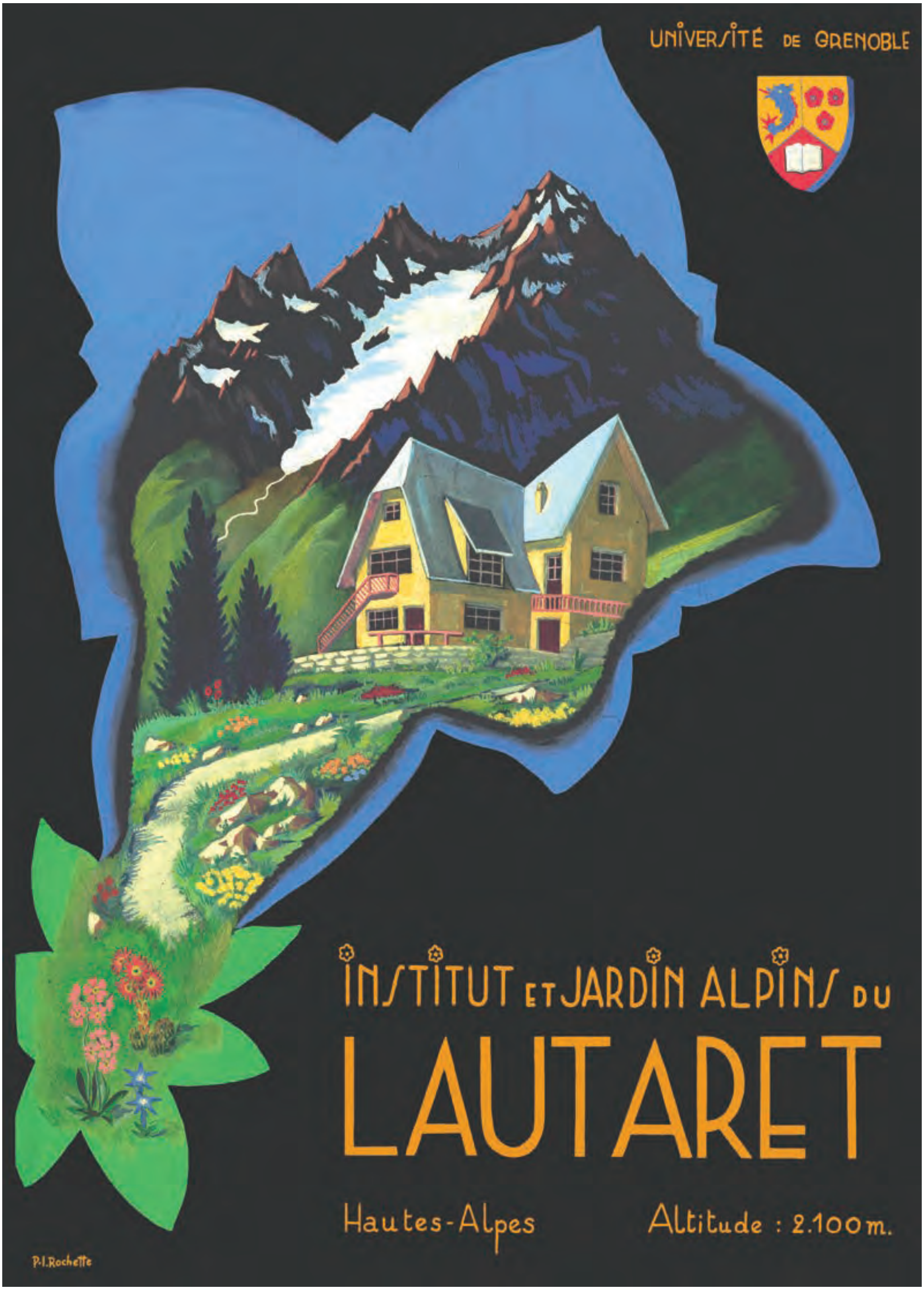
The Lautaret Alpine Botanical Garden

Guidebook

Serge Aubert



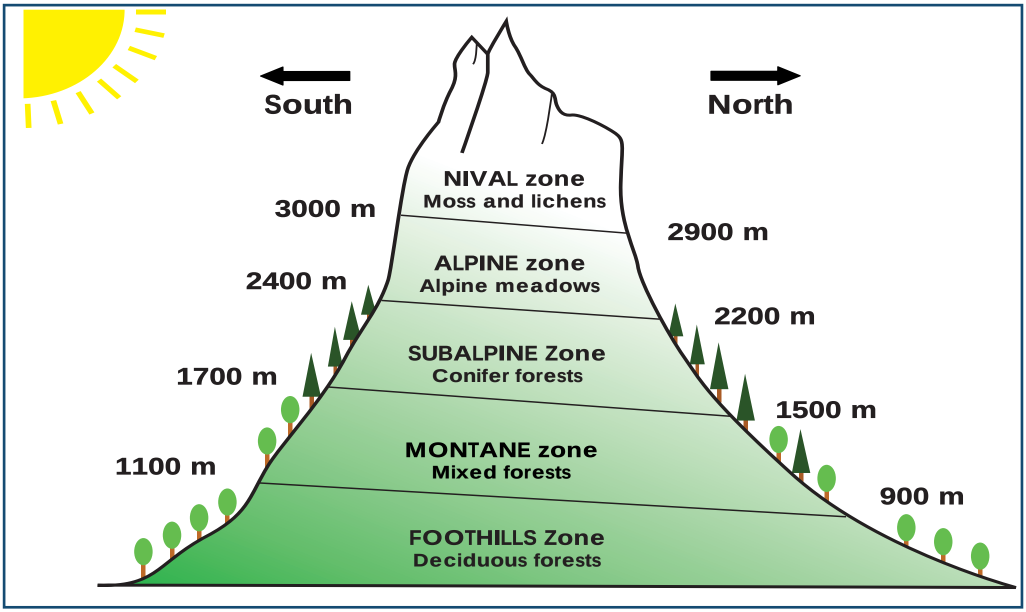
Poster showing the Lautaret Alpine Garden, inside a Gentian sketched in the 1960s by Paul Rochette (1923-1989); a teacher-researcher and botanist at the University of Grenoble.

Outline

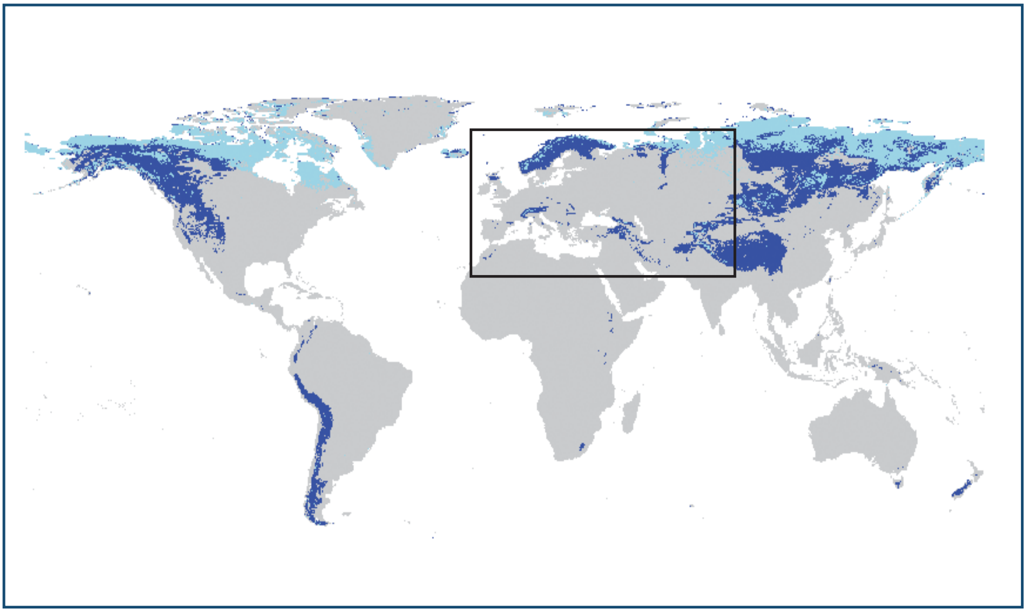
Alpine flora

What is an alpine plant?

It is important to clearly define exactly what the term "alpine" means. It is often thought to mean "from the Alps", referring strictly to the European Alps, but as used in this guide, it applies to the zone and plants found above the natural (as opposed to man-made) treeline in each particular region of the globe. In the French Alps for example, the alpine zone starts on average at 2300 metres altitude. In tropical and equatorial regions, this threshold is situated at around 4000 metres, whereas in polar regions it starts at sea level (Arctic, Spitzbergen) and is referred to as arctic tundra. These variations in altitude at different latitudes, depend largely on temperature.

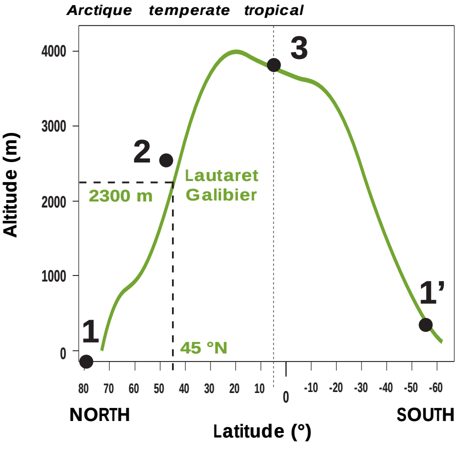


Altitudinal zonation of vegetation in the Alps in the Briançon region. The south-facing slopes are hotter, which explains why the vegetation zones are higher on this side. They have often undergone centuries of deforestation for agricultural purposes (pastures, terrace farming).



Representation of alpine zones (dark blue) and arctic tundra (light blue) across the globe, i.e. zones located above the natural treeline. This map was produced using the relationship between altitude and latitude (graph below) and a relief map of the world (produced by Ph. Choler). The mountain ranges within the rectangle are detailed on p. 37.

In alpine zones, living conditions become harsher with higher elevation which leads to lower temperatures, increases in UV radiation and wind speeds, etc. The biological form of a "tree" (a woody plant of over 2 m in height) is incompatible with the low temperatures and the brevity of the growing season found in this zone. With the exception of screes and rocky areas, the dominant vegetation types are meadows and occasionally low-growing shrubs.



The graph shows the altitudinal thresholds for alpine zones according to their latitude (based on Körner 1998 Oecologia 115: 445-459). It shows that beyond 75° North and 65° South, arctic and alpine plants grow at sea level. The following numbers correspond to some examples of typical alpine vegetation types growing at different latitudes. Note the differences in altitude.

Arctic meadows and heaths at Spitzbergen in Norway (alt: 50 m - lat: 80°N, point 1 on the graph on page 33), in the Longyearbyen region. The prostrate shrub which is dominant, together with herbaceous plants, is **Cassiope tetragona** *of the Ericaceae family.*

*An alpine meadow of Bellardi bog sedge (***Kobresia myosuroides***, Cyperaceae family) in the region of the Col du Galibier (alt: 2,800 m - lat: 45°N, point 2 on the graph page 33). This type of meadow is characteristic of windswept ridges where the snow is blown away by the wind and no longer protects plants during severe winter temperatures. In the background, the Meije massif (3987 m).*

Paramos growing in northern Ecuador (alt: 4,000 m - lat: 0.7°N, point 3 on the graph on page 33). These vegetation types, found in the Northern Andes, are characterised by rosette-forming Asteraceae, here **Espeletia pycnophylla** *ssp* **angelensis***. This plant known as a pachycaul (see below) growns only a few centimetres a year but can reach a height of 6-7 metres.*

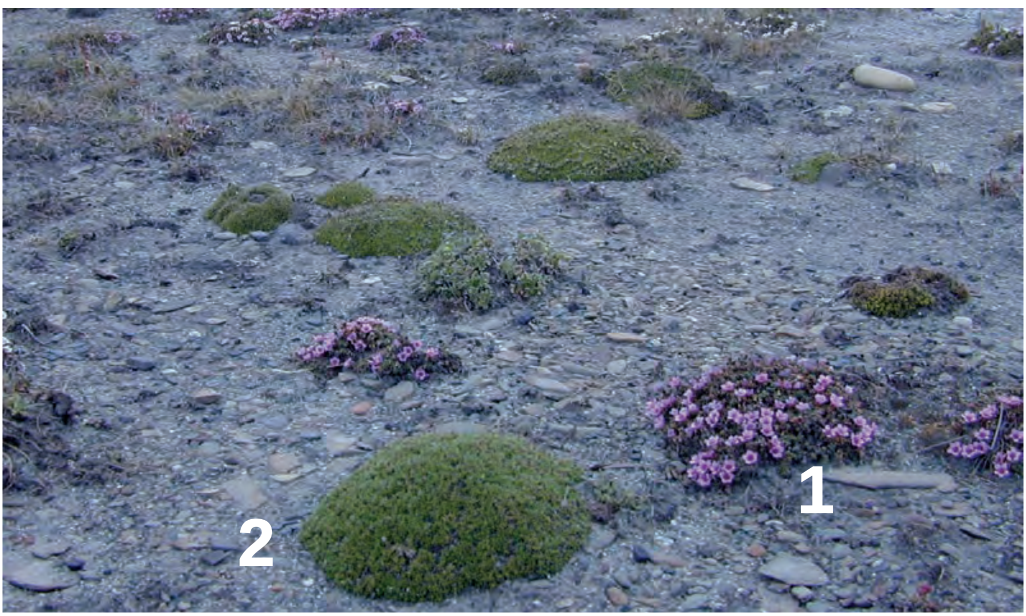
An example of vegetation dominated by thorny cushions (here **Acantholimon** *sp, Plumbaginaceae family) near Mt Albruz in the Caucasus mountain range in Iran (subalpine zone, around 2500 m). These formations are characteristic of cold, dry mountains, notably the Sierra Nevada in Spain, the Atlas mountains in Morocco, and the mountains of Iran and Afghanistan (photo: M. van der Brink).*

*These Engelmann spruce (*Picea engelmanii*, at around 3000 m in the Rocky Mountains in Colorado) show the impact of exposure to the constant high winds at altitude which cause unilateral branch growth in the direction of the wind. Trees such as these are known as "flag trees" (here the prevailing wind comes from the right).*

At higher altitudes, approaching the upper limits of tree growth, trees become deformed and stunted by the constant physical impact of the wind and the snow, until the only forms found are prostrate shrubs just tens of centimetres high. Their small size protects them from damage and means they are protected from winter freezing by snow cover. Interestingly, this is not a genetic characteristic, and when these plants are grown at lower altitudes they grow normally into full sized trees.

The boundary between the subalpine (forests of Nothofagus pumilio *(lenga beech, 1) and alpine zones, dominated by cushion species (in the foreground, the rounded green forms of the Apiaceae* Bolax gummifera, *2)(alt: 500 m - lat: 55°S, point 1' on the graph on page 33). In the background is the town of Ushuaia (Argentina), the Beagle canal and Navarino Island (Chile). The uppermost trees are deformed and just tens of centimetres high (the so-called "Krumholtz growth form").*

The locations of some of the mountain ranges represented in the Garden (see map p. 33): Atlas, Sierra Nevada, Pyrenees, Alps, Apennines, Balkans, Carpathians, Caucasus, and the Pontic mountains. Depending on the latitude and climate, the alpine zone starts at 500 m (the mountains of Norway), 2000-2300 m (Alps) or even above 3000 m in the Moroccan Atlas mountains and the mountains of Iran.



Purple mountain saxifrage (**Saxifraga oppositifolia**, Saxifragaceae, 1) and moss campion (**Silene acaulis**, Caryophyllaceae, 2) are cushion plants which grow at sea level in the arctic (here in Spitzbergen, at 79°N latitude) and at around 2700 m on the Galibier ridges. Such species are known as arctic-alpine species (see below). Purple mountain saxifrage holds the record for growth at high altitudes having been found growing at 4500 m in the Swiss Alps.

Some species of willow have adapted to the harsh living conditions found in alpine and arctic zones. They grow low to the ground and are just a few centimetres high. Due to the brevity of the growing season, these willows grow just a few milimetres a year. Even so, some individuals, such as the *Salix serpyllifolia* in the Alpine Garden, with a diameter of over 1 metre are actually several hundred years old. They are genuine prostrate bonsais: in these cases we are no longer dealing with trees but small low-growing shrubs with a chamaephyte growth form whose dwarfism is a fixed genetic characteristic. There are several other species of willow found in the Alps, notably in the Lautaret-Galibier region, these include dwarf willow (*Salix herbacea*) found in snow beds, and the net-leaved willow (*Salix reticulata*) on snowy slopes. We find the Polar willow (*Salix polaris*) in arctic tundra.

