
| <i>Aquilegia vulgaris</i> subsp. <i>nevadensis</i><br>(Boiss. & Reut.) T. E. Díaz    | Hc      | Endemic SN                                                 | Siliceous wet meadows                        | 1200-2500             | VU         |
| <i>Arabis margaritae</i> Talavera                                                    | Hc      | Endemic SN                                                 | Hygrophilous high-mountain pasturelands      | 2000-2500             | CR         |
| <i>Arenaria nevadensis</i> Boiss. & Reut.                                            | Th      | Endemic SN                                                 | Siliceous screes                             | 2950-3200             | CR*        |
| <i>Armeria filicaulis</i> subsp. <i>trevenqueana</i><br>Nieto Feliner                | Hc      | Endemic SN                                                 | Dolomitic sandy areas                        | 1700-2000             | EN         |
| <i>Artemisia alba</i> subsp. <i>nevadensis</i> (Willk.)<br>Blanca & Morales Torres   | Ch      | Endemic BM                                                 | Limestone montane cushion scrubs             | 1800-2200             | EN*        |
| <i>Artemisia umbelliformis</i> Lam.                                                  | Ch      | Alps, Apennines and Sierra Nevada                          | Rocky fissures and siliceous screes          | 2800-3000             | EN*        |
| <i>Astragalus granatensis</i> Lam.                                                   | Ch      | southern half of Spain and North Africa<br>(Atlas)         | Montane cushion scrubs                       | 1800-2700             | —          |
| <i>Carex compositi</i> Boiss. & Reut.                                                | Hc      | Endemic BM                                                 | Hygrophilous meadows on siliceous substrates | 1300-3000             | NT         |
| <i>Centaurea gadorensis</i> Blanca                                                   | Ch      | Endemic BM                                                 | Scrublands on calcareous substrates          | 1300-2000             | VU         |
| <i>Chaenorhinum glareosum</i> (Boiss.) Willk.                                        | Hc      | Endemic SN                                                 | Rocky fissures and siliceous screes          | 2400-3300             | —          |
| <i>Chamaespartium undulatum</i> (Em)<br>Talavera & L. Sáez                           | Ch      | Endemic SN                                                 | Dolomitic sandy areas                        | 1300-1700             | VU         |
| <i>Delphinium nevadense</i> Kunze                                                    | Hc      | Endemic BM                                                 | Mesophilous woodlands and thorny Shrublands  | 1100-1600             | VU         |
| <i>Draba hispanica</i> subsp. <i>laderoi</i><br>Rivas Martínez, M. E. García & Penas | Ch      | Endemic SN                                                 | Rocky fissures                               | 2400-3200             | —          |
| <i>Echinospartum boissieri</i> (Spach) Rothm.                                        | Ch      | Endemic BM                                                 | Scrublands on calcareous substrates          | 1000-1900             | —          |
| <i>Erigeron frigidus</i> Boiss.                                                      | Hc      | Endemic SN                                                 | Psychroterophilous pasturelands              | 2900-3400             | VU         |
| <i>Erodium boissieri</i> Coss.                                                       | Ch      | Endemic SN                                                 | Dolomitic sandy areas                        | 1300-2000             | VU         |
| <i>Erodium rupicola</i> Boiss.                                                       | Hc      | Endemic BM                                                 | Rocky fissures                               | 1500-1900             | VU         |
| <i>Gentiana lutea</i> L.                                                             | Hc      | Mountains of C-S Europe                                    | Wet meadows                                  | 1900-2300             | CR*        |
| <i>Hippocrepis prostrata</i> Boiss.                                                  | Ch      | Endemic SN                                                 | Montane cushion scrubs                       | 1800-2300             | CR*        |
| <i>Hormathophylla purpurea</i> (Lag. & Rodr.)<br>P. Küpfer                           | Hc      | Endemic SN                                                 | Psychroterophilous pasturelands              | 2500-3400             | VU         |
| <i>Hormathophylla spinosa</i> (L.) P. Küpfer                                         | Ch      | Iberian Peninsula and N Africa                             | Montane cushion scrubs                       | 1700-3300             | —          |
| <i>Lavandula lanata</i> Boiss.                                                       | Ch      | Endemic BM                                                 | Scrublands on calcareous substrates          | 1200-1900             | —          |
| <i>Linaria glacialis</i> Boiss.                                                      | Hc      | Endemic SN                                                 | Siliceous screes                             | 2400-3400             | VU         |
| <i>Moehringia fontqueri</i> Pau                                                      | Hc      | Endemic SN                                                 | Rocky fissures                               | 1800-2400             | EN         |
| <i>Narcissus nevadensis</i> Pugsley                                                  | Ge      | Endemic SN                                                 | Hygrophilous meadows                         | 1400-2000             | EN         |
| <i>Nardus stricta</i> L.                                                             | Hc      | Holarctic                                                  | Hygrophilous high-mountain pasturelands      | 2000-3200             | -          |



| Taxon                                                                                    | Biotype | Distribution               | Habitat                                           | Altitudinal range [m] | Threatened |
|------------------------------------------------------------------------------------------|---------|----------------------------|---------------------------------------------------|-----------------------|------------|
| <i>Odontites granatensis</i> Boiss.                                                      | Th      | Endemic SN                 | Juniper-genista patches over calcareous substrate | 1900-2200             | CR         |
| <i>Papaver lapeyrouisianum</i> Guterm.                                                   | Hc      | Sierra Nevada and Pyrenees | Psychroterophilous pasturelands                   | 3200-3450             | EN         |
| <i>Plantago nivalis</i> Boiss.                                                           | Hc      | Endemic SN                 | Hygrophilous high-mountain pasturelands           | 2400-3100             | —          |
| <i>Primula elatior</i> subsp. <i>lofthousei</i><br>(Hesl.-Harr. f.) W. W. Sm. & Fletcher | Hc      | Endemic BM                 | Hygrophilous meadows                              | 1500-2900             | VU         |
| <i>Senecio elodes</i> Boiss.                                                             | Hc      | Endemic SN                 | Hygrophilous meadows                              | 1800-2500             | EN*        |
| <i>Senecio nevadensis</i> Boiss.                                                         | Ch      | Endemic SN                 | Siliceous screes                                  | 2600-3300             | VU         |
| <i>Sorbus hybrida</i> L.                                                                 | Ph      | Mountains of Europe        | Mixed deciduous forests                           | 1800-2000             | CR*        |
| <i>Teucrium oxylepis</i> Font Quer & Pau<br>subsp. <i>oxylepis</i>                       | Ch      | Endemic BM                 | Scrublands                                        | 1700-1850             | CR*        |
| <i>Thymus serpylloides</i> Bory<br>subsp. <i>serpylloides</i>                            | Ch      | Endemic BM                 | Montane cushion scrubs                            | 1900-2900             | —          |
| <i>Vella spinosa</i> Boiss.                                                              | Ch      | southern Iberian Peninsula | Montane cushion scrubs                            | 1800-2200             | —          |

