Alpine environments occur worldwide above the maximum elevation at which trees can grow [@RN4750]. These treeless habitats are characterized by low temperatures, strong winds, unstable substrates, and short growing seasons [@RN2392]. Although some alpine plants may reproduce clonally, sexual reproduction is the main strategy to maintain genetic diversity and to colonize suitable habitats in response to environmental changes. The short reproductive season of alpine habitats constrains the phenological timing of flowering, mating, seed development and seed dispersal. Further, dispersed seeds will need to germinate in the most appropriate period to ensure survival of seedlings under extreme environmental stress [@RN4714; @RN2868; @RN4717]. The physiological process of seed germination is therefore an essential life stage that must be timed to occur when the environment is favourable for subsequent seedling survival and growth [@RN4691]. In alpine habitats, germination by seeds will be the final test for plant populations to cope with climate change and to determine whether they will persist or will go into extinction.

Natural selection should favour seed germination requirements reducing the probability of facing environmental conditions that are not appropriate for seedlings [@RN3375]. The main physiological drivers of germination, water availability and temperature [@RN3368], are also the main ecological signals regulated by climatic variation. Many plant species have further developed seed dormancy, by which germination is prevented during periods that are only ephemerally favourable (but with appropriate water and temperature conditions), ensuring germination in the right season [@RN3214]. Different degrees of dormancy also ensure the distribution of offspring emergence across time, a bet-hedge effect against unpredictable environments [@RN3065]. Other germination cues, such as the response to light [@RN4656] and alternating temperatures [@RN1380], allow for a fine-scale detection of germination niches and safe sites [@RN4719]. Given the heterogeneity of alpine climates and species lineages adapted to different regions, and the wealth of local studies on alpine seed ecology (reviewed in the following paragraphs), a current challenge is to synthesize, at the global level, the seed germination spectrum of alpine plants [@RN4655]. Such a global synthesis would allow us to (i) better understand how climatic changes will affect alpine plant diversity; and (ii) manage and eventually counteract regression of restricted alpine species.

Early studies on the germination ecology of alpine plants demonstrated that, in most species, recently dispersed (fresh) seeds require relatively high temperatures for germination [@RN3258; @RN3213; @RN4712]. High-temperature germination has been considered as an adaptation to prevent seed germination at the timing of seed dispersal (autumn) when temperatures are low and there is a high risk of frost [@RN3393]. Indeed, germination of alpine seeds tends to occur after winter, mainly in early summer [@RN2392; @RN2382]. In recent times, an increasing number of studies highlighted that fresh seeds of alpine plants also germinate at cool incubation temperatures or during cold stratification treatments [@RN2943; @RN3285; @RN2371; @RN4713]. This low-temperature germination could be an adaptation to germinate under snow or during snowmelt, which could presumably allow seedlings to develop a deeper root system before topsoil desiccation in summer [@RN4720], or to attain an optimal size for overwintering [@RN4712]. The main question here is the generality of warm-cued germination in alpine environments across micro-climatic niches.

Many alpine species have also been described as having deep physiological dormancy [@RN2943; @RN3703; @RN3214]. Dormancy in fresh seeds would prevent precocious germination under autumn cold conditions, when appropriate soil moisture and temperature are not likely to persist for more than a few weeks or days [@RN3330]. A requirement for cold stratification to break dormancy would allow seeds to sense the snow season, thereby postponing germination to a better period for seedling survival and development. Thus, it can be expected that a cold stratification period is a common requirement for seed germination in alpine plants. Nonetheless, an early review [@RN3213] suggested that cold stratification was not a requirement for the seed germination of several alpine species from different mountains in the USA, an idea that was repeated in subsequent investigations [@RN1484; @RN2995; @RN4721]. More recently, research on Australian alpine plant found that a cold stratification period only increased germination in half of the species tested [@RN3703; @RN3285]. In contrast, cold stratification increased seed germination over a range of temperatures in most of the plant species studied in the alpine zone of Japan [@RN707]. Along an elevational gradient in the central Chilean Andes, cold stratification was an important requirement for seed germination in species from lower elevations, while species from higher sites did not germinate after cold stratification [@RN4713]. Therefore, how important cold stratification is for seed germination in alpine plant species remains unclear.

Besides germination temperature and patterns of dormancy, the response of alpine seeds to light and alternating temperatures can provide further information on their capacity to detect fine-scale environmental cues. The preference of alpine species to germinate in light [@RN4730; @RN4729] could favour the creation of a persistent soil seed bank [@RN4718], which is advantageous in temporally and spatially unpredictable alpine environments [@RN4731; @RN4732]. Indeed, alpine soil seed banks are more frequent than it was previously supposed, as it has been consistently reported in the last years [@RN4718](Venn & Morgan 2010; review). Nevertheless, other alpine species seem to prefer dark germination (Schwienbacher *et al.*, [2011](#ref-RN2943)), which may be interpreted as a strategy for detecting safe sites in rock crevices (Arslan *et al.*, [2011](#ref-RN3008)). Regarding alternating temperatures, a study of 445 species from the Qinhai-Tibet plateau found that species from high elevation alpine meadows did not show a significant response to diurnal temperature oscillations (Liu *et al.*, [2013](#ref-RN3376)). This is intriguing given that alpine habitats typically have a strong day-night climatic variation during the growing season. Although some germination studies report laboratory experiments conducted for constant and alternate temperatures, or light/dark conditions, they are very much case-dependent, therefore it is difficult to evaluate whether these factors have a consistent pattern across global alpine ecosystems.

Here, we collect primary germination data from eight alpine regions and four continents to investigate the germination response of alpine plant species to key environmental factors. We used raw data obtained from laboratory experiments to test the response of seed germination to temperature, cold stratification, light and alternate temperatures, and their relationships with seed mass, dormancy classes and embryo: endosperm ratio obtained from bibliographic data. Our central question was to investigate the seed germination spectrum of alpine plants to test the consistency of general assumptions about seed germination ecology at the global scale. To understand the ecological constrains of our meta-analysis on alpine species pools, we further analyze how the germination responses differ between strict alpine species which mostly occur above the treeline, and generalist species that also occur at lower altitudes.