In the foreground is Salix serpillyfolia *(Salicaceae family), photographed in the Alpine Garden. This species, which normally grows in the alpine zone at over 2500 m altitude, grows prostrate even when grown at altitudes (here 2100 m) at which trees can grow normally (subalpine level). This characteristic is genetically fixed.*

The dwarf willow, Salix herbacea *(here at Galibier, 2700 m altitude) is often found in snow beds, locations such as troughs or depressions in which snow accumulates, favouring a long duration of snow cover* *(p. 115).*

Net-leaved willow, Salix reticulata *(here at Galibier, 2600 m) is typically found in low-lying heaths found on slopes with a long duration of snow cover in the alpine zone.*

Polar willow, Salix polaris *(here at Spitzbergen, 50 m) is a species found in abundance in circumpolar arctic tundra. It dominates in the final stages of succession in areas freed up by glacier retreat.*

Around the garden: Why are there no trees at the Col du Lautaret

Although the Col du Lautaret is located at just 2056 m altitude, the landscape contains almost no trees. In this case it is not the climate but human actions which are to blame for the lack of forest, as the area around the pass has been intensively deforested to create grazing land and to obtain wood for building and heating purposes. Indeed, fossilised tree imprints have been found around the Col du Lautaret. Recent recolonisation by Larch forests and the successful planting of a variety of trees in the Alpine Garden clearly show that local conditions are favourable to succesful tree growth. In the background is the Pics du Combeynot National Nature Reserve (Ecrins National Park).

Alpine plant diversity

Like all living organisms, alpine plants are the result of biological evolution. Their growth forms, life histories and reproduction are adapted to high altitude conditions and have been selected over time. As each habitat or ecological niche is comprised of a unique combination of constraints, the "adaptive solutions" used to colonise these habitats are also extremely varied. Plant life is found in a whole host of alpine environments: scree, rocky ledges, grasslands and meadows, snow beds and marshes. The diversity of alpine flora is primarily determined by the diversity of these habitats.

Androsace helvetica ***(left) is a Primulaceae which has a globular form which helps to limit heat and water loss (see p.86). It colonises rocky crevices up to over 3000 m. On the right, Cobweb house-leek (*****Sempervivum arachnoideum*****) shows a remarkable ability to thrive despite the lack of water and nutrients present in the bare rockfaces it colonises. It is part of the Crassulaceae family, which contains a large number of succulent plants adapted to very dry conditions.***

The stemless gentian,* Gentiana acaulis, *is a species found in siliceous grasslands, photographed here on the road to the Col du Galibier. To the untrained eye it is easily confused with the "Clusisus" gentian (next page) which grows in calcareous grasslands.

One mechanism by which new species appear can be explained as follows. A population may become separated either geographically (for example by being present on two different mountains) or ecologically (by being present in two different environments). If these two parts of a population become reproductively isolated (they become too distant or have different flowering times), each part could then evolve independently i.e. acquiring their own morphological, physiological and genetic characteristics. It is probably this mechanism that explains the origin of vicariance,the existence of related species in locations which are geographically or ecologically different, as seen with species of gentians or saxifrages.

The species concept

A species is defined as a set of individuals presenting the same specific morphological characteristics and which are capable of engendering fertile offspring.

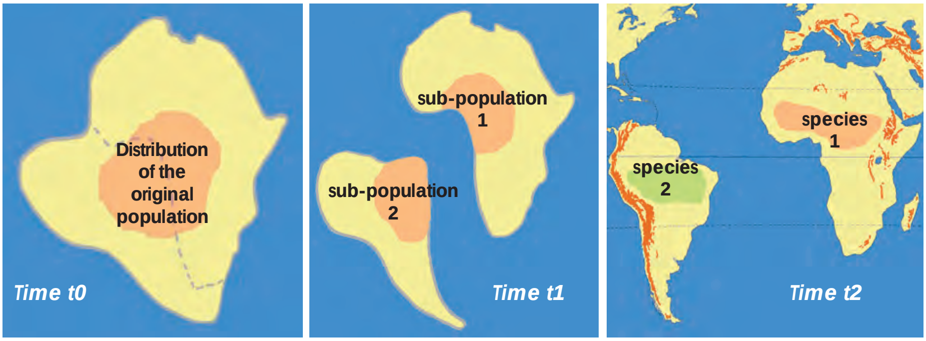
*The "Clusius" gentian (*Gentiana clusii*), along with the Stemless gentian (opposite), is an example of ecological vicariance. The two species probably derive from the same ancestral population from which two population sets diverged. This resulted in the evolution of two species, one growing in acidic grasslands and the other in calcareous grasslands.*

*Purple gentian (*Gentiana purpurea*, left) is a pasture species from the Northern Alps (also found in Italy, Bavaria, Austria, Hungary and Norway), whilst* Gentiana corymbifera *(right) is a species found in the calcareous screes of the mountains of New Zealand. These two species are indicative of the diversification of gentians (400 species), which have colonised a wide variety of environments and continents (for further examples see pages 81, 108 and 149).*

The genus Eryngium *belongs to the Apiaceae family (Umbelliferae or Apiaceae) and includes over 200 species distributed across the world, with the centre of diversity being in South America. The two types of Eryngium shown above are different species, separated geographically:* Eryngium alpinum, *alpine sea holly or queen of the Alps, is found in the Alps (left) whilst* Eryngium bourgatii *is found in the Pyrenees (right).*

When the two species Eryngium alpinum *and* Eryngium bourgatii *are grown in a garden they produce a hybrid that does not occur naturally and is known as* Eryngium x zabelli*. This is a sterile hybrid, like the mule in the animal kingdom, the sterile offspring of a male donkey and female horse.*

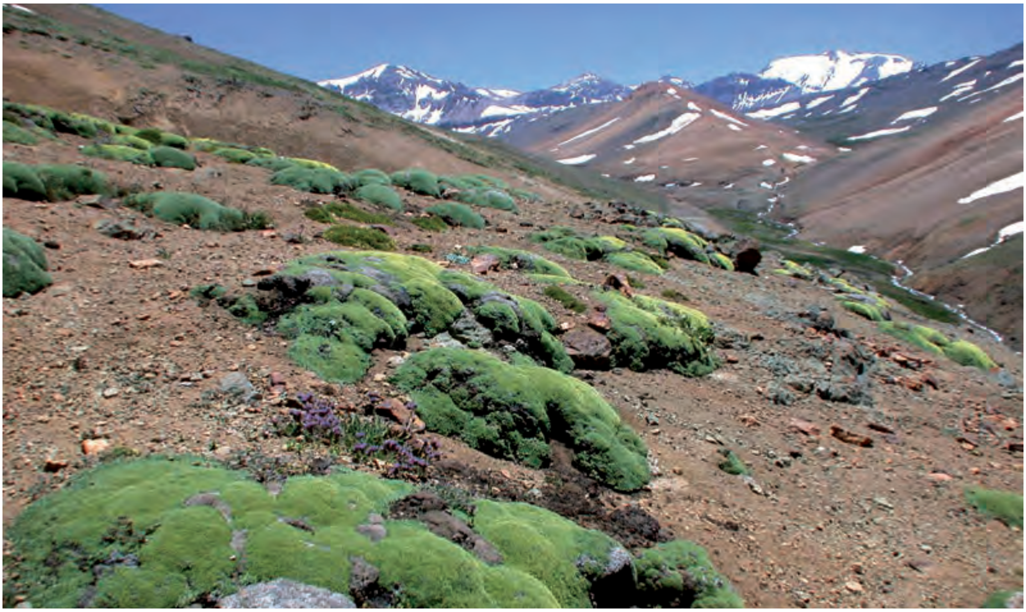
Geographic isolation and speciation



Geographic barriers can isolate and split an original grouping into several sub-sets. Tectonic plate movements have caused major separations which have impacted the development of flora and fauna. The opening of the South Atlantic ocean which isolated Africa and South America is a prime example. Botanists have described groups of related plants which are today found either side of the Atlantic ocean.

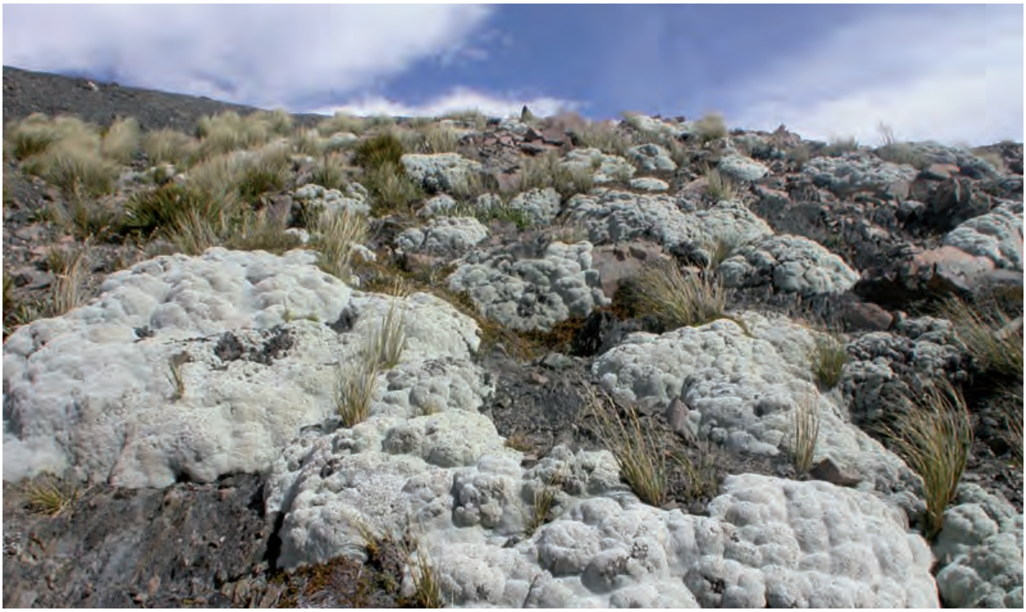
In other cases, long-distance dispersal events such as seeds transported by birds or the wind, have played a part in the creation of geographical isolation barriers.

Whilst evolution is responsible for the diversification of organisms, it also can cause entirely unrelated plants to take on shared characteristics when they live in environments under similar constraints. This is the evolutionary phenomenon known as morphological or physiological convergence. Cushion plants are a prime example from the global mountain flora. Over 1000 species have acquired this specific type of morphology which constitutes an adaptation to avoid heat loss (and water loss, see below). They belong to around sixty different families including Caryophyllaceae (p. 57), Umbelliferae or Apiaceae (p. 56), Primulaceae (p. 51), Leguminosae or Fabaceae (p. 56), Compositae or Asteraceae (p. 57), etc. They are found in most mountainous and cold regions across the world, with the highest diversity seen in the Andes and Patagonia.



Azorella monantha *(Apiaceae), the dominant species in this ecosystem in the dry Andes in the centre of Chile (Valle Nevado, 3000 m). The genus* **Azorella** *includes around 70 species which grow mainly in the Andes (two species present in sub-antarctic islands).*

From left to right and top to bottom: **Petunia patagonica** *(Solanaceae, Argentine Patagonia),* **Burkhartia lanigera** *(Asteraceae, Argentine Patagonia),* **Anarthrophyllum desideratum** *(Fabaceae, Argentine Patagonia),* **Oxalis erythrorhiza** *(Oxalidaceae, Argentine Andes),* **Viola pygmea** *(Violaceae, páramo of the Andes of Ecuador),* **Paepalanthus karstenii** *(Eriocaulaceae, humid páramo of the Venezuelan Andes).*

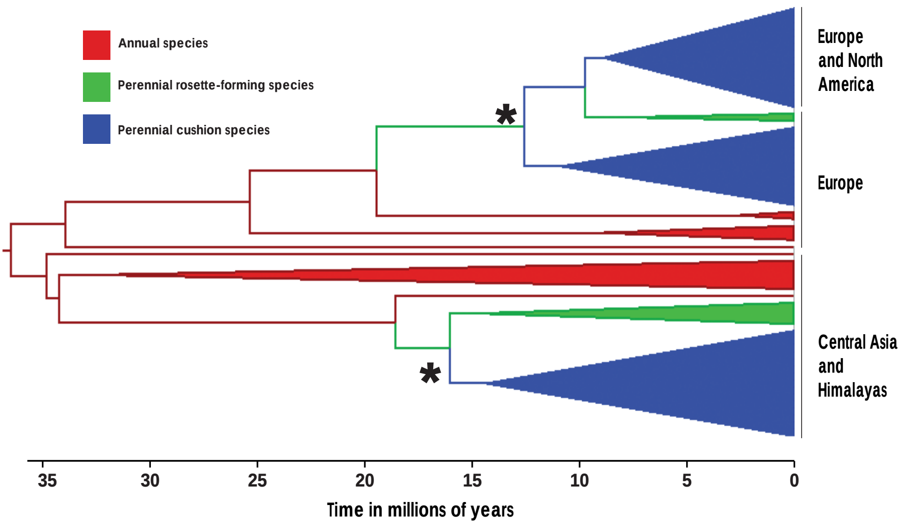


Raoulia eximia ***(Asteraceae) in New Zealand (Mount Hutt, 1500 m). This plant forms cushions of up to several metres in area composed of an amalgamation of thousands of tiny capitula. The*** **Raoulia** ***genus includes numerous species, all endemic to New Zealand.***

From left to right and top to bottom: **Centrolepis monogyna** ***(Centrolepidaceae, cold peatland, Tasmania),*** **Donatia novae-zelandiae** ***(Stylidiaceae, cold peatland, Tasmania),*** **Gypsophilla aretioides** ***(Caryophyllaceae, Iran),*** **Arenaria polytrichoides** ***(Caryophyllaceae, Yunnan),*** **Chionocharis hookeri** ***(Boraginaceae, China),*** **Convolvulus boissieri** ***(Convolvulaceae, Atlas) (photos: S. Aubert, M. van der Brink, J. Quiles).***

The appearance of cushion life forms in the Androsace family

The *Androsace* genus (Primulaceae) includes around one hundred species found in the temperate and cold zones of the Northern Hemisphere. They are either annual, rosette-forming or cushion-forming perennial species.



Androsace septentrionalis
(Annual species)

Androsace adfinis ssp. *brigantina*
(Perennial rosette-forming species)

Androsace alpina
(Perennial cushion species)

This phylogenetic tree shows the evolutionary history of the genus Androsace *which appeared around 35 million years ago. Genetic comparisons reveal the evolutionary relationships between species. Annual species (in red) are shown to have appeared first, probably in the Asian steppes. Cushion species appeared more recently and independently (stars), in both the Himalayas (approximately 15 million years ago, probably in relation to the uplift of the Tibetan plateau) and in Europe (approximately 10 million years ago, probably in relation to the uplift of the Alps). The cushion growth form and its adaptation to cold were probably key to making these colonisations of high altitude environments possible (simplified version of the graph produced by Boucher et al 2012, work carried out by the Laboratory of Alpine Ecology in Grenoble, in collaboration with the Joseph Fourier Research Station).*

Tropical alpine vegetation dominated by so-called pachycauls. On the left, paramo in Venezuela (alt: 4,000 m - lat: 8.5°N), with a **Coespeletia timotensis** *(Asteraceae) (photo S. Lavergne). On the right,* **Senecio keniodendron** *(Asteraceae), a giant groundsel on Mount Kenya (alt: 4,200 m - lat: 5°N). These plants are another example of adaptive convergence.*

A remarkable example of evolutionary convergence is that of the pachycaul growth form, in which plants form rosettes with their upper-most leaves and have a large stem covered in dead leaves which protect the plant from the night-time freezing. Another example concerns plants with imbricated leaves which resemble thujas, an arrangement which helps them to reduce water loss (an adaptation to drought conditions). When these plants are not flowering even an expert botanist can find it hard to distinguish the different species.