collection dates). Fruits were collected from at least 50 individuals per species whenever possible, except for *Sorbus hybrida*, as population size was below 50 individuals. Seeds were manually cleaned and separated from the fruit coats, eliminating any visually malformed seeds. Three subsamples of 100 seeds were weighed to determine mean propagule mass (except in two species; Table 2). Seeds were thereafter stored in darkness in paper bags under ambient conditions (ca. 20°C and ca. 30% relative humidity) for ca 5-7 months until the start of germination tests (10-11 months in *Narcissus nevadensis* and *Aquilegia vulgaris*, see Table 2). Seeds were the target of this study in all cases except in *Compositae* (where achenes were used) or *Plumbaginaceae* (seeds with calyx); these do not differ functionally from seeds from the standpoint of managing these species, and thus hereafter we refer to all propagules types as seeds.

Seeds were germinated in an incubator chamber (ASL,  $\pm 0.1^\circ\text{C}$ ) with a photoperiod of 16 h and alternating temperatures of 15°C during dark periods and 20°C during light periods. Alternating day-night temperatures between 10 and 20°C have been reported as promoter of highest germination rates in alpine species (e.g. BLISS, 1971; KÖRNER, 1999). Prior to germination experiments, seeds were disinfected by immersion in a 1% sodium hypochlorite solution for 10 min, followed by thorough rinsing with sterile distilled water. Seeds were thereafter placed in plastic Petri dishes of 9 cm diameter containing a disk of filter paper resting on a layer of vermiculite in order to maintain the moisture level, all material being previously sterilised. Each Petri dish contained from 25 to 100 seeds, with 4 (occasionally 3 or 5) replicates (see Table 2 for details). Dishes were randomly repositioned within the chamber every 5 days.

Germination, identified as visible radical protrusion, was recorded at 2-3 days interval during a 25-85 days period (Table 2). The germination rate was estimated as  $T_{50}$ , i.e. the time needed for manifestation of half of the final germination level.

#### Data analysis

The relationship between 1) germination percentage and the speed of germination ( $T_{50}$ ), 2) germination percentage and altitude, 3)  $T_{50}$  and altitude, and 4) germination percentage and diaspore mass, were analysed using the Pearson's product-moment correlation. For this, all the species with germination values lower than 5% were eliminated from the analysis, assuming that those values are indicative of deep dormancy and could bias the correlations. In all these analyses, the values of germination or  $T_{50}$  were the mean values of the four replicates per species (Table 2). The  $T_{50}$  values were not calculated in case lower than 5% germination. Seeds that were attacked by fungi were removed from the plates and eliminated from analysis; in those cases the germination percentage was calculated considering the number of non-contaminated seeds. Analyses were performed with JMP 5.0 software (SAS Institute). Throughout the paper, means are followed by  $\pm$  SE.

#### Results

Contamination of plates was low (0 to < 5% of seeds contaminated in most cases), with only *Linaria glacialis* and *Gentiana lutea* showing severe fungal attack ( $11.5 \pm 2.0\%$  and  $28.0 \pm 7.6\%$  of seeds contaminated, respectively). Seed germination varied considerably, from 0% germination to around 95%

**Table 2.** – Seed-germination percentage and some details related to germination experiments for the 37 taxa from Sierra Nevada high mountain used in this study (**Germ.** = Date of the start of the germination test, **N** = Number of replicates used for germination experiments (Petri dishes), **SPD** = Seeds per Petri dish, **DE** = Days of experiment (number of days in which germination was monitored), **Seed mass** = Weight for 100 seeds, **T<sub>50</sub>** = Time (in days) needed for reaching 50% of the final germination percentage, — = not calculated. \*Seed mass from ANGOSTO & MATILLA (1993)).

|         | <b>Family</b>    | <b>Taxon</b>                                             | <b>Date collection</b> | <b>Altitude<br/>[m]</b> | <b>Germ.</b> | <b>N</b> | <b>SPD</b> | <b>DE</b> | <b>Seed mass<br/>[g]</b> | <b>Germination<br/>[%]</b> | <b>T<sub>50</sub></b> |
|---------|------------------|----------------------------------------------------------|------------------------|-------------------------|--------------|----------|------------|-----------|--------------------------|----------------------------|-----------------------|
| Group 1 | Amarillydaceae   | <i>Narcissus nevadensis</i>                              | <b>6/2002</b>          | 2100                    | 5/2003       | 5        | 100        | 55        | 0.573                    | 0.0±0.0                    | —                     |
|         | Caryophyllaceae  | <i>Arenaria nevadensis</i>                               | <b>8/2000</b>          | 3000                    | 12/2000      | 5        | 50         | 55        | 0.014                    | 0.0±0.0                    | —                     |
|         | Cyperaceae       | <i>Carex composii</i>                                    | <b>7/2002</b>          | 2350                    | 3/2003       | 4        | 100        | 30        | 0.121                    | 0.5±0.5                    | —                     |
|         | Gentianaceae     | <i>Gentiana lutea</i>                                    | <b>8/2002</b>          | 2250                    | 3/2003       | 4        | 100        | 55        | 0.010                    | 0.3±0.3                    | —                     |
|         | Papaveraceae     | <i>Papaver lapeyrousianum</i>                            | <b>9/2002</b>          | 3300                    | 4/2003       | 4        | 100        | 35        | 0.008                    | 2.0±0.6                    | —                     |
|         | Poaceae          | <i>Nardus stricta</i>                                    | <b>9/2002</b>          | 2730                    | 4/2003       | 4        | 100        | 55        | 0.040                    | 4.5±1.0                    | —                     |
|         | Ranunculaceae    | <i>Aquilegia vulgaris</i><br>subsp. <i>nevadensis</i>    | <b>7/2002</b>          | 2010                    | 5/2003       | 4        | 100        | 55        | 0.133                    | 0.0±0.0                    | —                     |
|         | Rosaceae         | <i>Sorbus hybrida</i>                                    | <b>10/2002</b>         | 1850                    | 3/2003       | 5        | 25         | 55        | 1.200                    | 0.0±0.0                    | —                     |
|         | Scrophulariaceae | <i>Linaria glacialis</i>                                 | <b>8/2002</b>          | 3050                    | 4/2003       | 4        | 100        | 40        | 0.051                    | 1.1±0.4                    | —                     |
|         | Scrophulariaceae | <i>Odontites granatensis</i>                             | <b>8/2000</b>          | 2160                    | 12/2000      | 4        | 50         | 30        | 0.054                    | 0.0±0.0                    | —                     |
| Group 2 | Geraniaceae      | <i>Erodium boissieri</i>                                 | <b>7/2002</b>          | 1850                    | 3/2003       | 4        | 42         | 60        | 0.350                    | 13.6±2.7                   | 12.3±1.9              |
|         | Labiatae         | <i>Thymus serpylloides</i><br>subsp. <i>serpylloides</i> | <b>8/2002</b>          | 2360                    | 5/2003       | 4        | 100        | 30        | 0.008                    | 18.3±4.4                   | 3.5±0.5               |
|         | Liliaceae        | <i>Allium schoenoprasum</i>                              | <b>9/2000</b>          | 2450                    | 12/2000      | 4        | 100        | 45        | 0.175                    | 13.8±2.0                   | 13.5±1.0              |
|         | Papilionaceae    | <i>Anthyllis tejedensis</i>                              | <b>7/2002</b>          | 1758                    | 3/2003       | 4        | 110        | 55        | 0.301                    | 20.2±1.4                   | 16.0±0.7              |
|         | Papilionaceae    | <i>Echinospartum boissieri</i>                           | <b>7/2002</b>          | 1680                    | 3/2003       | 4        | 100        | 55        | —                        | 5.0±1.0                    | 35.8±3.5              |
|         | Papilionaceae    | <i>Hippocrepis prostrata</i>                             | <b>8/2002</b>          | 1850                    | 3/2003       | 4        | 100        | 55        | 0.283                    | 8.5±1.0                    | 8.0±1.3               |
| Group 3 | Caryophyllaceae  | <i>Moehringia fontqueri</i>                              | <b>8/2002</b>          | 2169                    | 4/2003       | 4        | 100        | 40        | 0.008                    | 76.3±0.9                   | 9.0±0.0               |
|         | Compositae       | <i>Artemisa alba</i><br>subsp. <i>nevadensis</i>         | <b>8/2000</b>          | 1890                    | 11/2000      | 4        | 100        | 25        | 0.022                    | 31.2±2.4                   | 9.5±1.4               |
|         | Compositae       | <i>Artemisia umbelliformis</i>                           | <b>9/2000</b>          | 2900                    | 12/2000      | 3        | 100        | 30        | 0.032                    | 90.7±1.2                   | 12.0±0.0              |
|         | Compositae       | <i>Centaurea gadorensis</i>                              | <b>7/2002</b>          | 1380                    | 3/2003       | 4        | 100        | 85        | 0.446                    | 54.7±2.8                   | 14.8±2.7              |
|         | Compositae       | <i>Erigeron frigidus</i>                                 | <b>9/2000</b>          | 3100                    | 11/2000      | 4        | 100        | 30        | 0.020                    | 93.0±1.2                   | 4.0±0.4               |
|         | Compositae       | <i>Senecio elodes</i>                                    | <b>8/2000</b>          | 2044                    | 11/2000      | 4        | 100        | 30        | 0.068                    | 32.0±1.7                   | 9.0±0.4               |
|         | Compositae       | <i>Senecio nevadensis</i>                                | <b>9/2000</b>          | 3189                    | 01/2001      | 4        | 100        | 25        | 0.041                    | 22.8±2.5                   | 11.0±0.4              |
|         | Cruciferae       | <i>Arabis margaritae</i>                                 | <b>7/2002</b>          | 2350                    | 5/2003       | 5        | 100        | 35        | 0.015                    | 88.8±1.9                   | no data               |
|         | Cruciferae       | <i>Draba hispanica</i><br>subsp. <i>laderoi</i>          | <b>8/2002</b>          | 2580                    | 3/2003       | 4        | 100        | 50        | 0.014                    | 93.8±0.9                   | 12.3±0.3              |
|         | Cruciferae       | <i>Hormathophylla</i><br><i>purpurea</i>                 | <b>8/2002</b>          | 2980                    | 3/2003       | 5        | 110        | 40        | 0.124                    | 43.6±2.3                   | 5.6±0.2               |
|         | Cruciferae       | <i>Hormathophylla</i><br><i>spinosa</i>                  | <b>8/2002</b>          | 2050                    | 3/2003       | 4        | 100        | 30        | 0.070                    | 94.8±1.7                   | 3.0±0.0               |
|         | Cruciferae       | <i>Vella spinosa</i>                                     | <b>8/2002</b>          | 2100                    | 4/2003       | 4        | 100        | 35        | —                        | 35.8±2.6                   | 7.3±0.2               |
|         | Geraniaceae      | <i>Erodium rupicola</i>                                  | <b>6/2002</b>          | 2000                    | 3/2003       | 3        | 75         | 60        | 0.245                    | 54.7±4.0                   | 14.0±1.1              |
|         | Labiatae         | <i>Lavandula lanata</i>                                  | <b>9/2002</b>          | 1600                    | 4/2003       | 4        | 100        | 35        | 0.143                    | 31.1±3.8                   | 15.0±0.4              |
|         | Labiatae         | <i>Teucrium oxylepis</i><br>subsp. <i>oxylepis</i>       | <b>11/2002</b>         | 1750                    | 5/2003       | 4        | 100        | 65        | 0.092                    | 49.5±9.6                   | 7.8±0.3               |