Hebe ochracea, *photographed here in the Alpine Garden, a Plantaginaceae (ex Schropulariaceae) which grows in New Zealand and which is closely related to the genus* **Veronica.**

Around the garden: The richness of the flora around the Col du Galibier

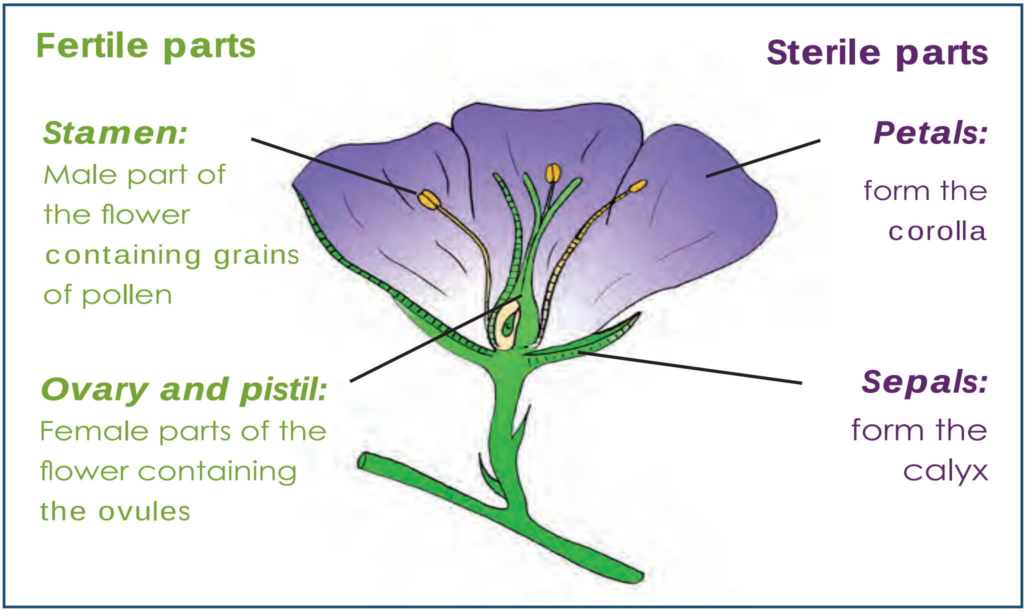
The Col du Galibier area is a Mecca for botanists. Here, the French Botany Society botanizes on the ridges of Galibier for its 141st extraordinary session held in July 2007 at the Alpine Garden. The species which can be found in the area include Androsace helvetica, Campanula cenisia, Linaria alpina, Saxifraga biflora, Eritrichium nanum, *etc. (Aubert et al 2011).*

Botany basics

The flower

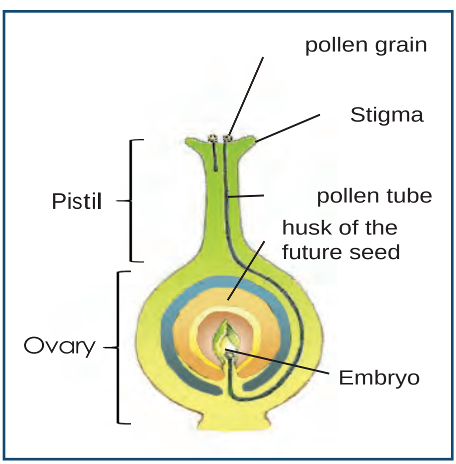
Beyond all of the symbolism attached to flowers, the biologist's perspective is that their main function is sexual reproduction. The flowers of alpine plants are often exceptional in their size, shape and spectacular colours. These features facilitate plant reproduction in environmentally harsh conditions, with short growing seasons and few pollinators.

Pulsatilla alpina*, the alpine anemone is a particularly beautiful alpine plant which flowers in the Lautaret grasslands during June. It is part of the large Ranunculaceae family, which appeared early in the evolution of flowering plants. It is characterised by its clearly separate petals and its large number of stamens arranged in a spiral (the yellow crown shown in the photo).*



The botanical study of plants requires a precise description of the parts of flowers (sterile and fertile), based on a longitudinal cross-section. The example shown here is* Linum alpinum*, Alpine flax. Its defining characteristics include the number of floral parts, their symmetry and their arrangement (sketch, P. Choler).

As with animals, the male fertile parts (the pollen-producing stamens) and the female fertile parts (ovaries) produce reproductive cells or gametes called antherozoids and oospheres (equivalent to spermatozoids and ovules in animals). The fertilisation or fusion of gametes takes place after pollination. This pollination stage involves the transport of pollen containing the male gametes to the female reproductive parts (the pistil), usually of a different flower.

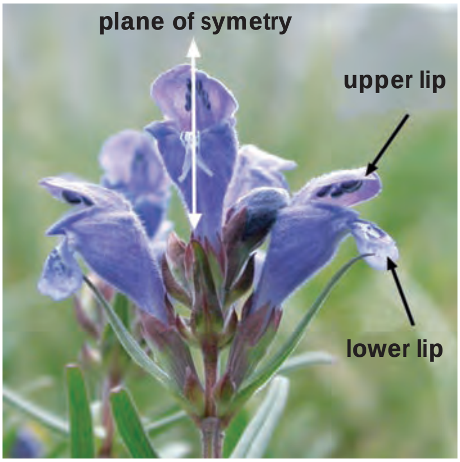


The diagram opposite shows the stages which follow pollination. The pollen grain is deposited on the stigma (the female receptive part). It then germinates and forms a pollen tube via which the male gamete accesses the female gamete (located in the ovary). The two then fuse to form the egg cell, which will form an embryo inside the seed. The ovary then becomes a fruit containing seeds (sketch P. Fernandez).

Flower symmetry: actinomorphic or zygomorphic.

Etymologically, the term "actinomorphic" comes from two Greek words: *aktis*, ray (of light) and *morphè*, shape. In the same way, the term "zygomorphic" comes from the two Greek words: *zugon*, yoke and *morphè*, shape.

*Two examples of flowers with radial symmetry (actinomorphic flowers): peacock-eye pink (*Dianthus pavonius*, Caryophyllaceae, pink) and the large-leaved helianthum (*Helianthemum grandiflorum*, Cistaceae, yellow) photographed in the meadows surrounding the orientation table close to the Alpine Garden.*



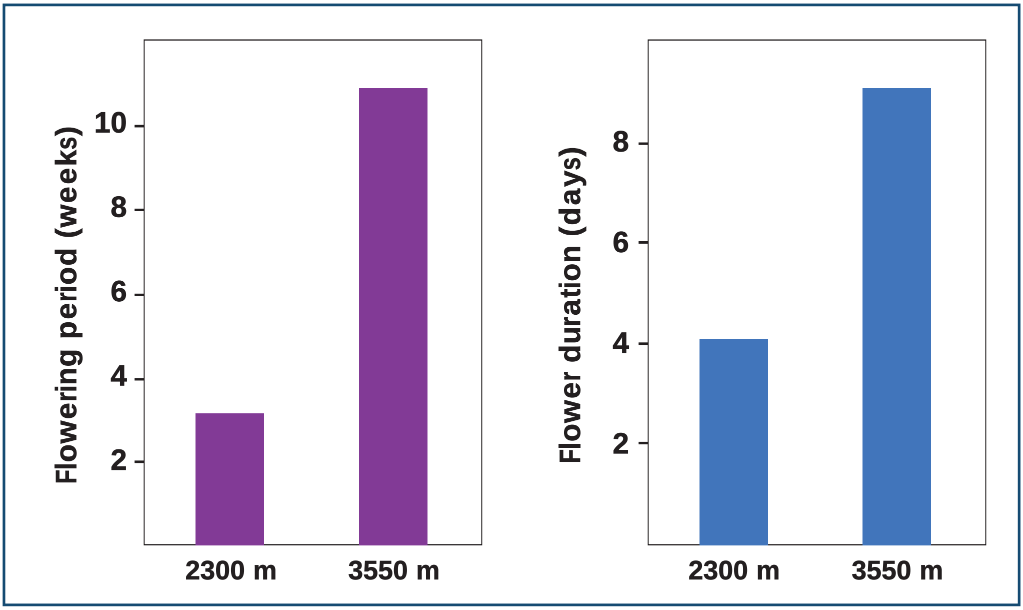
*The Northern dragonhead (*Dracocephalum ruyshiana*, Lamiaceae) has very obvious zygomorphic flowers. Its five petals form two lips. The upper lip protects the fertile parts (four stamens and the pistil) and the lower lip acts as a landing strip for pollinators. This species is characteristic of steppe-like meadows (p.7).*

*The hummingbird hawk moth (*Macroglossum stellatum*) is a butterfly which uses its long proboscis to gather the nectar located deep inside flowers, in this case a carnation in the Pyrenees rock garden at the Alpine Garden.*

Several systems are used to transport pollen. One strategy is pollination by insects. Such flowers usually have attractive shapes and colours which attract insects. These visual stimuli are reinforced by the flower's scent and nectar, a sweet substance produced by the plant which is strategically located at the heart of the flower. Pollination is therefore almost always a mutually beneficial process: the insect ensures the plant's reproduction in exchange for food. Since the appearance of flowering plants, plants and insects have evolved in parallel (co-evolution) which has led to certain plant species becoming specialised in their association with a given type of pollinator.

*A bee visiting an orange hawkweed (*Hieracruim aurantiacum*, Asteraceae) in the Alpine Garden. The ball of pollen which accumulates on the insect's legs will be taken back to the hive.*

*Many of the most well-known alpine plants are brightly coloured, such as the orange lily shown here (*Lilium bulbiferum*, Liliaceae), growing alongside* Iris pallida *(Iridaceae) and* Genista radiata *(Fabaceae) in the "Balkans" rock garden.*



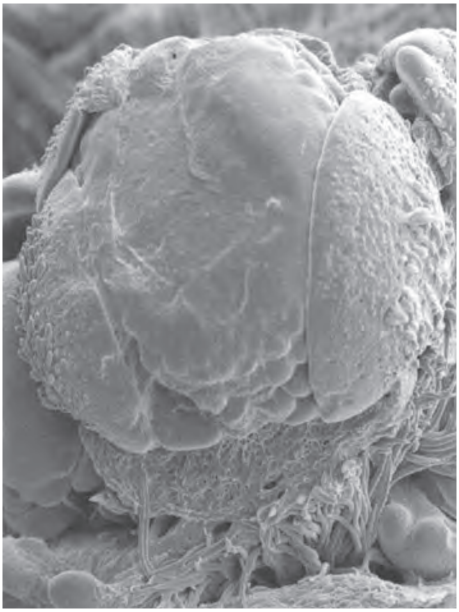
Research carried out in the Chilean Andes has shown that plants which grow at high altitudes have a far longer flowering period than their low-altitude congeners (left). Their flowers also stay open for longer (right). This adaptation helps to compensate for the scarcity of pollinating insects at altitude (Arroyo et al 1982 in *Aubert et al 2006).*

It is often said that flowers which grow at altitude have brighter colours than those found in plains in order to attract pollinators more effectively. Whilst it is true that many well-known alpine species are very brightly coloured, studies carried out in the mountains of Norway have found no case for generalisation. There was no significant increase in colour, size, or any other characteristic associated with attracting insects such as a zygomorphic shape (p. 64) or the size of spurs, with increasing altitude (Totland et al 2005 *in* Aubert et al 2006). However, research carried out in the Andes has shown that plants at altitude have longer flowering periods and durations, allowing them to compensate for the small number of insects.

Indeed, there are very few insects at high altitudes and this limits the possibilities for pollination. Many of the species which dominate alpine meadows are in fact wind pollinated, Poaeceae and Cyperaceae for example.

Several alpine plants, including glacier crowfoot and numerous Saxifrages, can pre-form their flower buds, sometimes one or two years in advance allowing them to bloom rapidly as soon as the conditions are favourable.

Furthermore, many alpine species reproduce by means of vegetative reproduction, which, due to its greater reliability, provides a contingency against the risks associated with sexual reproduction (p. 85).

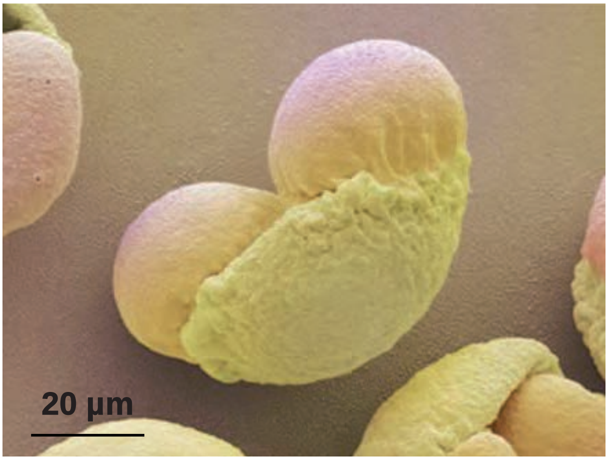


On the left, glacier crowfoot (**Ranunculus glacialis*****, Ranunculaceae) is a species which only grows in alpine zones in the European Alps, between 2300 m and 4250 m, and is amongst the plant species growing at the highest recorded altitudes. It favours wet scree, in particular shale, as found here on the ridges of the Col du Galibier. On the right, a flower bud seen using scanning electron microscopy: the bud is pre-formed a year in advance, allowing the plant to take full advantage of the short growing season (In Körner 2003).***

Plants and the wind

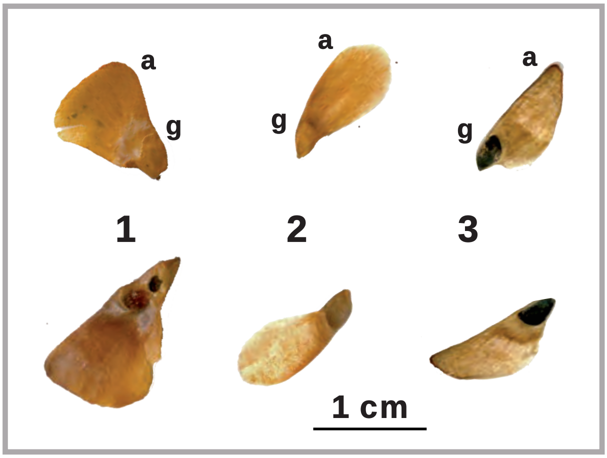
The wind is a constraint for plants which causes mechanical damage and drying. However, as plants are sessile organisms which cannot move, the wind can also be an asset used for transportation. Many plants therefore utilise the wind as a pollen vector or for seed dispersal. In both cases large quantities of pollen or seeds are produced to compensate for the uncertain nature of this form of transport. Other adaptations to increase the efficiency of wind transport include a small size of seed and pollen or the development of specialised structures to increase seed surface area.

*The bay willow (*Salix pentandra*) a native species found in the Alpine Garden, produces small downy seeds which are dispersed by the wind in September. Other such examples are commonly found in epilobium or poplars. In the latter, the masses of downy seeds produced in the spring are often mistaken for pollen. The cottongrasses commonly found in boggy environments are known as* Eriophorum*, which etymologically means "which wears wool" and refers to the downy seeds, which in the past were used to fill cushions.*



Pine pollen grains, here from Scots pine, have two lateral bladders full of air which lower the seed's density and allow it to be easily carried in the wind. Photographed here using scanning electron microscopy, http://www.psmicrogra- phs.co.uk/.

In the Poaceae (grasses) the X-shaped stamens (E) grow along a long filament (f) and are moved by the wind freeing the pollen, which is then subsequently trapped by the long downy stigma (S).



The seeds (g) of various conifers, here spruce (1), larch (2) and Scot's pine (3), have a wing (a) which helps them to "fly" and facilitates their dispersal. One notable exception is Pinus cembra. *Its large wing-less seeds are dispersed instead by the spotted nutcracker bird.*

Around the garden: The globeflower, the paradox of the closed flower

*The globeflower (*Trollius europaeus*, Rannunculacea) is abundant in the alpine meadows surrounding the Col du Lautaret, here shown growing alongside poet's daffodil, (*Narcissus poeticus*, Amaryllidaceae). This plant has the unusual characteristic of never opening. In fact, the tiny openings between its petals allow the small *Chiastocheta* fly to enter the flower. This fly is a very special kind of pollinator: It uses the flower as a shelter to lay its eggs in the ovules, and its larvae parasitise the flower by feeding on some of its seeds. This cost is offset by the benefit the plant derives from pollination (research carried out by Laurence Després' team at the Laboratory of Alpine Ecology in Grenoble, see Ibanez and Després 2009).*

Relationships between species

Plants are immobile living organisms. Fixed to the ground (or onto other plants) they extract the elements they need to live from the surrounding environment: water and nutrients from the soil, CO_2 from the air, and light to provide the energy required for photosynthesis. However, plants rarely grow in isolation and the presence of neighbouring plants can significantly improve or hamper an individual's performance.