| Family           | Taxon                                                   | Date collection | Altitude<br>[m] | Germ.  | N | SPD | DE | Seed mass<br>[g] | Germination<br>[%] | T <sub>50</sub> |
|------------------|---------------------------------------------------------|-----------------|-----------------|--------|---|-----|----|------------------|--------------------|-----------------|
| Papilionaceae    | <i>Astragalus granatensis</i>                           | 10/2002         | 2180            | 4/2003 | 4 | 100 | 30 | 0.520*           | 41.5±7.2           | 8.8±0.3         |
| Plantaginaceae   | <i>Plantago nivalis</i>                                 | 8/2002          | 2857            | 2/2003 | 4 | 100 | 60 | 0.121            | 20.7±1.2           | 7.3±0.3         |
| Plumbaginaceae   | <i>Armeria filicaulis</i><br>subsp. <i>trevanqueana</i> | 7/2002          | 1600            | 5/2003 | 5 | 50  | 35 | 0.072            | 94.8±1.7           | †               |
| Primulaceae      | <i>Primula elatior</i><br>subsp. <i>lofthousei</i>      | 8/2002          | 2073            | 4/2003 | 4 | 100 | 55 | 0.084            | 79.5±2.5           | 14.7±0.9        |
| Ranunculaceae    | <i>Delphinium nevadense</i>                             | 8/2002          | 1230            | 4/2003 | 5 | 50  | 40 | 0.138            | 96.0±1.7           | †               |
| Scrophulariaceae | <i>Chaenorhinum</i><br><i>glareosum</i>                 | 8/2002          | 3150            | 3/2003 | 4 | 100 | 60 | 0.006            | 79.3±4.7           | 12.5±0.7        |

(Table 2). Similarly, T<sub>50</sub> varied considerably across species (Table 2), ranging from 3 (*Hormathophylla spinosa*) to 35.8 (*Echinopartium boissieri*). No correlation was found between T<sub>50</sub> and germination percentage ( $P = 0.19$ ; Fig. 1).

The percentage of germination was not correlated with the altitude where the population grows ( $P = 0.74$ ), nor was there any correlation between altitude and T<sub>50</sub> values ( $P = 0.17$ ). By contrast, there was a marginally significant, negative correlation between propagule mass and germination percentage ( $r^2 = 0.15$ ,  $P = 0.056$ ; Fig. 2).