When an environment contains a large number of species with similar ecological requirements, some resources can begin to become limiting. For example, if some plants grow to a significant height, light may become a limiting factor for shorter shaded individuals. However, tall plants can also protect smaller neighbouring plants from the harmful effects of excessive light.

The fescue meadow (*Festuca paniculata*, Poaceae family) is a remarkable environment found in the Lautaret region. It is mainly found on gentle, south-facing slopes up to 2400 m altitude. The biodiversity found in this environment is quite simply exceptional as it contains over sixty species including leopard's bane (*Arnica montana*, Asteraceae, yellow), bearded bellflower (*Campanula barbata*, Campanulaceae, blue) and the pink globe orchid (*Traunsteinera globosa*, Orchidaceae, pink).

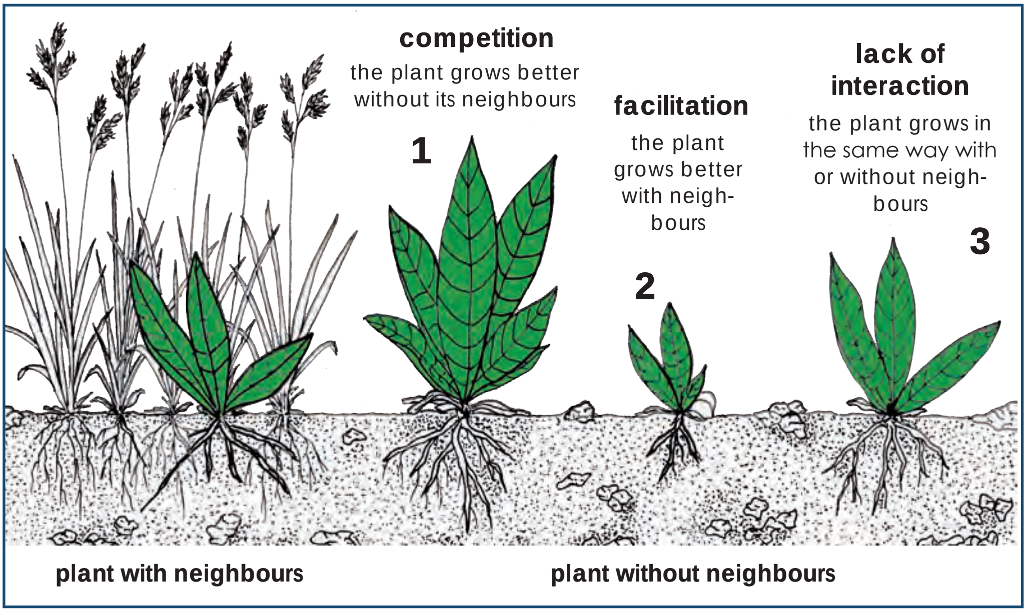


Diagram showing the three types of interactions between plant species: when a plant's neighbours are removed experimentally, it either grows better (1), less well (2) or identically (3). This reveals the type of relationships existing between the plant and its neighbours.

Competition implies a "struggle" between species for the use of a resource vital to their growth, such as light, water or mineral nutrients from the soil. This phenomenon is most commonly observed in rich environments where there is an abundance of available resources. In these conditions, some dominant species (such as *Festuca paniculata*) often prove capable of capturing the majority of the available resources. They generate intense competition with other species whose growth is consequently limited.

Conversely, in more hostile habitats, such as on steep slopes, poor soils or in very cold environments, colonisation is simply impossible for many species. However, the growth of one species well adapted to the conditions can prepare the way and act as a refuge for other, more fragile species.

This is the phenomenon known as facilitation, which refers to the positive relationships between plants. A study carried out by several laboratories (including the Laboratory of Alpine Ecology in Grenoble) in several mountain ranges across the world (including in the Alps in the Lautaret area) has shown that in alpine zones, where constraints are at their highest, more facilitation is observed than competition, whilst the opposite is true in the less stressful conditions of the subalpine zone (Callaway et al 2002).

*Violet fescue (*Festuca violacea*) is a Poaceae with a highly developed root system which enables it to grow on steep slopes creating a landscape of mini-terraces (here on shale screes at the Col Agnel in the Queyras massif). Numerous so-called facilitated species then take advantage of the ground which has been stabilised by this structuring species (see close-up below).*

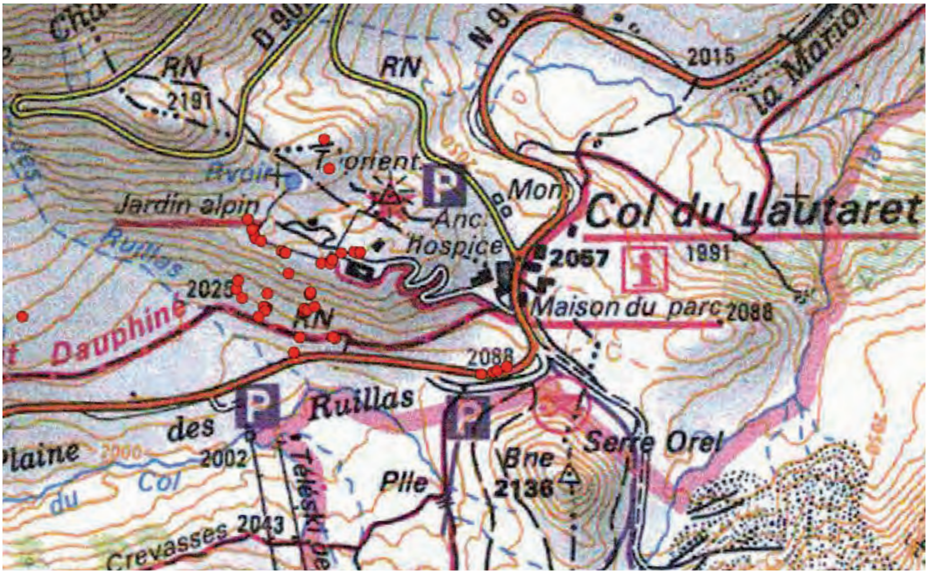
*Close up of a mini-terrace (above, in the Galibier area) where the growth of violet fescue (*Festuca violacea*) allows numerous other species less suited to these unstable slopes to establish. Here we can see* Senecio incanus *(Asteraceae, yellow),* Cerastium arvense *ssp.* strictum *(Caryophyllaceae, white), and* Campanula scheuchzeri *(Campanulaceae, blue).*

Pulling up a plant which has escaped from the Alpine Garden, here the primrose Primula auriculata*, a Primulaceae which is found naturally in the Caucasus, Turkey, Iran, Iraq, Afghanistan and Turkmenistan (photo: P. Salze).*

The intense competition in the natural meadows surrounding the Alpine Garden explains why so few species have escaped from the Garden: in one hundred years and with the introduction of over 10,000 exotic species, only around ten species have escaped from the Garden. These escapees are carefully monitored by the garden's botanists and any escaped plants are regularly weeded out.

*This Jacob's ladder (*Polemonium caeruleum*, Polemoniaceae) escaped from the Alpine Garden a long time ago: the notebooks of Robert Ruffier-Lanche, former head gardener at the Alpine Garden, indicate that the species was already growing outside of the Alpine Garden in the 1950s.*

Senecio adonidifolius *(Asteraceae) has started to grow beyond the fences of the Alpine Garden. Measures are currently being taken to ensure its eradication beyond the garden's boundaries.*



Map showing the distribution of Jacob's ladder outside of the Alpine Garden, produced in 2012 by the garden's botanists, Christophe Perrier and Rolland Douzet. There has been no significant spread since the previous inventory carried out in 2003. This monitoring is carried out in partnership with the Ecrins National Park, as part of the 2000 Natura zone "Ecrins- Lautaret-Combeynot". Base map SCAN 25 ® - © IGN / PFAR CRIGE 2000.

*Allelopathic competition is a concept which the botanist de Candolle already observed in 1834. Certain species, such as the Mouse-ear hawkweed (*Hieracium pilosella*, Asteraceae) shown here, are so toxic that they render the soil unfit for even their own offspring to develop. This is known as autotoxicity.*

Relationships between plants also include a form of chemical competition, known as allelopathy, in which plants release inhibitory substances into the soil which have a toxic effect on seeds and even on mature individuals of other species.

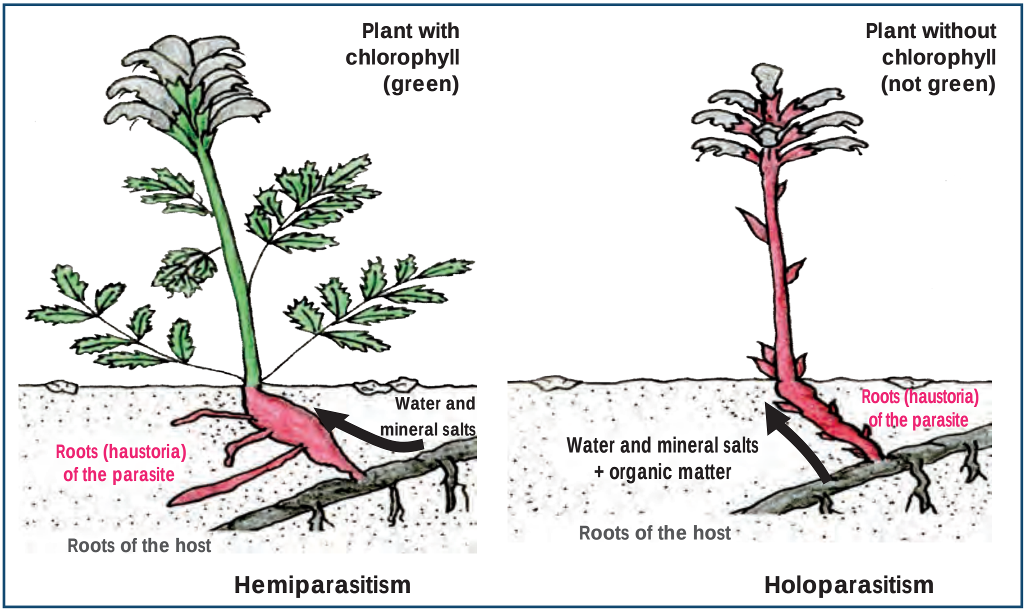
Chemical interactions also have a role to play in the relationships between plants and herbivores, as plants often synthesise toxic molecules to ensure their protection. Some of these substances can have pharmaceutical properties at low doses, but can also be extremely harmful or even lethal for human beings.

*Two examples of highly toxic plants: large yellow foxglove (*Digitalis grandiflora*, Plantaginaceae, left) and monskhood (*Aconitum napellus*, Rannunculacea, right). The toxins they contain are lethal but in low doses can regulate cardiac activity (digitaline) or reduce pain (aconitine).*

The broomrape **Orobanche laserpitiisileris** *(Orobanchaceae, yellow-orange) is a holoparasitic plant without chlorophyll. It draws water, mineral salts and organic matter up through haustoria which grow into the host plant's roots. In this case, the host is* **Laserpitium siler** *an Apiaceae, with white inflorescences which is found in rocky areas between 500 and 2500 m altitude.*

In the case of parasitism, a plant develops on a host plant from which it extracts the elements it requires but gives nothing in return. This exploitation may only concern water and minerals or may also include organic matter synthesised by the host.

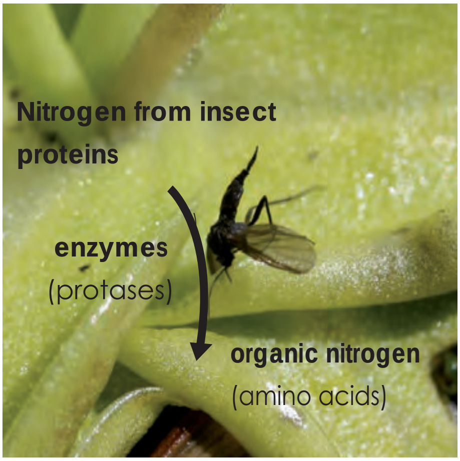
Conversely, in cases of symbioses, the relationship can be mutualistic with shared benefits for each partner, and the species become interdependent.



Hemiparasitic plants draw water and mineral salts from the host plant's sap (roots and stems) but remain green and capable of photosynthesis (ynthesis of carbohydrates). Holoparasitic plants are no longer capable of photosynthesis: they not only draw water and mineral salts, but also organic matter from their host's sap. Sketch: Ch. Perrier.

The lousewort Pedicularis rostratospicata *is an Orobanchaceae found in the Alps and Carpathian mountains. It is commonly found in the subalpine and alpine meadows of the Lautaret-Briançonnais area between 1500 and 2700 m. It is hemiparasitic: photosynthesis takes place in its green leaves whilst its roots parasitise other plants to obtain water and minerals.*

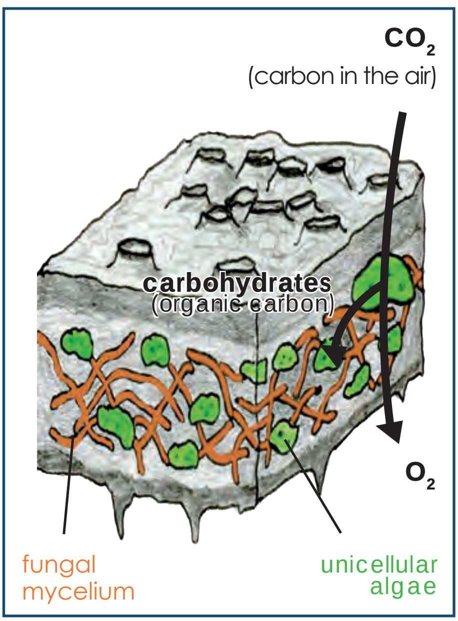
The alpine paintbrush Castilleja rhexifolia *(Orobanchaceae) is a hemiparasitic plant found in the mountains of North America and can be seen in flower in the Alpine Garden during August. Growing these parasite species in Gardens is a complicated process as the host plant also has to be grown.*



*A digested insect on the sticky leaves of the common butterwort (*Pinguicula vulgaris*, Lentibulariaceae) growing in the tufa formation in the Alpine Garden.*

Carnivorous plants grow in boggy environments characterized by low in oxygen and nitrogen. These plants trap insects in their leaves, which are then digested by enzymes (proteases) produced by the leaves. The amino acids released are absorbed by the leaves, making it possible for the plant to synthesise proteins.

In cases of symbiosis, a mutually beneficial relationship develops between two protagonists such as a plant and bacteria (p. 96) or an alga and fungus (such as in lichens, organisms which colonise extreme environments).



Lichens are a symbiotic association of a photosynthetic alga (in green) and a fungus (in brown). On the right, two species, Xanthoria elegans *(orange) and* Rhizocarpon geographicum *(yellow-green), photographed on a granite block of the Scott monument in the Alpine Garden.*

Around the garden: The monument to Captain Scott and its lichens

In the upper section of the Garden, the monument erected in 1913 is a reminder of Captain Robert Falcon Scott's visit to Lautaret in the winter of 1908 when he tested his equipment, accompanied by the French explorer and doctor Jean-Baptiste Charcot, before embarking on his expedition to the South Pole. Scott sadly never returned from this expedition as he died on the return journey in 1912. Over the years, this cairn has been colonised by lichen, notably Xanthoria elegans *which gives it its orange colour. The monument is shown here with snow kites in the background, the Col du Lautaret being a prime location for this extreme sport.*

Adaptations to alpine life

Unlike animals which can move to find more favourable conditions, plants are fixed in one place, meaning they are directly exposed to the conditions in their given environment: climatic factors (temperature, precipitation, light, wind and humidity), edaphic factors (soil characteristics), biotic factors (the influence of other plants and herbivores) and anthropogenic factors (human activity). In alpine zones, these factors are either limiting (low temperatures, scarcity of nitrogen) or in excess (light, especially UV radiation).