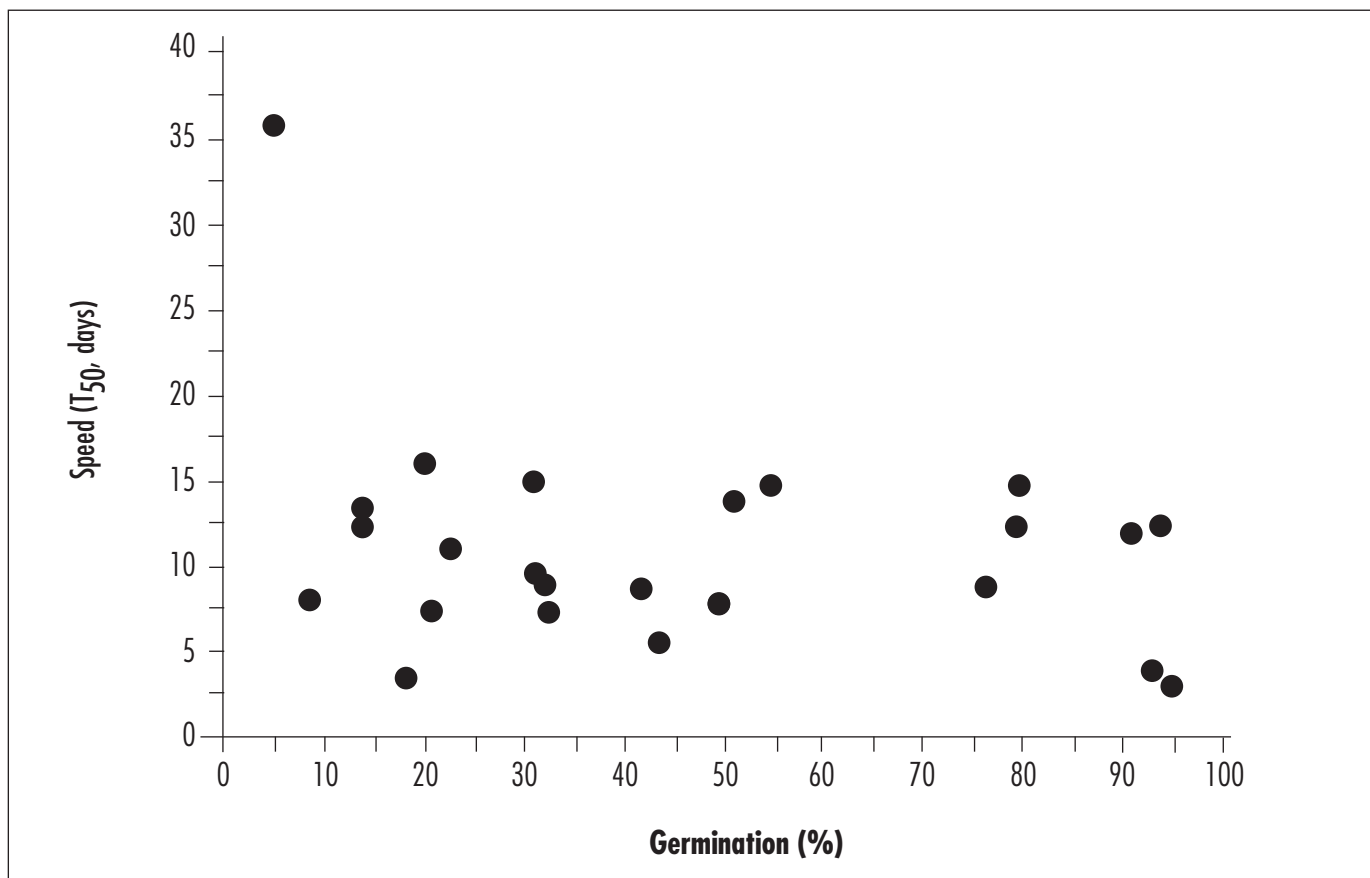
## Discussion

### *Differences in germination percentages across species*

The results reveal substantial differences in germination among species, as might be expected due to the heterogeneity of the genera and families studied. However, three main groups of taxa can be distinguished according to germination percentages. First, 10 species had low (below 5%) or null germination (Table 2). Some of these species belong to genera or families with a characteristic physiological dormancy. For instance, *Carex* species germinates better after cold stratification, and many of them even fail to germinate without chilling (SCHÜTZ & RAVE, 1999). Seeds of *Gentiana* species also need stratification for germination (i.e. *Gentiana kurroo*; RAINA & al., 2003; see also BASKIN & BASKIN, 1998, for other species of *Gentianaceae*). Seeds of most temperate *Sorbus* species are dormant at maturity and needs moist chilling to enable germination (e.g. YAGIHASHI & al., 1998; JENSEN, 2003; TAKOS & EFTHIMIOU, 2003), and similarly seeds of *Aquilegia* species also require stratification for germination (e.g. FINNERTY & al., 1992). For species closely related to *Narcissus nevadensis* (*N. longispatus* and *N. bugei*), germination values of around 10% were registered after cold stratification,

and about 50% after one year of sowing in a nursery (BLANCA & al., 1999). This suggests that *Carex camposii*, *Gentiana lutea*, *Sorbus hybrida*, *Aquilegia vulgaris* subsp. *nevadensis* and *Narcissus nevadensis* may require moist chilling to promote germination. There are still other possibilities to explain the low germination percentages in this group of species. For instance, some *Linaria* species show higher germination or emergence percentages both after chilling or coat scarification (e.g. SANER & al., 1995; STÖCKLIN & BÄUMLER, 1996; SCHWIENBACHER & ERSCHBAMER, 2002). This suggests that both physical and physiological dormancy may be operating in the dormancy of *Linaria glacialis* seeds here studied. BLISS & GOLD (1999) found a low germination percentage (7%) for seeds of the arctic species *Papaver radicum* after 40 days (thus five days more than in our experiment), but germination rose to 23% after 90 days of experiment, pointing out that the germination of species such as *P. lapeyrousianum* may require longer time. We are not aware of any information for *Arenaria nevadensis*, *Nardus stricta* or *Odontites granatensis* (or closely related species), all of these with low germination percentages in the present study. However, a cold, moist stratification would probably help to encourage their germination, as is common in many alpine and arctic species with dormancy (BASKIN & BASKIN, 1998; KÖRNER, 1999).

A second group of species can be formed with those having a germination percentage between 5 and 20% (Table 2). This is relatively low, but germination in these species is not likely to be a major problem for their management and conservation for several reasons. First, some belong to genera and/or families with a characteristic physical dormancy imposed by hard coats, as is the case of *Papilionaceae* (see BASKIN & BASKIN, 1998; LÓPEZ & al., 1999, for discussion of physical dormancy in this family). It is thus likely that high germination percentages in *Echinopartium boissieri*, *Hippocrepis prostrata*, *Anthyllis tejedensis* and *Astragalus*

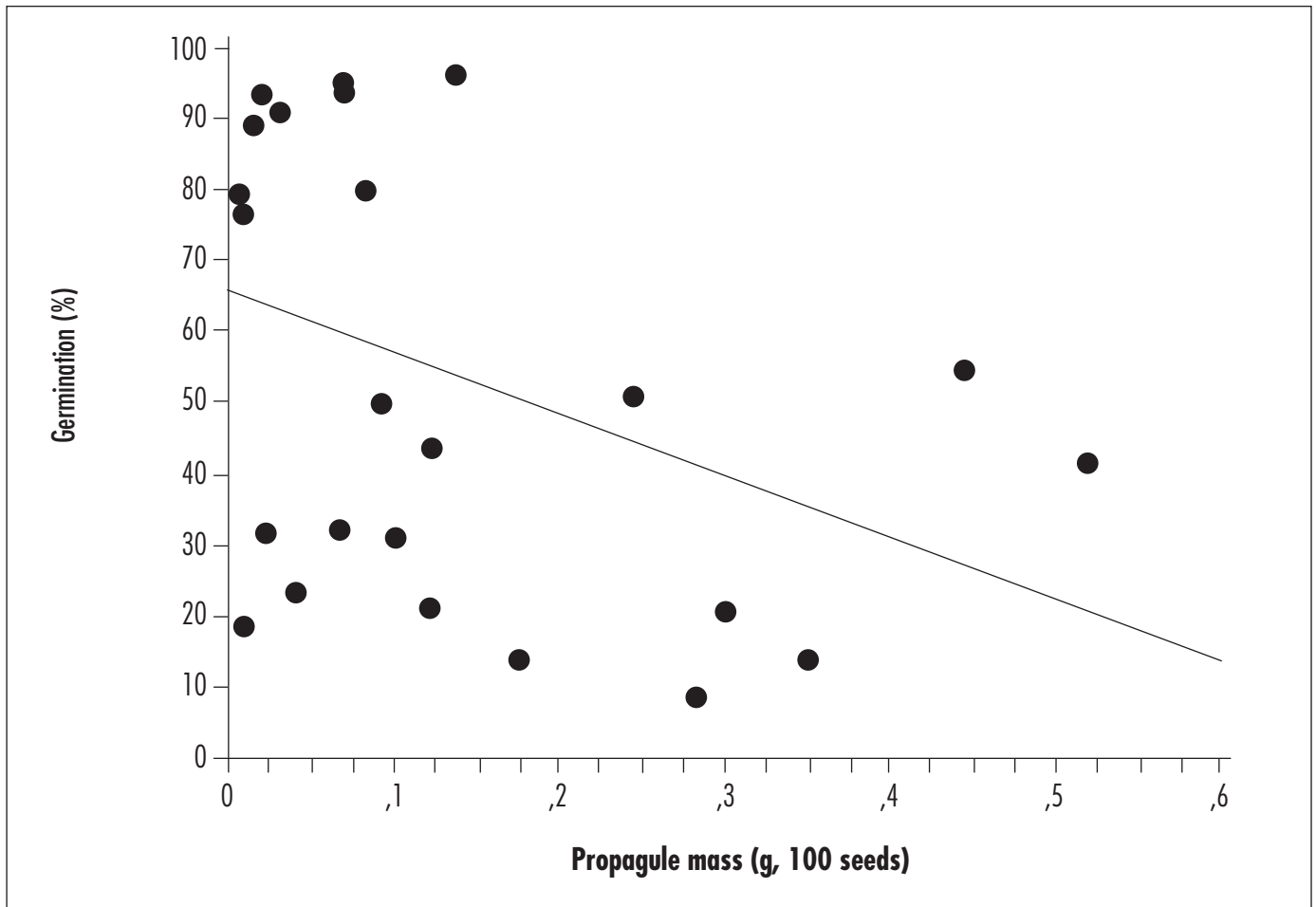


**Fig. 1.** – Scatter graph showing the relationship between germination percentage and speed of germination (estimated as the  $T_{50}$ , days) for seeds of 24 endemic and/or rare species from Sierra Nevada high mountain germinated without promoting treatments. For each species, values are the mean of the replicates used in the germination experiments (see Table 2 for details). All the species used had a germination rate of 5%.