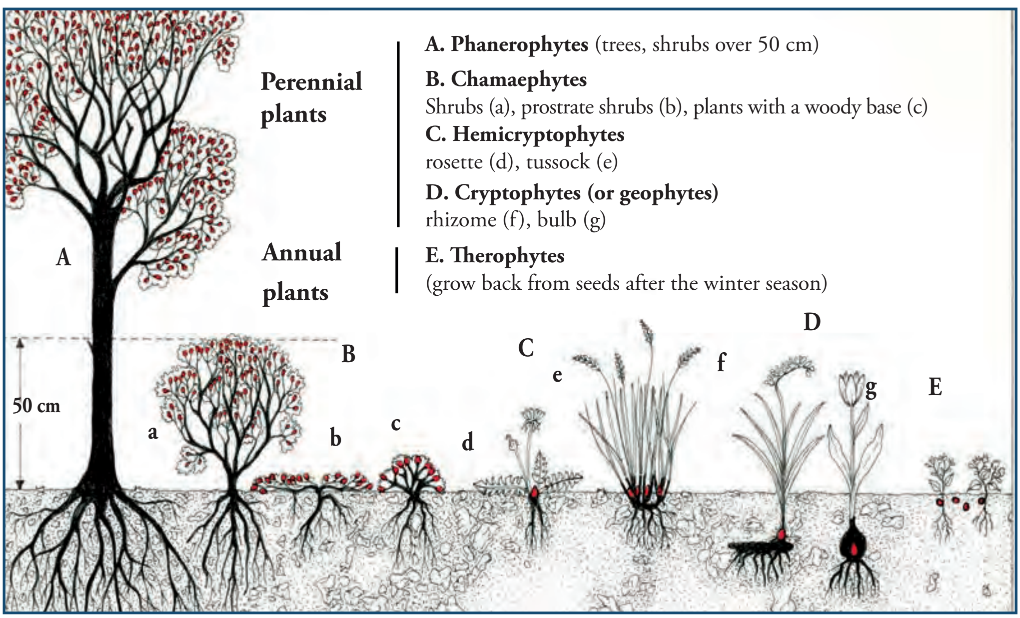
Snow gentian (*Gentiana nivalis*, Gentianaceae, left) and dark stonecrop (*Sedum atratum*, Crassulaceae, right) are two examples of annual plants, a biological form rarely found in alpine zones.

The most obvious constraint at altitude is the cold temperature. The drop in temperatures as altitude increases (0.5 to 0.7°C every 100 m) reduces the length of the growing season. This means many plants find it extremely difficult to complete their life cycle in time.

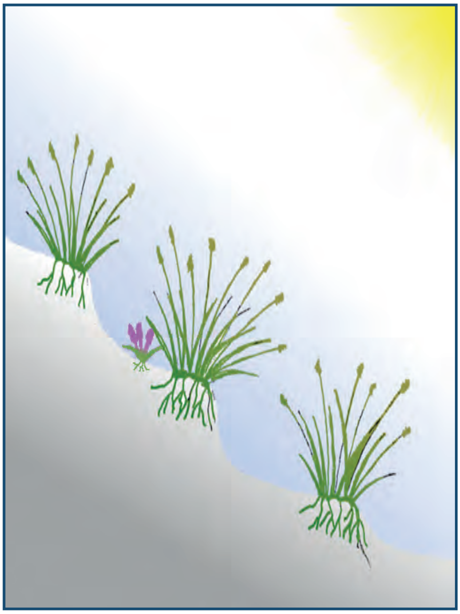
Annual plants, which germinate each spring from new seeds, usually do not have time to complete a full life cycle at altitude. They are therefore rare in alpine zones where perennials dominate, representing 95% of species.

Perennial plants grow back each year from the same rootstock. Their aerial parts may persist at soil-level as a rosette of leaves (hemicryptophyte plants), as a cushion or as tufts of leaves. At the start of the growing season, new young leaves develop within the old, dried out shoots from the previous year.

Some alpine plants have persistent woody shoots near the ground, these are known as chamaephytes. Others are completely buried underground. This is the strategy used by geophyte plants. Their underground organs are called bulbs or rhizomes (underground stems).



The main plant life form categories for plants growing in temperate and arctic regions are defined according to the position of their buds in winter (shown in red). In black, the perennial parts remaining from one year to another. Dotted lines indicate the parts which die off in the winter. Etymology: "phanero", visible; "chamae", dwarf; "hémi", half; "crypto", hidden; "théro", summer (sketch: Ph. Danton).



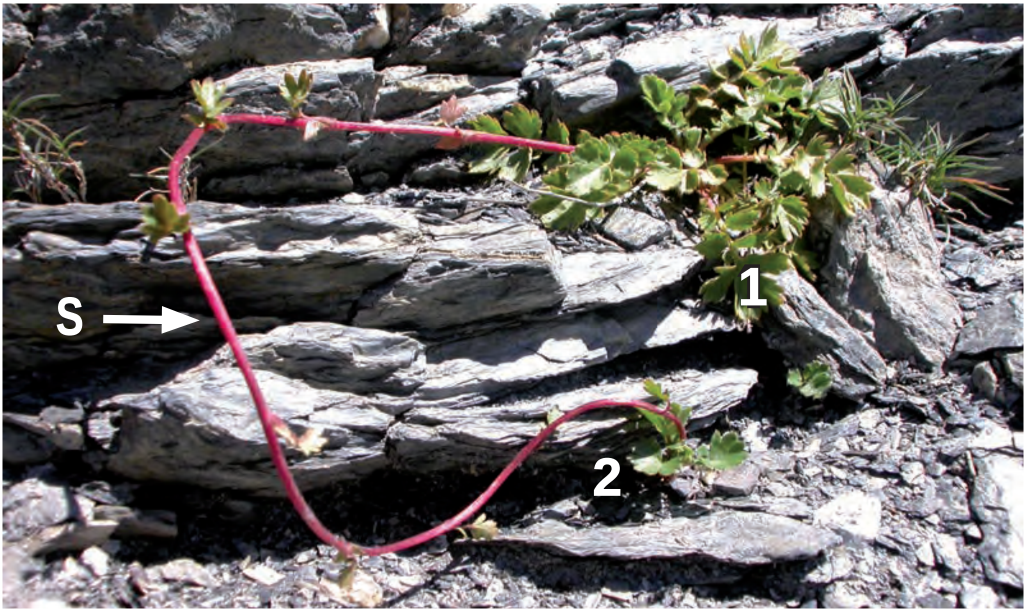
*Blue moor grass (*Sesleria caerulea*) is a Poaceae (Gramineae) which colonises steep slopes, especially above the Garden on the slopes of the Chaillol mountain. It is shown here around the Col de l'Izoard. This grass acts as a facilitator for other species (p. 72, sketch P. Fernandez).*

*Pygmy hawkshead (*Crepis pygmea*, Asteraceae) is a plant typically found on the shale scree of the slopes near the Galibier pass, up to 2800 m. This hemicryptophyte species is a perennial with a creeping root that survives from year to year.*

*Alpine foxtail (*Alopecurus alpinus*, Poaceae) is a snow bed species, shown here near the Galibier tunnel at 2500 m. The plant can be identified by the blue-green colour of its leaves. At the start of the growing season, in July, as shown here, it has a complex network of rhizomes (centre of the picture) containing stored reserves which allow the plant to survive over winter as well as to reproduce vegetatively.*

Many alpine plants use vegetative reproduction or clonal propagation to avoid the uncertainties of sexual reproduction. In these forms of reproduction, exact copies of the parent individual (clones) are formed, as in the case of identical twins. Such new clones often initially form on a horizontal stem, before becoming separate individuals. In many shrubs, this occurs through layering, where buds develop at the points where low-lying branches touch the soil (e.g. rhododendron and green alder).

*Green alder (*Alnus viridis*, Betulaceae) uses layering for clonal reproduction. This shrub has very flexible branches which allow it to resist being covered by snow. The low-lying stems form roots where they touch the soil (see arrows) before breaking apart to form clones.*



*Like the strawberry plant which also belongs to the Rosaceae family, the creeping avens (***Geum reptans***) produces flowers (sexual reproduction, see below) and stolons (aerial stems, S) which allow the species to reproduce clonally and colonise shale scree. Once the connecting stolon is destroyed, the new plant (2) breaks off from the mother plant (1).*

In other cases, individuals identical to the mother plant are produced via stolons (horizontal aerial stems) or rhizomes (underground stems). Alpine plants often make use of both sexual and clonal reproduction, to maximise the possibility of successful reproduction under harsh climatic conditions.

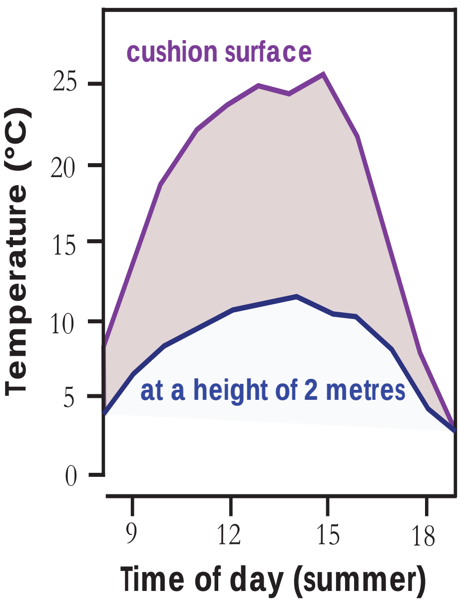
*The beautiful flowers of the creeping aven (***Geum reptans***), which uses both sexual and clonal reproduction (see above) to ensure its propagation in scree slopes in alpine zones. It is shown here at 3000 m on the shale slopes of the Pic Blanc du Galibier.*

Numerous plants growing in screes (called lithophytes) can change their location using a number of different strategies. From left to right, independently migrating lithophytes (here Ranunculus glacialis*, in which the bulb can reestablish after movement of the scree); lithophytes migrating by vegetative reproduction (here* Saussurea depressa*, in which movement occurs via rhizomes with a high capacity for regeneration); and lithophytes migrating through the continuous elongation, breakage and regeneration of roots (shown here for* Viola cenisia*) (Somson 1983; Huc 2010* in *Aubert et al 2011) (sketches : Ph. Danton).*

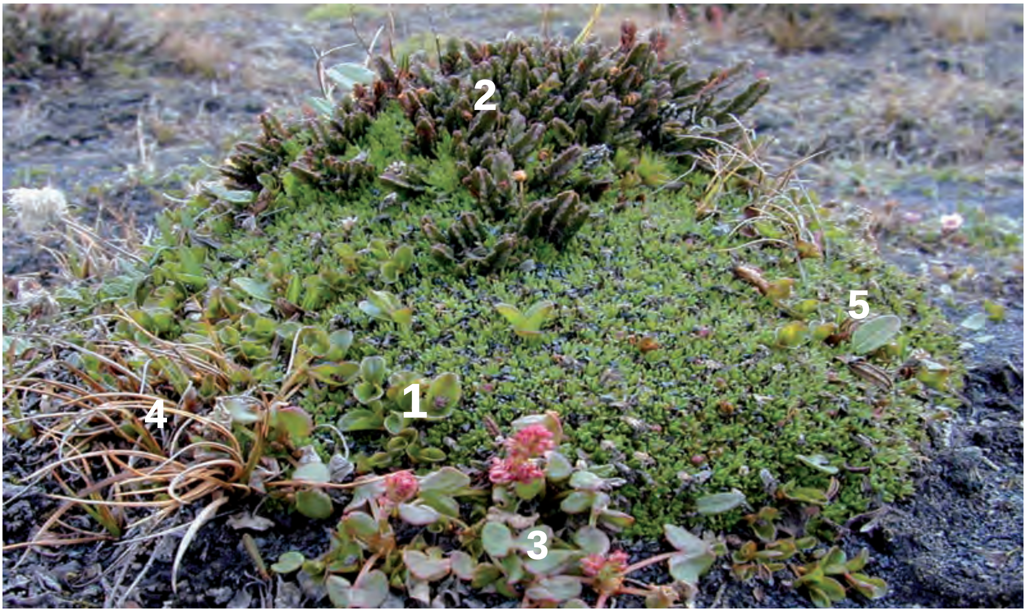
In unstable environments such as scree slopes, alpine plants have developed several different types of underground systems (roots and rhizomes, above). One of the most remarkable adaptations in alpine flora is the cushion form. Many species growing amongst rocks, often in highly exposed locations, have adopted this habit (Ruffier-Lanche 1964). It greatly improves the plant's heat balance, as a sphere is the geometric shape with the lowest surface area for a given volume. This means the least possible amount of heat (and water) is lost. The cushion therefore constitutes a microclimate, offering more favourable thermal and moisture conditions than the surrounding environment. This explains why cushions are often colonised by other plant or animal species (small insects). In the case of plants, this phenomenon is known as facilitation (p. 72). Many cushion plants have been described as "ecosystem engineers", as they facilitate the development of other species in extreme environments.

Numerous Poaceae and Cyperaceae grow as tussocks, which also create a microclimate favourable in terms of thermal and moisture conditions.

Moss campion (*Silene acaulis*, Caryophyllaceae, pink flowers) growing at the Col Agnel in the Queyras (Hautes-Alpes), around 2600 m. When the plants are not flowering (green cushions), they look much like moss, hence their common name.



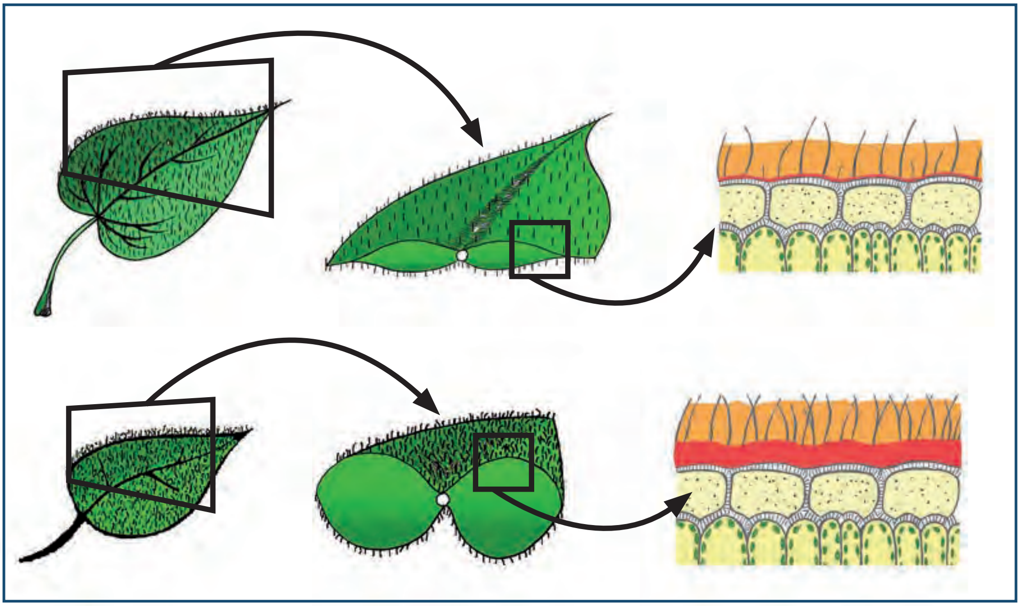
On the left, the temperature of the surface of a moss campion cushion compared to the air temperature measured two metres from the ground (*in *Körner 2003). On the right, a moss campion cushion at the Alpine Garden in the rock garden devoted to plants typically growing in rocky areas in the European Alps.



An example of facilitation on a moss campion cushion growing in an Arctic climate in Spitzbergen (Norway). The species shown benefiting from the microclimate are the two Arctic species **Salix polaris** *(1) and* **Cassiope tetragona** (2) *and several arctic-alpine species:* **Oxyria digyna** *(3),* **Carex rupestris** *(4),* **Polygonum viviparum** *(5).*

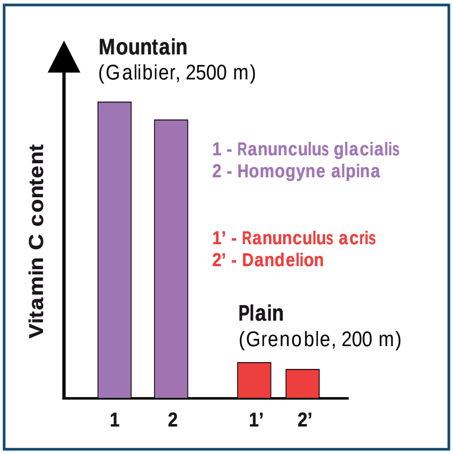
Alpine plants often have small leaves, densely covered in hairs, which trap a thin layer of air close to their surface. This acts as a form of insulation, preventing heat loss and limiting the drying effect of the wind. Furthermore, this dense hair coverage coupled with a thick cuticle (see diagram p. 89) also reflect, just like a mirror, a part of the very intense radiation experienced at altitude. Plants use light in the process of photosynthesis, a complex mechanism which allows them to produce carbohydrates. However, in excessive quantities, as is often the case in alpine zones, intense light can actually damage the leaves.