*granatensis* could be achieved after coat scarification with abrasive methods, either sulphuric acid or sandpaper (see APARICIO & GUISANDE, 1997; IBÁÑEZ & PASSERA, 1997; LÓPEZ & al., 1999 for increased germination after coat scarification in related species; and ANGOSTO & MATILLA, 1993 for similar results with *A. granatensis*). Physical dormancy imposed by coats is also characteristic in *Geraniaceae* (BASKIN & BASKIN, 1998; MEISERT, 2002), suggesting that the germination of *Erodium boissieri* (14%) could be easily promoted. The germination percentage for *Allium schoenoprasum* (14%) was similar to that reported by GIMÉNEZ-BENAVIDES & al. (2005) (seeds from central Spain) and close to values around 20% reported by SPECHT & KELLER (1997), supporting the idea that the populations from Sierra Nevada have no particular impediments for germination. In addition, germination of this species was boosted by cold-wet stratification (up to 98%; GIMÉNEZ-

BENAVIDES & al., 2005). *Thymus serpylloides* registered 18% germination, which is below the commonly high values of germination in other *Thymus* species; for instance, *T. pulegioides* ca. 60% (WIERZBICKA & OBIDZINSKA, 1998), *T. loscosii*, *T. mastichina*, *T. vulgaris* and *T. zygis*, above 70% (ALBERT & al., 2002; GONZÁLEZ-BENITO & al., 2004). This endemic species, however, is abundant in Sierra Nevada, and collection of an amount of seeds large enough to supply nursery and conservation demands is not a problem.

Finally, there is a third group of 21 taxa in which the germination percentage was above 20%, and even more, 15 out of the 37 species studied had a germination percentage above 40%, many actually above 75% (Table 2). These species therefore need no particular treatments for their germination, and may be propagated soon after seed collection. This should be taken into account in order to optimise time and efforts in



**Fig. 2.** – Correlation between propagule mass and germination percentage for 25 endemic and/or rare species from Sierra Nevada high mountain germinated without promoting treatments. See Table 2 for species identity and propagule mass. Germination values are the mean of the replicates used in the experiments (see Table 2 for details). All the species used had a germination rate of 5%.

conservation and restoration programs. For instances, *Primula* species are commonly cold stratified before germination (MCKEE & RICHARDS, 1998; WATANABE & al., 2003; CERABOLINI & al., 2004), including the taxa *Primula elatior* (JACQUEMYN & al., 2001), closely related to *P. elatior* subsp. *lofthousei* studied here. However, our results reflect a germination percentage of 79% without chilling, even above the values of around 55% found by JACQUEMYN & al. (2001) after 8 weeks of moist chilling (see also SHIMONO & WASHITANI, 2004, for 20-60% germination without chilling in *Primula modesta*). The endemic *Plantago nivalis* showed the lowest germination percentage in this group of species (21%), but its relatively high abundance guarantees seeds for propagation and conservation. Some endangered species (e.g. *Arabis margaritae*, *Armeria fillicaulis* subsp. *trevenqueana*, *Artemisia*

*umbelliformis* or *Moehringia fontqueri*) have the advantage of a high germination percentage, which may compensate the scant seed material available. Members from the *Geraniaceae*, *Labiatae* and *Papilionaceae* may likely increase their germination percentage after coat stratification (see above), although in any case their germination may be high enough. Overall, this group of taxa with high germination percentage was dominated by members from *Compositae* and *Cruciferae*.

#### *High germination percentage in alpine species*

The overall high germination percentage in the species here studied (15 out of the 37 taxa with above 40% germination, see above) is somewhat surprising given the generally assumed requirements of cold stratification for germination of seeds

from alpine habitats (e.g. BASKIN & BASKIN, 1998; KÖRNER, 1999). This may be explained by two non-exclusive possibilities. First, seeds from high mountain species may not require dormancy (or have dormancy requirements lower than populations from lower altitudes) given that germination will be blocked by the low temperatures registered in the site after seed dispersal, which will prevent germination until the next growing season (KÖRNER, 1999; JENSEN, 2003; FENNER & THOMPSON, 2005). Second, there is an overrepresentation of *Cruciferae* and *Compositae* species in this group of taxa, all of them with a high germination percentage that might be characteristic of the family, or at least of the genera studied here (see below), creating a possible phylogenetic bias. In any case, high germination percentages were found across families and genera (see Table 2), implying that seeds from the Mediterranean high mountain are in many cases physiologically prepared for germination just or soon after dispersal (see GIMÉNEZ-BENAVIDES & al. (2005) for similar results with orophilous species from central Spain).

#### *Patterns of germination across species*

The analysis of the relationship between germination percentage, speed of germination and altitude indicates some trends of ecological and management interest. First, the lack of a relationship between  $T_{50}$  and germination percentage (Fig. 1) support the idea that the speed of germination is an intrinsic characteristic for each species. A low germination speed is therefore not indicative of low germination ability, and even seeds with a low initial germination may finally reach high percentages (e.g. BLISS & GOLD, 1999). Second, there was a weak but significant negative correlation between germination percentage and propagule mass, which could be used as a preliminary screening to plan conservation efforts (e.g. preferential selection of species with higher seed mass as those putatively showing more problems for germination). In any case, this trend was too weak to postulate generalizations, and further studies with a wider pool of alpine species are necessary to draw conclusions (a phylogenetic effect related to the abundance of fast germinating *Compositae* and *Cruciferae* might be present; see below).