The plant **Craspedia incana** *(Asteraceae) grows in scree in the alpine zones of the mountains in the South of New Zealand. Like the famous Edelweiss (p. 163), it is entirely covered with thick, downy hairs which protect it from the cold, from drying out and from the harmful effects of excess light.*



Common morphological differences between leaves from low altitudes (top) and in alpine zones (bottom). At altitude, most leaves are small, thick and densely covered in hairs. They are covered with a protective layer called the cuticle (shown in red on the cross-sections on the right), which is much thicker than in low altitude plants (sketch: P. Fernandez).

Alpine plants have various mechanisms which dissipate excess light: protection in the form of an epidermis which reflects some incident energy or absorbs it by means of pigments such as flavonoids; dissipation of incident energy as heat; or the synthesis of molecules which neutralize the toxic compounds (oxidising agents) produced under strong light. Regarding this last category, special mention should be made of so-called antioxidants, molecules such as ascorbic acid (Vitamin C) which are often found in high levels in the leaves of alpine plants.



Vitamin C content in related mountain and plains species. This antioxidant molecule, used in the food industry, is naturally synthesised and stored by alpine plants to combat the oxidative stress induced by excess light and UV radiation. This research has been carried out at Lautaret by Peter Streb from the Paris XI University, in collaboration with the Laboratory of Plant Cell Physiology in Grenoble (Streb and Cornic 2012, Aubert and Bligny 2012).

Around the garden: Examples of cushion plants

*Some examples of cushion plants in the alpine zone of the Col du Lautaret region. Above, mossy cyphel (*Minuartia sedoides*, Caryophyllaceae, green) and Pyrenean whitlow grass (*Petrocallis pyrenaica*, Brassicaceae, pink), two species from shale grasslands. Below, mossy saxifrage (*Saxifraga bryoides*, Saxifragaceae, white) and Herald of Heaven or king of the Alps (*Eritrichium nanum*, Boraginaceae, blue), two species commonly found growing on siliceous rocks.*

A remarkable range of environments

Tall-herb communities

The Col du Lautaret, being situated in a transitional zone, is home to a wide variety of habitats. One habitat found in the area, the tall-herb community, is a good example of the luxuriant and diverse vegetation that can be seen in the subalpine zone. Tall-herb communities are composed of both tall herbs and plants with large leaves. The leaves form a canopy under which a humid and shady microclimate develops. The vegetation is dense and offers optimal conditions for plant development, with soils rich in water and nitrogen, and high levels of humidity, even in the summer.

On the Sentier des Crevasses footpath, at an altitude of 2000 m in the Ecrins National Park. The leaves of Adenostyles alliariae *(Asteraceae) are unexpectedly large at this altitude, a fact explained by the water and nitrogen-rich soil.*

Etymology

The French word "mégaphorbaie" used for tall-herb communities originates from the Greek *méga* (big) and *phorbè* (pasture).

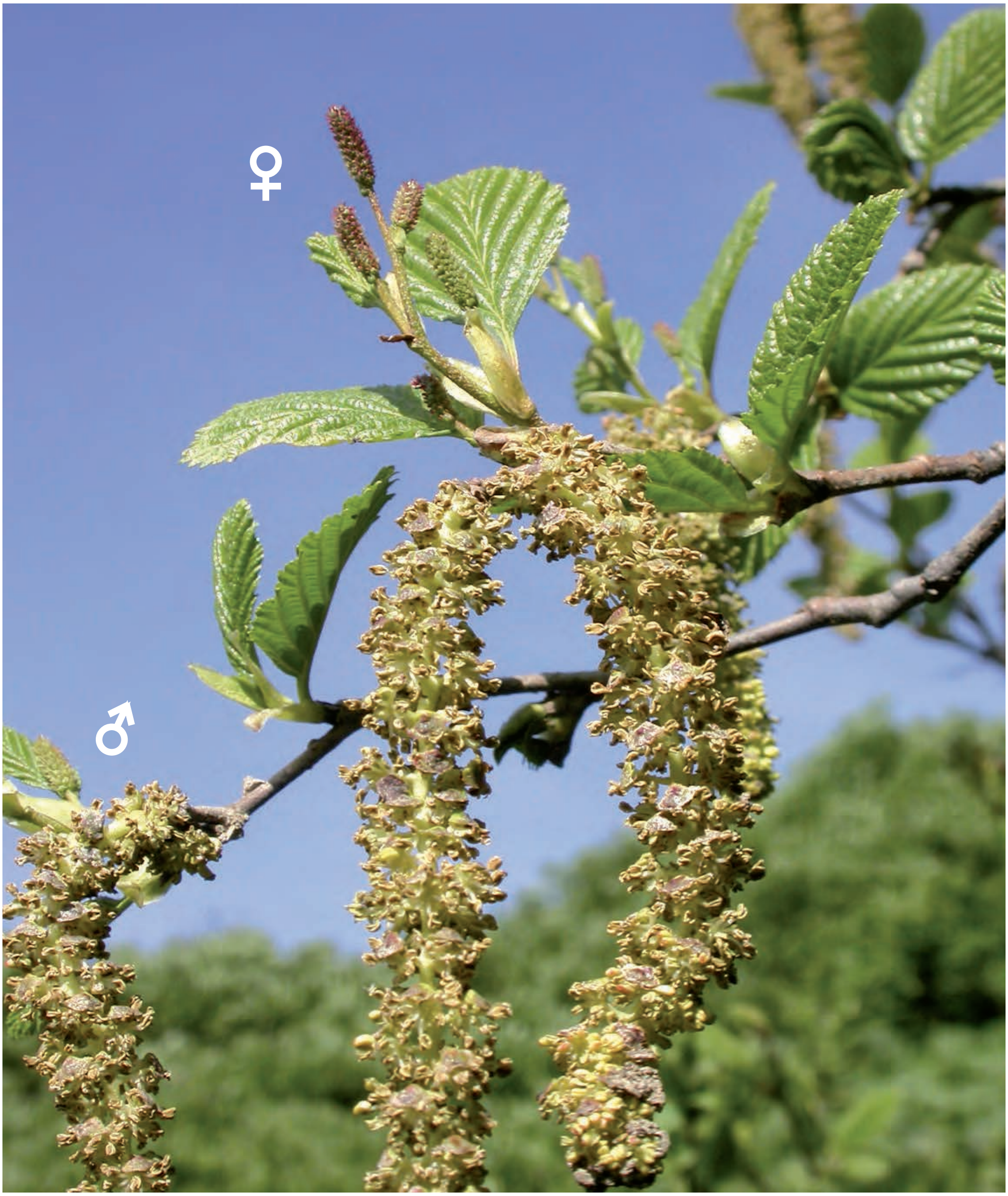
In the Lautaret region, tall-herb communities mainly occur in cool and humid areas on north-facing slopes. They are particularly common in disturbed areas, regularly rejuvenated by avalanches. They are often found alongside woods of green alder (known locally as "vernes") which play a key role by enriching the soil with nitrogen (see below). As conditions become less disturbed, larch forests can begin to succeed.

Tall-herb communities boast a wide variety of flowering plants. These include alpen rose (*Rosa pendulina*, a thornless Rosaceae), wood cranesbill (*Geranium sylvaticum*, Geraniaceae), great masterwort (*Astrantia major*, Apiaceae), martagon lily (*Lilium martagon*, Liliaceae), wolfsbane (*Aconitum lycoctonum* subsp. vulparia, a toxic Rannunculacea).

The complex inflorescence of* Adenostyles alliariae*. Like all Asteraceae (daisy, dandelion, etc.), its flowers are actually capitula of small flowers. Here the inflorescence is made up of numerous small capitula, each composed of 3 – 6 flowers.

*Two tall-herb species: to the left, wolfsbane (*Aconitum lycoctonum *subsp.* vulparia*) is a highly toxic Rannunculacea. It contains lethal alkaloids (in particular aconitine). To the right, great masterwort (*Astrantia major*) is an attractive Apiaceae, several varieties of which are grown in gardens in plain areas (in moist, rich soils which imitate its natural habitat).*

*The tall-herb community near Combeynot (Ecrins National Park) is home to many magnificent species such as the alpine leek (*Allium victoriale*, Amaryllidaceae, white) and the martagon lily (*Lilium martagon*, Liliaceae, pink). It is strictly forbidden to remove any plant or animal species from the Ecrins National Park. Elsewhere in the Hautes-Alpes, the collection of martagon lilies is strictly regulated, limited to one handful per person with the removal of roots forbidden (p. 103).*



The Green alder has very discreet flowers. This is because it is wind pollinated and therefore does not need to attract insects with brightly coloured petals. Note that the the same tree carries both separate female and male flowers (catkins). This is an example of a monoicous plant (from the Greek:* mono*, one and* oikos*, house; see also p.104). In most plants, the flowers are hermaphrodites, containing both the male and female parts.

Green alder (*Alnus viridis*, Betulaceae) is a subalpine shrub, found in north-facing locations in the mountains of the Northern Hemisphere right up into the Arctic region. This species is very well adapted to deep snow cover and unstable environments (avalanche paths): its flexible branches bend under the weight of the snow, giving the plant its distinctive structure (p. 84).

The roots of the Green alder have numerous nodules which contain colonies of the bacteria (*Frankia*), capable of fixing nitrogen from the air (N_2), and turning it into organic nitrogen in the form of amino acids. The alder makes use of this and in return shelters the bacteria and provides them with nutrients from the photosynthesis which takes place in its leaves. The alder therefore does not need to draw mineral nitrogen (nitrates) from the soil which gives it a competitive advantage at high altitudes. Indeed, generally speaking the soil at altitude is nitrogen poor due to both harsh microclimatic conditions which hamper the mineralisation of organic matter and the fact that the chemical composition of the leaf litter of alpine plants is particularly slow to decompose. This symbiosis (a mutually beneficial relationship between two protagonists) is so successful that the alder cannot make use of all the nitrogen fixed by the bacteria. The excess provides a natural fertiliser for plants in the tall-herb community, which, together with the availability of water, explains their large size.

A similar mechanism is found in plants of the Fabaceae family (Leguminosae), which includes numerous cultivated species such as alfalfa, clover or sainfoin. These plants have a root symbiosis with bacteria called *Rhizobium* which play a vital role in enriching the soil in both natural and agricultural ecosystems.

Green alder root nodules contain colonies of bacteria of the genus* Frankia *which fix the nitrogen from the air.

Leguminosae (Fabaceae) nodules

*Several Fabaceae can be found in this meadow, photographed along the access road to the Alpine Garden: mountain clover (*Trifolium montanum*, white),* Astragalus onobrychis *(purple), alpine bird's foot (*Lotus alpinus*, yellow) and mountain sainfoin (*Onobrychis montana*, pink). These species play a key role in mountain ecosystems by enriching the soil with nitrogen which is then made available to other plants.*

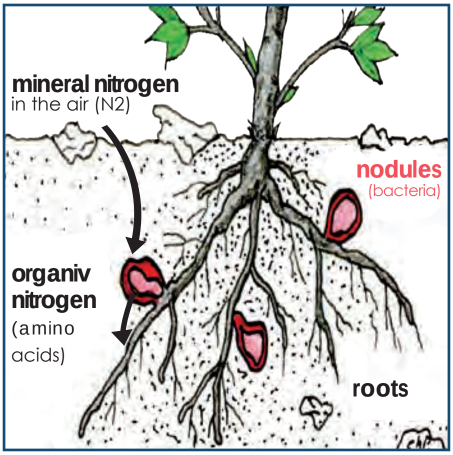


*Diagram showing how root nodules in Green alder and Fabaceae function. The nodules contain symbiotic bacteria (*Frankia *or* Rhizobium*). These in turn contain enzymes which reduce the nitrogen found in the air, using the energy from the carbohydrates produced by the plant from photosynthesis.*

The alpine tall–herb community in the garden

A tall-herb community under green alder has been recreated in the Alpine Garden. It contains plants which naturally grow on the slopes of Combeynot (opposite the Garden, north-facing). The south-facing garden does not offer optimal ecological conditions for the tall-herb community but the chosen site imitates a terrace where snow accumulates, and a stream has been created to provide sufficient water. In the foreground is the garden's peat bog.

*Alpine blue sowthistle (*Cicerbita alpina*) is an Asteraceae found in tall-herb communities and on the banks of streams. Easily recognisable when flowering, it is rare in the Hautes-Alpes where its presence is concentrated in the Ecrins National Park.*

*The Caucasus tall-herb community is one of the most spectacular areas of the Alpine Garden, here are shown the Arietina peony (*Paeonia arietina*, Ranunculaceae) and the Caucasian lily (*Lilium monadelphum*, Liliaceae). These tall-herb communities are remarkable for the height of the different species which can grow to over 2 metres.*

*Giant hogweed (*Heracleum mantegazzianum*) is an Apiaceae which can grow to a height of 5 metres. Note that this plant, introduced into Europe and America, is a phototoxic invasive plant. Its sap contains a light-activated substance which can cause serious burns and inflammation of the skin. In the Alpine Garden, the inflorescences are cut and burned before seeds develop to stop the plant from spreading.*

Around the garden: the Sentier des Crevasses footpath (Ecrins National Park)

The Sentier des Crevasses *is located exactly opposite the Alpine Garden. The Ecrins National Park has put into place information signs about this ecosystem which contains a mosaic of tall herb (see above), and green alder and willow brush environments. In the past, the shrubs ("vernes") were cut down for wood and to create pasture. Since this practice has been abandoned the area has been recolonised by alder, willows and larch (Girel et al 2010).*

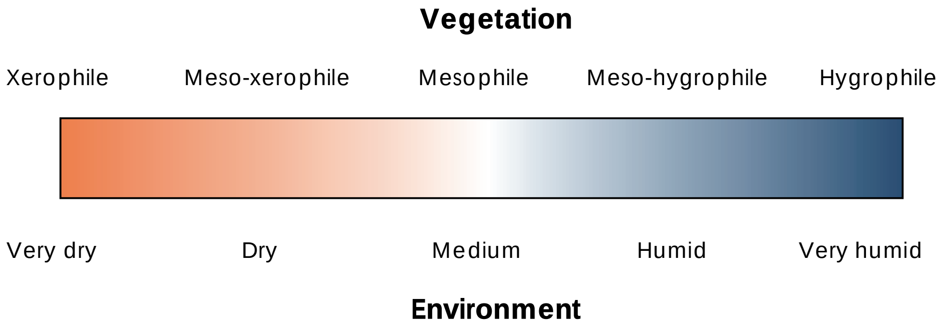
Wetlands

There are several types of wetlands in the Lautaret region, where these ecosystems are often localised and fragile (Manneville et al 2006).

Common sedge bogs occur in fragmented patches close to the sources of the Guisane River. These are peat bogs which develop on an acid substratum (Combeynot granite). Typical species are sedges (*Carex nigra*, *Carex echinata*), cottongrasses (*Eriophorum angustifolium*, *Eriophorum vaginatum*) and bulrushes (*Trichophorum alpinum*, *Trichophorum cespitosum*). Several cushions of *Spaghnum* moss, very rare in the Hautes-Alpes and therefore protected by local by-laws, can also be observed. There are no true *Spaghnum* peat bogs in the Lautaret region due to the relatively dry climate, although such bogs are commonly found in both the external Alps and the Northern Alps.