Germination patterns across species were presumably determined by phylogenetic relationship among species, at least in some cases. There are clearly some families where germination was consistently high, mostly *Compositae* and *Cruciferae*. Species of *Papilionaceae*, *Labiatae* and *Geraniaceae* showed lower germination percentages, but germination in these species is likely to be promoted with easy and fast treatments (see above). These results are of great interest for conservation plans of the Sierra Nevada, endemic and/or endangered flora: more than 30% of the whole flora and a similar percentage of the threatened flora (40 taxa of the 125 threatened

species, according to BLANCA, 2002) belong to these five families. Thus, although the germination behaviour of any species may not be ascertained solely by its phylogeny and may in fact be determined by other traits related to the natural history of the species (e.g. BASKIN & BASKIN, 2003), the results found here support the contention that, in the alpine flora of Sierra Nevada, conservation efforts related to seed germination may be applied to members of other families if a choice must be made.

#### *Summary of guidelines proposed*

In summary, our results demonstrate that the germination percentages of these species from Sierra Nevada vary widely but may reach high values in a considerable number of species. Taxa from *Compositae*, *Cruciferae*, *Geraniaceae*, *Labiatae* and *Papilionaceae* are prone to easy germination. Major efforts should be addressed to those species which, in addition to low germination percentages, have a critical conservation status (critically endangered, endangered, or vulnerable, according IUCN 2001 categories, see Table 1), which in this set of 37 taxa are mainly *Aquilegia vulgaris* subsp. *nevadensis*, *Arenaria nevadensis*, *Carex camposii*, *Gentiana lutea*, *Linaria glacialis*, *Narcissus nevadensis*, *Odontites granatensis*, *Papaver lapeyrousianum* and *Sorbus hybrida*, most of them endemic of the area.

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#### **References**

- ALBERT, M. J., J. M. IRIONDO & F. PÉREZ-GARCÍA (2002). Effects of temperature and pretreatments on seed germination of nine semi-arid species from NE Spain. *Israel J. Pl. Sci.* 50: 103-112.
- ANGOSTO, T. & A. J. MATILLA (1993). Germination, seed-coat structure and protein patterns of seeds from *Adenocarpus decorticans* and *Astragalus granatensis* growing at different altitudes. *Seed Sci. Technol.* 21: 317-326.
- APARICIO, A. & R. GUISANDE (1997). Replenishment of the endangered *Echinospartum algibicum* (Genisteae, Fabaceae) from the soil seed bank. *Biol. Conservation* 81: 267-273.

- BAÑARES, A., G. BLANCA, J. GÜEMES, J. C. MORENO & S. ORTIZ (ed.) (2003). *Atlas y libro rojo de la flora vascular amenazada de España*. Ciutat.
- BASKIN, C. C. & J. H. BASKIN (1998). *Seeds - Ecology, biogeography and evolution of dormancy and germination*. Academic Press.
- BASKIN, C. C. & J. H. BASKIN (2003). Biogeography, and phylogenetic relationships of seed dormancy. In: SMITH, R. D., J. B. DICKIE, S. H. LININGTON, H. W. PRITCHARD & R. J. PROBERT (ed.), *Seed conservation: turning science into practice*: 519-545. The Royal Botanic Gardens, Kew.
- BLANCA, G. (ed.) (2002). *Flora amenazada y endémica de Sierra Nevada*. Consejería de Medio Ambiente, Junta de Andalucía.
- BLANCA, G., B. CABEZUDO, E. HERNÁNDEZ-BERMEJO, C. M. HERRERA, J. MOLERO-MESA, J. MUÑOZ, & B. VALDÉS (1999). *Libro Rojo de la Flora Silvestre Amenazada de Andalucía. Tomo I: Especies en Peligro de Extinción*. Consejería de Medio Ambiente, Junta de Andalucía.
- BLANCA, G., M. CUETO, M. J. MARTÍNEZ-LIROLA, & J. MOLERO (1998). Threatened vascular flora of Sierra Nevada (Southern Spain). *Biol. Conservation* 85: 269-285.
- BLISS, L. C. (1971). Arctic and alpine plant life cycles. *Annual Rev. Ecol. Syst.* 2: 405-438.
- BLISS, L. C. & W. G. GOLD (1999). Vascular plant reproduction, establishment, and growth and the effects of cryptogamic crusts within a polar desert ecosystem, Devon Island, N.W.T., Canada. *Canad. J. Bot.* 77: 623-636.
- BLONDEL, J. & J. ARONSON (1999). *Biology and wildlife of the Mediterranean region*. Oxford university Press.
- CABEZUDO, B., S. TALAVERA, G. BLANCA, C. SALAZAR, M. CUETO, B. VALDÉS, E. HERNÁNDEZ-BERMEJO & C. M. HERRERA (2005). *Lista roja de la flora vascular de Andalucía*. Consejería de Medio Ambiente, Junta de Andalucía.
- CERABOLINI, B., R. DE ANDREIS, R. M. CERIANI, S. PIERCE & B. RAIMONDI (2004). Seed germination and conservation of endangered species from the Italian Alps: *Physoplexis comosa* and *Primula glaucescens*. *Biol. Conservation* 117: 351-356.
- DOMÍNGUEZ, F., D. GALICIA, J. L. MORENO-RIVERO, J. C. MORENO-SÁIZ & H. SAÍNZ-OLLERO (1996). Threatened plants in Peninsular and Balearic Spain: a report based on the EU Habitats Directive. *Biol. Conservation* 76: 123-133.
- ESCUADERO, A. & J. M. IRIONDO (2003). Restauración de poblaciones de especies amenazadas. In: REY, J. M., T. ESPIGARES & J. M. NICOLAU (ed.), *Restauración de ecosistemas mediterráneos*: 113-139. Universidad de Alcalá.
- FENNER, M. & K. THOMPSON (2005). *The ecology of seeds*. Cambridge University Press.
- FINNERTY, T. L., J. M. ZAJICEK & M. A. HUSSEY (1992). Use of seed priming to bypass stratification requirements of three *Aquilegia* species. *HortScience* 27: 310-313.
- GASTON, K. J. (1994). *Rarity*. Chapman & Hall.
- GIMÉNEZ-BENAVIDES, L., A. ESCUDERO & F. PÉREZ-GARCÍA (2005). Seed germination of high mountain Mediterranean species: altitudinal, interpopulation and interannual variability. *Ecol. Res.* 20: 433-444.
- GÓMEZ, A., A. PALACIOS, M. RAMOS, L. M. TANARRO, L. SCHULTE & F. SALVADOR (2001). Location of Permafrost in Marginal Regions: Corral del Veleta, Sierra Nevada, Spain. *Permafrost & Periglacial Process* 12: 93-110.
- GÓMEZ, A. (2002). *Geomorphological map of Sierra Nevada; glacial a periglacial geomorphology*. Consejería de Medio Ambiente. Junta de Andalucía.
- GONZÁLEZ-BENITO, M. E., M. J. ALBERT, J. M. IRIONDO, F. VARELA & F. PÉREZ-GARCÍA (2004). Seed germination of four thyme species after short-term storage at low temperatures at several moisture contents. *Seed Sci. Technol.* 32: 247-254.
- GREUTER, W. (1991). Botanical diversity, endemism, rarity, and extinction in the Mediateranean area: an analysis based on the published volumes of Med-Checklist. *Bot. Chron.* 10: 63-79.
- HENNINGBERG, K. J. & H. BRUELHEIDE (2003). Ecological investigations on the northern distribution range of *Hippocrepis comosa* L. in Germany. *Pl. Ecol.* 166: 167-188.
- HEYWOOD, V. (1995). The mediterranean flora in the context of world biodiversity. *Ecol. Medit.* 21: 11-18.
- IBÁÑEZ, A. N. & C. B. PASSERA (1997). Factors affecting the germination of albaida (*Anthyllis cytisoides* L.), a forage legume of the Mediterranean coast. *J. Arid Environm.* 35: 225-231.
- IUCN (2001). *IUCN Red List Categories and Criteria: Version 3.1*. IUCN Council.
- JACQUEMYN, H., R. BRYNS & M. HERMY (2001). Within and between plant variation in seed number, seed mass and germinability of *Primula elatior*: effect of population size. *Pl. Biol. (Stuttgart)* 3: 561-568.
- JENSEN, M. (2003). Effect of seed maturity and pretreatment on dormancy and germination of *Sorbus mougeotii* seeds. *Scand. J. Forest Res.* 18: 479-486.
- KÖRNER, C. (1999). *Alpine plant life. Functional plant ecology of high mountains ecosystems*. Springer.
- LÓPEZ, J., J. A. DEVESA, T. RUIZ & A. ORTEGA-OLIVENCIA (1999). Seed germination in Genistaceae (Fabaceae) from South-West Spain. *Phyton (Horn)* 39: 107-129.
- LORITE, J., F. B. NAVARRO & F. VALLE (2006). Estimation of threatened orophytic flora and priority of its conservation in the Baetic range (S. Spain). *Pl. Biosyst.* 141: 1-14.
- McKEE, J. & A. J. RICHARDS (1998). The effect of temperature on reproduction in five *Primula* species. *Ann. Bot. (Oxford)* 82: 359-374.
- MÉDAIL, F. & P. QUÉZEL (1999). Biodiversity hotspots in the Mediterranean Basin: setting global conservation priorities. *Conservation Biol.* 13: 1510-1513.
- MEISERT, A. (2002). Physical dormancy in Geraniaceae seeds. *Seed Sci. Res.* 12: 121-128.