*The sources of the Guisane river are subject to by-laws for habitat protection. This bog of common sedge (*Carex nigra*) contains a spaghum moss peat bog. The photograph shows the only cottongrass (*Eriophorum vaginatum*) population in the Provence-Alpes-Côte d'Azur region. In the background, the Pics du Combeynot National Nature Reserve.*

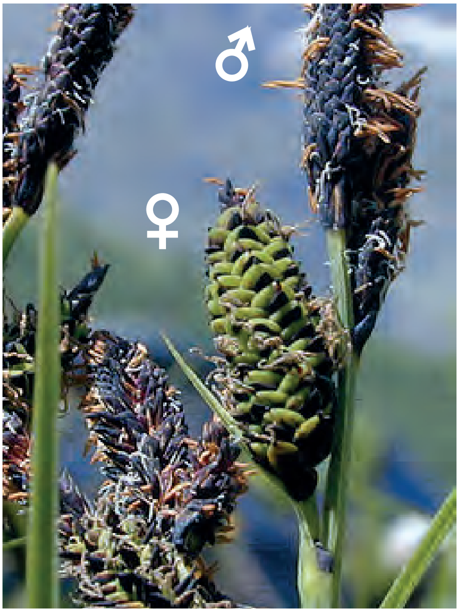
Plant classification in terms of water requirements

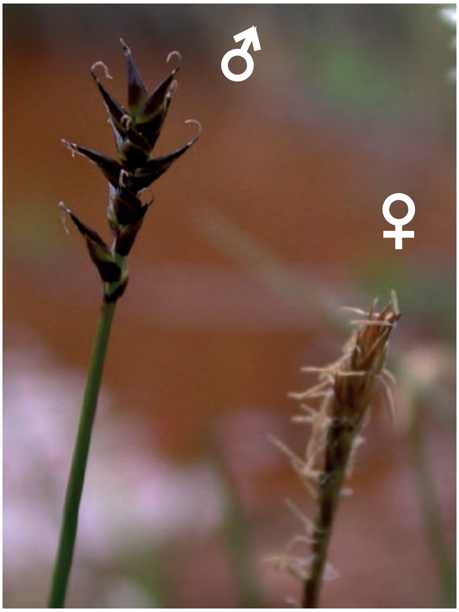


Davall's sedge fens are a typical community found in subalpine zones on calcareous substrates. They develop on terraces at the bottom of the valley and along streams. The characteristic species are Davall's sedge (*Carex davalliana*, one of the rare dioecious sedges, with separate male and female plants), Felwort (*Swertia perennis*, a superb Gentianaceae) and two butterworts (*Pinguicula vulgaris* and *Pinguicula alpina*, Lentibulariaceae) which are insect-eating plants. The most brightly coloured species are the Bird's eye primrose (*Primula farinosa*, Primulaceae), the Common tormentil (*Potentilla erecta*, Rosaceae), Alpine bartsia (Bartsia alpina, Orobanchaceae), Alpine asphodel (Tofieldia calyculata, Tofieldiaceae) and Alpine dactylorhiza (*Dactylorhiza alpestris*, Orchidaceae). The rare Brown bogrush (*Schoenus ferrugineus*, Cyperaceae) can also be found locally around the Col du Lautaret, in areas with calcium-rich runoff.

Brown bog-rush (*Schoenus ferrugineus*, Cyperaceae) is a protected species. It is relatively abundant in the Col du Lautaret area.

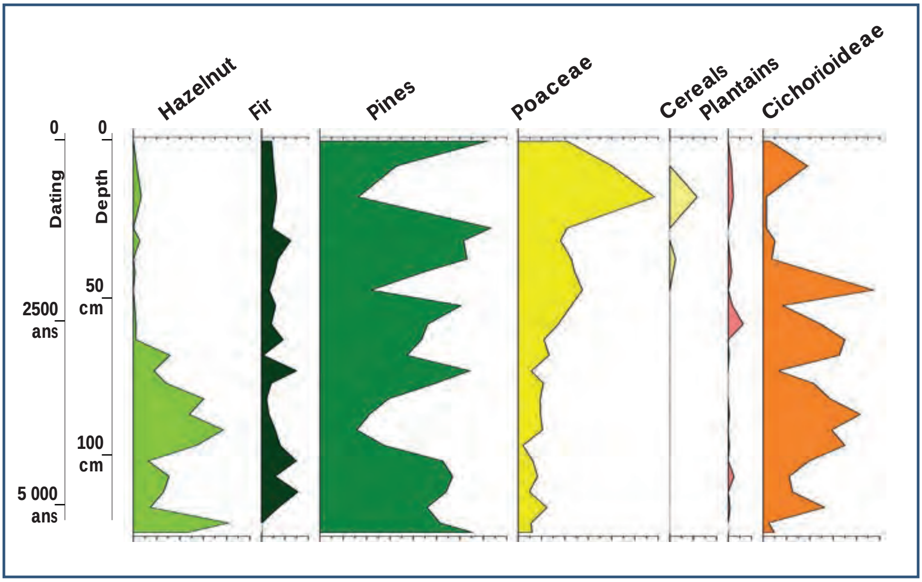
- *The removal of plants, animals and rock specimens from the central zone of the Ecrins National Park is strictly prohibited. The adhesion zone which includes local municipalities which have signed up the Park Charter is subject to less stringent regulations.*
- *The Pics du Combeynot National Nature Reserve, set up under the law dated 15 May 1974, is managed by the Ecrins National Park. Its regulations specify that collecting, destroying or pulling up plants is strictly prohibited. There is however an exception which allows land owners or authorised individuals designated by the local council for the land it owns, free access to medicinal plants and other wild products.*
- *The by-law protecting the Guisance sources habitat, dated 1st April 1987, is intended to protect a specific habitat, in this case a high altitude wetland, but not the individual species themselves. It is strictly forbidden to pull up, collect or introduce plants, except for specific agricultural or forestry purposes.*
- *The Ecrins-Lautaret-Combeynot Zone Natura 2000 is part of the European network of ecological sites which has the combined objectives of preserving biological biodiversity and promoting the area's natural heritage. Two European Directives, the Bird Directive (1979) and the Habitats Directive (1992) set out the regulatory framework for the network. In contrast with Nature Reserves, a Natura 2000 site is a natural space managed by local stakeholders with actions implemented under contract. The concept of ecological compensation measures applies to projects with "particularly harmful effects" i.e. whose harmful impact on the conservation of habitats and species cannot be reduced.*
- *Several ZNIEFF (Natural Sites of Ecological, Faunistic and Floristic Interest) cover the Col du Lautaret area, notably the ZNIEFF 05-101-10 (covering the south-facing slopes of Villar-d'Arène, the Col du Lautaret, the Col du Galibier, Grand Galibier and Roche Colombe). The ZNIEFF inventory is constituted for information purposes only and does not offer direct legal protection.*
- *The species protected at national level are listed in the order dated 20th January 1982 (modified in 1995) which bans their collection, sale and trade. Alpine sea holly (*Eryngium alpinum, *Apiaceae) and* Potentilla delphinensis *(Rosaceae) both feature on this list.*
- *Several species are protected at regional level (order dated 9 May 1994 lists the plants protected in the Provence-Alpes-Côte d'Azur region) and/or local level (by-law dated 22 November 1993 for the Hautes-Alpes, modified on 3 July 2008). In the Hautes-Alpes, the collection of three species of genepy (*Artemisia genipi, A. glacialis and A. umbelliformis, *Asteraceae) is limited to 100 sprigs per person, per day with a ban on destroying, pulling up or removing the roots, an obligation to cut the sprigs with secateurs, and a ban on their trade, sale or purchase. It is prohibited to collect the species* Artemisia eriantha. *As regards Edelweiss (*Leontopodium alpinum, *Asteraceae), its collection is forbidden in the municipalities of Gap, La Roche-des-Arnauds, Rabou, Manteyer, Pelleautier and Chateauneuf d'Oze, whereas in other municipalities (including the Lautaret area) its collection is restricted to one adult handful, with a ban on its destruction, uprooting, trade, sale and purchase.*



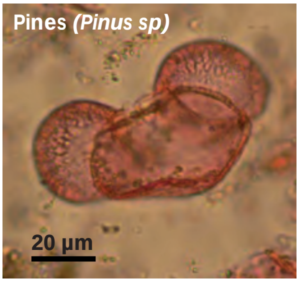


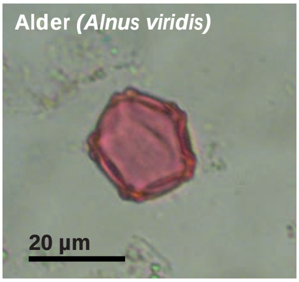
On the left, common sedge (Carex nigra, Cyperaceae), a species commonly found in bogs. It is a monoicous species, which has male flowers (grouped in black spikes, top right) and female flowers (grouped in green spikes, centre) growing separately on the same stalk. On the right, Davall's sedge (Carex davalliana), a species commonly found in fens. It is a dioecious species, i.e. with separate male and female plants.

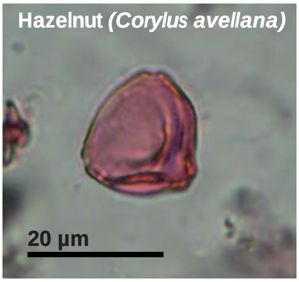
Examples of fen species. On the left, bird's eye primrose (Primula farinosa, Primulaceae, pink) and alpine butterwort (Pinguicula alpina, Lentibulariaceae, white). On the right, common butterwort (Pinguicula vulgaris).

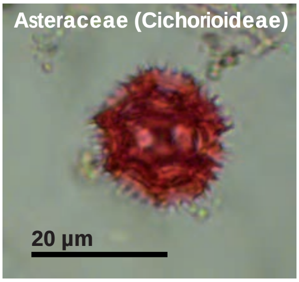


Peat bogs and fens trap pollen grains (examples below) which are preserved for thousands of years in the peat. Analysing these pollen grains allows us to reconstitute the different types of plants which have existed successively over time. The diagram above was produced in 2012 from the Charmasses bog 500 m from the Col du Lautaret. It retraces changes in the vegetation over the last 5 millennia due to associated climate change and human impacts (deforestation, increase in pasture lands, cereal farming and the expansion of associated plants such as plantains and chicory). Produced by A.-L. Cabanat (Master 2 Research placement supervised by F. David and S. Aubert).





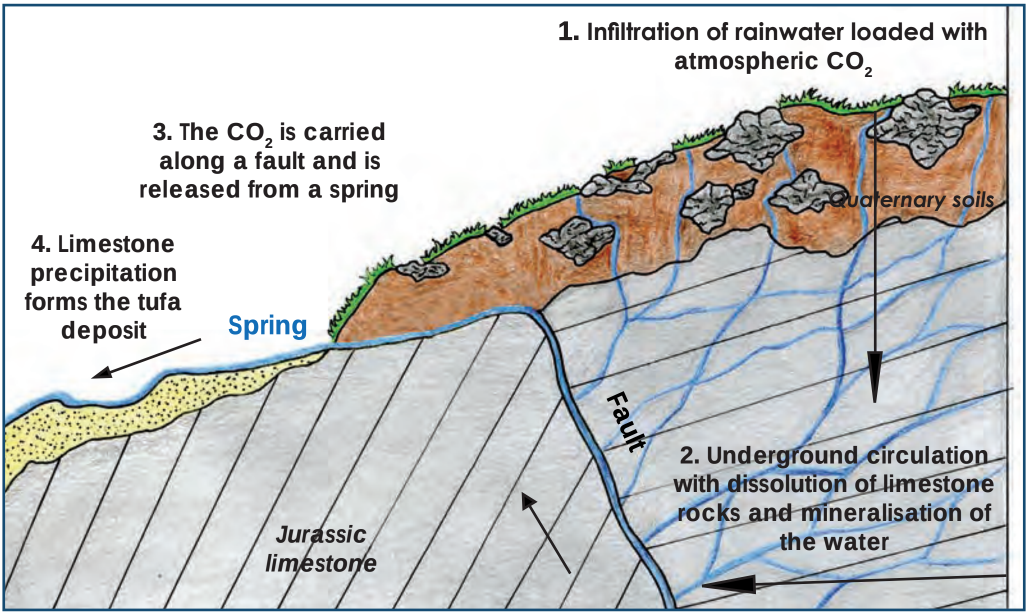




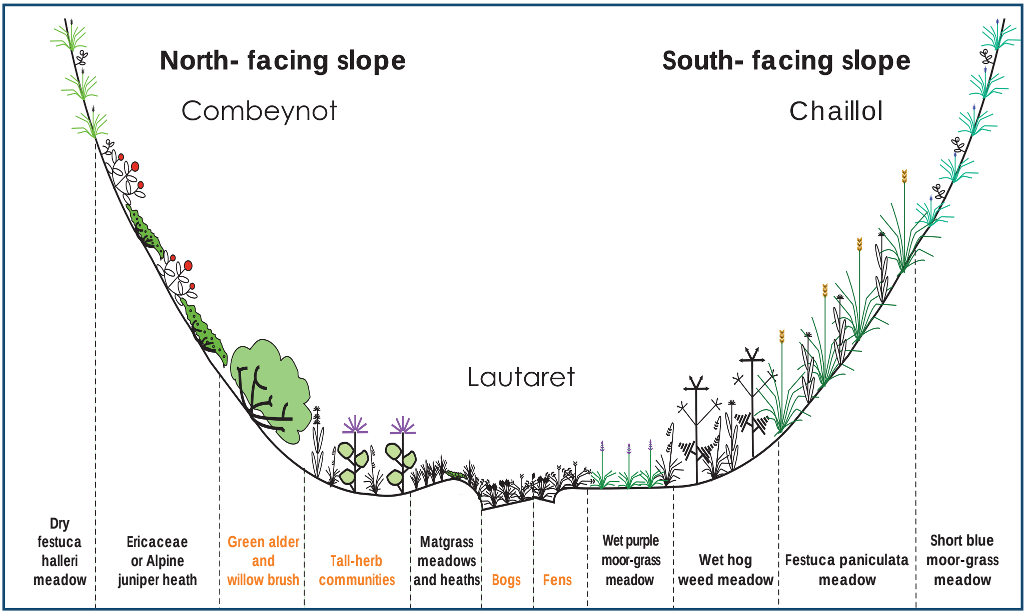
Tufa deposits, one of which is located close to the gazebo in the Alpine Garden, are formed when water passing through surrounding calcareous rocks, becomes loaded with bicarbonates which subsequently precipitate in the form of limestone, forming a petrified spring. A sloping fen then develops, containing a rich flora. The travertine (or calcareous tufa) which accumulates over several thousands of years, captures and fossilises the neighbouring plants. Studying these deposits makes it possible to reconstitute past environments (Latil et al 2012, p. 109). This habitat is now protected under the European Natura 2000 programme.

Alpine dactylorhiza (*Dactylorhiza alpestris*, Orchidaceae) in the tufa deposit located in the upper section of the Alpine Garden.

The active tufa deposit in the Alpine Garden. Iron deposits colour the limestone which has precipitated at the petrified spring, red.



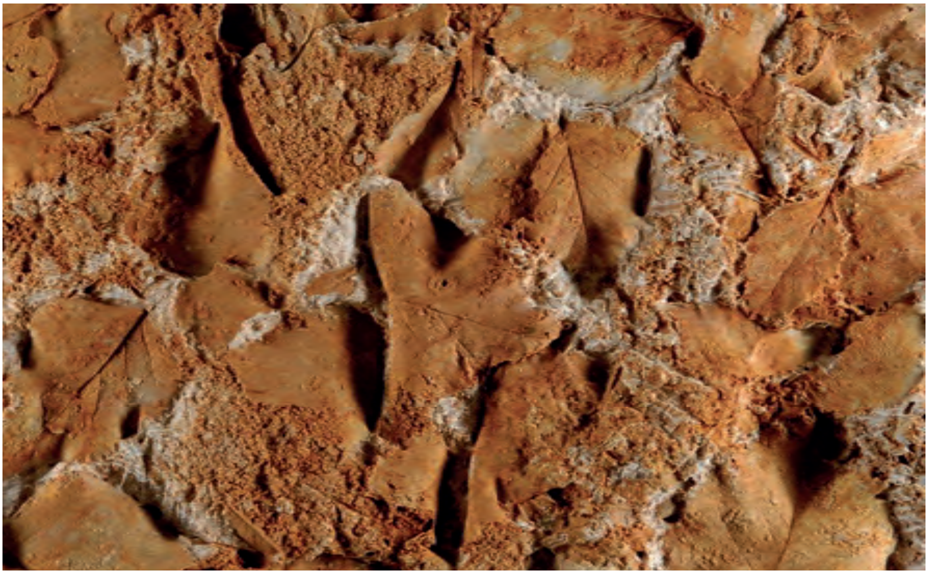
Rainwater acidified by atmospheric carbon dioxide (CO_2) dissolves limestone rock (calcium carbonate: $CaCO_3$) it passes through during its underground journey. The water becomes mineralised, loaded with dissolved ions (calcium Ca^{2+} and hydrogencarbonate HCO_3^-). When it reaches the spring, the water contains more CO_2 than the air and this excess carbon gas is degassed or absorbed by algae and photosynthetic bacteria. The calcium ions precipitate in the form of calcium carbonate ($CaCO_3$) which encrusts plants and fossilises them. Sketch Ch. Perrier.



Transect showing the distribution of plant groups in subalpine zones in the Col du Lautaret area, on the south and north-facing slopes. In orange, the environments described in this section (from Molinier and Pons 1955, Bull. Soc. Scient. du Dauphiné 69:2-19, details in Aubert et al 2011).