- MORENO-SÁIZ, J. C., F. DOMÍNGUEZ & H. SAÍNZ-OLLERO (2003). Recent progress in conservation of threatened Spanish vascular flora: a critical review. *Biol. Conservation* 113: 419-431.
- PEÑAS, J., F. PÉREZ-GARCÍA & J. F. MOTA (2005). Patterns of endemic plants and biogeography of the Baetic high mountains (south Spain). *Acta Bot. Gallica* 152: 247-360.
- RAINA, R., M. C. BEHERA, R. CHAND & Y. SHARMA (2003). Reproductive biology of *Gentiana kurroo* Royle. *Curr. Sci.* 85: 667-670.
- SANER, M. A., D. R. CLEMENTS, M. R. HALL, D. J. DOOHAN & C. W. CROMPTON (1995). The biology of Canadian weeds. 105. *Linaria vulgaris* Mill. *Canadian J. Pl. Sci.* 75: 525-537.
- SCHÜTZ, W. & G. RAVE (1999). The effect of cold stratification and light on the seed germination of temperate sedges (*Carex*) from various habitats and implications for regenerative strategies. *Pl. Ecol.* 144: 215-230.
- SCHWIENBACHER, E. & B. ERSCHBAMER (2002). Longevity of seeds in a glacier foreland of the Central Alps – a burial experiment. *Bull. Geobot. Inst. E. T. H.* 68: 63-71.
- SHIMONO, A. & I. WASHITANI (2004). Seedling emergence patterns and dormancy/germination physiology of *Primula modesta* in a sub-alpine region. *Ecol. Res.* 19: 541-551.
- SPECHT, C. E. & E. R. J. KELLER (1997). Temperature requirements for seed germination in species of the genus *Allium* L. *Genet. Resources Crop Evol.* 44: 509-517.
- STÖCKLIN, J. & E. BÄUMLER (1996). Seed rain, seedling establishment and clonal growth strategies on a glacier foreland. *J. Veg. Sci.* 7: 45-56.
- TAKOS, I. A. & G. S. EFTHIMIOU (2003). Germination results on dormant seeds of fifteen tree species autumn sown in a northern Greek nursery. *Silvae Genet.* 52: 67-71.
- THOMPSON, J. D. (2005). *Plant evolution in the Mediterranean*. Oxford University Press.
- WATANABE, A., K. GOKA, & I. WASHITANI (2003). Effects of population spatial structure on the quantity and quality of seeds set by *Primula sieboldii* (Primulaceae). *Pl. Spec. Biol.* 18: 107-121.
- WIERZBICKA, M. & J. OBIDZINSKA (1998). The effect of lead on seed imbibition and germination in different plant species. *Pl. Sci. (Elsevier)* 137: 155-171.
- YAGIHASHI, T., M. HAYASHIDA & T. MIYAMOTO (1998). Effects of bird ingestion on seed germination of *Sorbus commixta*. *Oecologia* 114: 209-212.