*Two superb Gentianaceae from the Alpine Garden tufa deposit: willow gentian (*Gentiana asclepiadea*, left) and felwort (*Swertia perennis*, right). Willow gentian grows in the mountains of central and eastern Europe, especially in moist forests. Felwort is a species found in the Northern hemisphere (Eurasia and North America), typically in fens, which is very sensitive to habitat destruction.*

Studying fossils in the tufa deposits in the Alpine Garden has provided us with a good historical overview of the plant life and some of the fauna in the area studied. In particular, the presence of forests of Pinus uncinata *(above) and deciduous trees (below) dating back 10,000 years raises questions regarding the expansion of forests and movement of glaciers at this time, at the end of the glacial cycle (Latil et al 2012).*



Around the garden: Tufa deposits and construction

Calcareous tufa or travertine, which is light and easy to carve, is used for many types of buildings, and is commonly used to make cornerstones. The church at Villar d'Arène was built using tufa from Lautaret, and the church at Terrasses using tufa from the Vallon de la Buffe. This house in the Rivets hamlet (in the municipality of La Grave) has cornerstones (on all four corners) and frames (door and window surrounds) made alternately from shale and tufa blocks. The lintels are made of larch wood. The fireplace has also been renovated in the same style.

Plants and snow

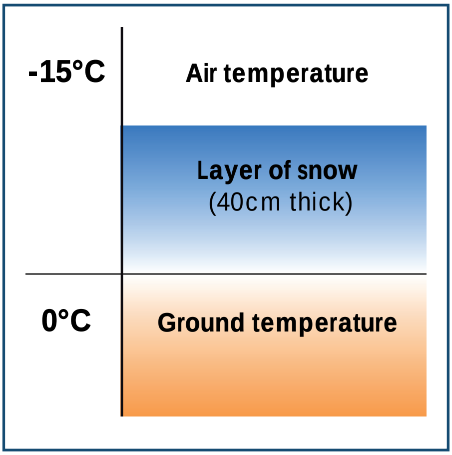
One of the main constraints in alpine zones is the cold, and one of the consequences of low temperatures is snowfall. Snow causes serious damage in the winter, especially to trees and shrubs. It is also one of the factors which determine how plant communities are structured by altitude.

Snow is destructive, but it can also be protective. Indeed, it is a very poor heat conductor. The temperature under very thick snow cover does not drop below zero even in the depths of winter. This is because the snow cover traps lots of air which has insulating properties.

Summer visitors to the Alpine Garden may find it hard to believe that it is covered in snow for over half the year. Note that the Mountain pines* Pinus mugo *disappear under the snow (p. 164, 180, 186).

The duration of snow cover is a factor which determines the length of the growing season and a plant's opportunities for growth. Snow cover varies widely, depending not only on altitude, but also on aspect.

*This picture taken at the Alpine Garden in February 2001 shows a larch whose trunk was broken off by the snow in a previous winter. A side branch has taken over. In the background we can see the flexible branches of the Siberian dwarf pine (*Pinus pumila*, Pinaceae) which bend without breaking, like the branches of the green alder (p. 95) or mountain pine (p. 111). These pines are practically invisible in the winter as they are covered by the snow.*



The diagram opposite shows that a layer of snow of just 40 cm is enough to insulate the ground from negative temperatures. This snow cover protects plants and even certain animals such as snow voles which live at the interface between the ground and the snow.

A weather station set up close to the Alpine Garden measures meteorological data including air and ground temperature and humidity, direct and reflected light intensity, wind speed and snow cover. This station was set up in 2012 in order to measure gas flows (notably of CO_2), and water and energy exchanges between the ground, the plant life, the snow and the atmosphere. Images are also used to analyse the dynamics of snow cover and vegetation development. This project was born out of a collaboration between the SAJF (Joseph Fourier Alpine Research Station), the LECA (Laboratory of Alpine Ecology in Grenoble), the LTHE (Laboratory for the Study of Transfers in Hydrology and the Environment), and the LGGE (Laboratory of Glaciology and Environmental Geophysics – an OSUG@2020 laboratory of excellence and innovative strategies for observing and modelling natural systems). The project is one of the activities of the Zone Atelier Alpes (Alps Workshop Zone), a mechanism set up by the CNRS's institute of ecology and environment to bring together different stakeholders researching alpine ecosystems, notably in the Ecrins National Park.

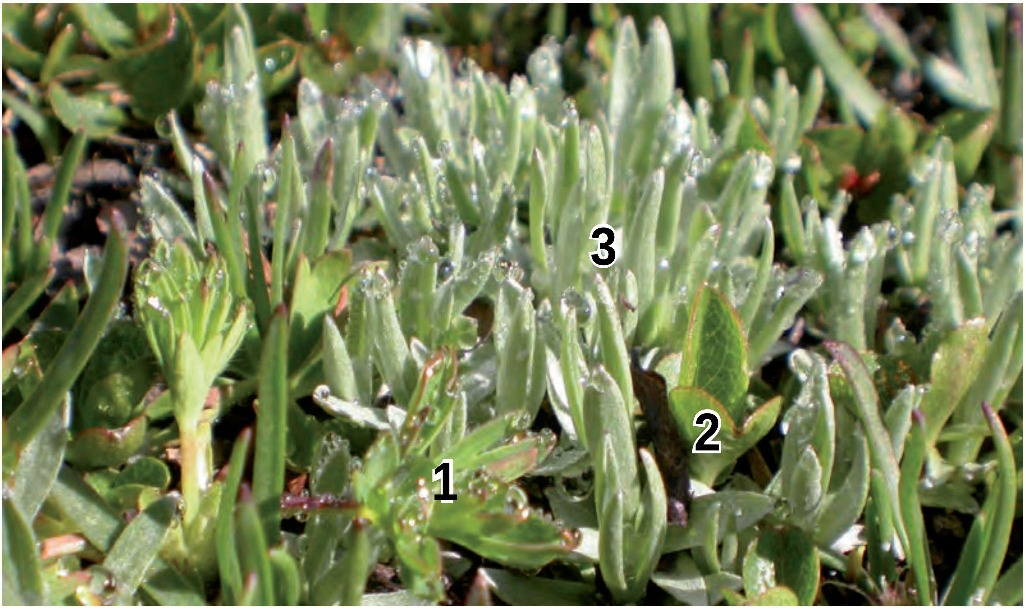
*An example of opposite facing slopes on the Chaillol mountain (which dominates the Garden to the north). The south-facing slope thaws several weeks before the north-facing slope. The growing season is longer but plants have to adapt to increases in frost and excess light. The types of vegetation commonly found on the upper parts of the south-facing and north-facing slopes are respectively, blue moor grass (*Sesleria caerulea*, Poaceae, picture bottom left) and Ericaceae heaths, including alpenrose (*Rododendron ferrugineum*) and the bilberry (*Vaccinium myrtillus*, picture bottom right). In the autumn, the blueberry leaves colour the north-facing slopes of the mountains red.*

Snow beds: Advantages and disadvantages

Plants in snow beds are protected throughout the winter by snow cover. However, in years with high levels of snow cover, the growing season is almost non-existent as the snow doesn't have time to melt over the summer. Under these conditions, plants can survive for one, sometimes two, years under the snow. The following year they will make another attempt to grow and flower.

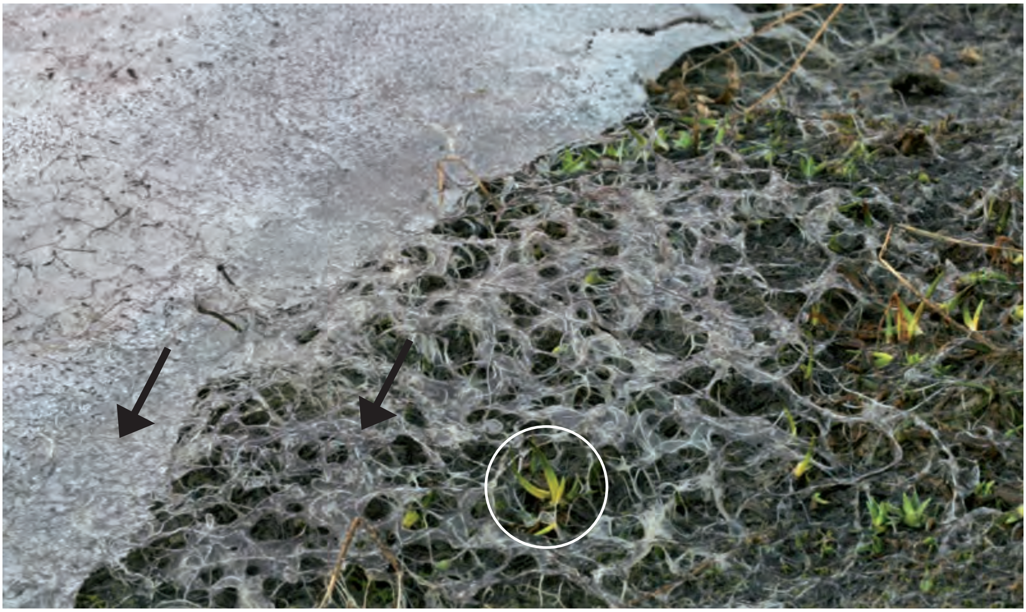
Snowbeds are particularly fascinating environments. These are troughs in the ground where particularly thick snow cover of several metres accumulates and where extremely tiny plants are found. This is as should be expected since the time required for the snow to thaw means the growing season is very short, allowing plants just 2 to 3 months to grow and reproduce, in a good year. The only way to really get to know these species is down on all fours with your nose to the ground!

Recent research at the Laboratory of Alpine Ecology in Grenoble (by Ph. Choler, R. Geremia and shown here, J.-C. Clément and S. Ibanez) looks at the dynamics and functioning of microbial communities in mountain soils. Bacteria and fungi remain active under the snow (see picture above taking winter samples from a snow bed) with different species found during snowmelt and during the summer. These micro-organisms play a key role in carbon and nitrogen cycles (photo Ph. Choler).



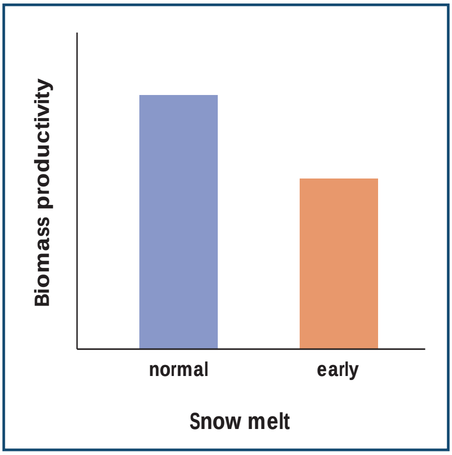
These discreet communities of dwarf plants, characteristic of snow beds can be found towards the end of July and during the month of August. Here we can see, Alchemilla pentaphyllea *(1, Rosaceae),* Salix herbacea *(2, Salicaceae),* Omalotheca supina *(3, Asteraceae).*

Two flowers from snow bed plants. On the left, Sibbaldia procumbens*, a dwarf Rosaceae with a flower measuring just a few millimetres; on the right, alpine foxtail (*Alopecurus alpinus*), a Poaceae whose silky inflorescences make it very easy to recognise.*



*When the snow melts, young alpine foxtail plants (*Alopecurus alpinus*, Poaceae, white circle) develop a root network which grows at the interface between the snow and the soil (arrows). They probably facilitate the assimilation of the nitrogen present in the snow cover, as demonstrated in a snow bed plant in the Caucasus.*

Unlike snow beds, ridges are exposed to the wind and the plants are only covered in snow for a few weeks each winter. They have a long growing season but have to cope with more intense stresses: extreme cold, drought, excess solar radiation, poor soils. These plants have adapted both morphologically (tussock and cushion plants which conserve heat, for example) and physiologically (frost resistance, recycling of mineral elements from dead leaves, etc.).



Experiments with early snow melt in snow beds have been carried out at the Alpine Station with the aim of imitating global warming. The plants which emerge from the snow cover earliest have the lowest productivity (production of biomass in relation to the number of days without snow) even though they have a longer growing season. It would appear that they have a low resistance to frost at the start of the season when they are unprotected by snow cover. Paradoxically climate warming will actually leave these plants more exposed to the cold (research work coordinated by Ph. Choler at the Laboratory of Alpine Ecology in Grenoble; Baptist et al 2010).

The first plants to grow in the garden after the thaw

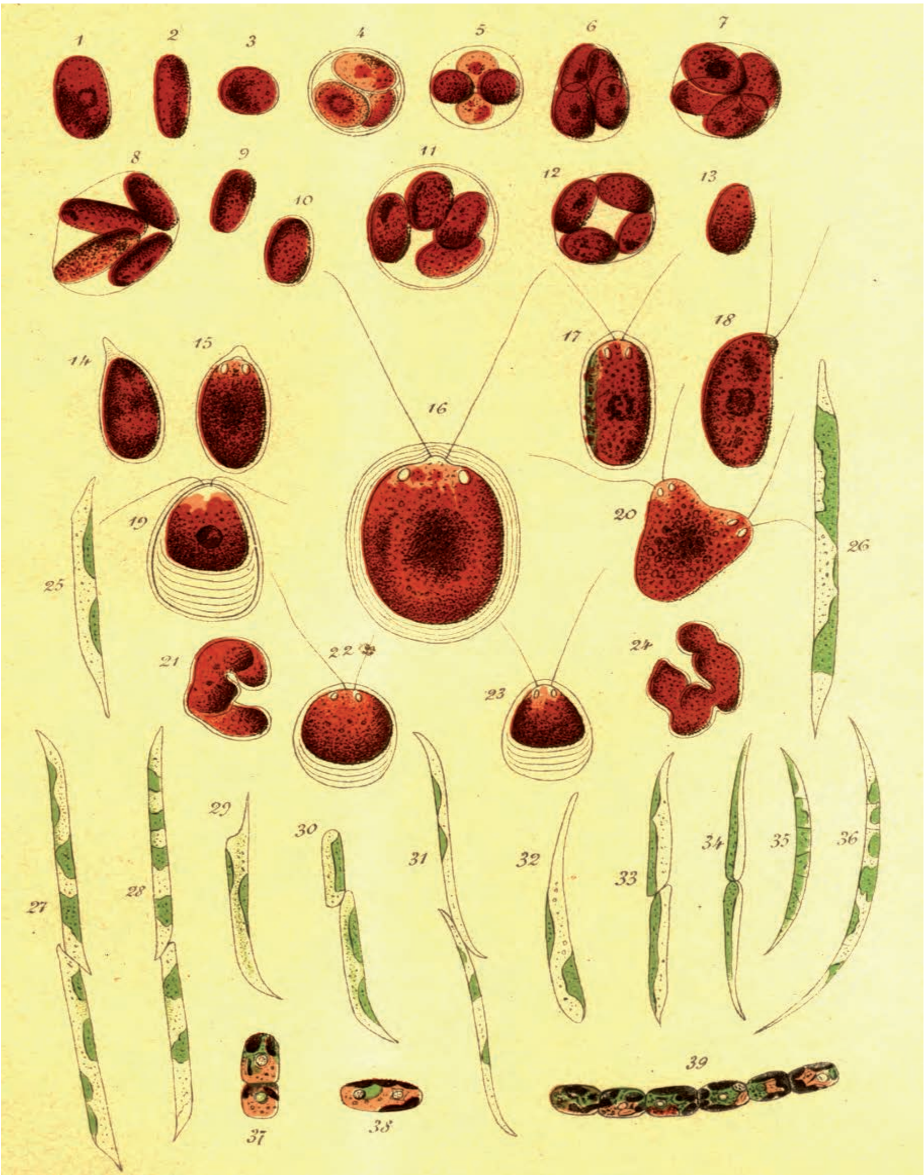
*The white marsh marigold (*Caltha leptospala*, Ranunculaceae) is found in humid environments in the west of North America. It grows from Alaska down to New Mexico in subalpine and alpine zones.*

On the left, Primula rosea *(Primulaceae), a splendid species found in humid areas at altitude in the Himalayas. On the right,* Erythronium grandiflorum, *a bulbous Liliaceae found in the subalpine forests of the west of Canada and the United States of America.*

Adonis pyrenaica *(Ranunculaceae) is rare plant protected nationally (Appendix I). It grows in rocks and scree in the French and Spanish Pyrenees, as well as very locally in the Alpes-Maritimes.*

*Left, Michael's flower (***Fritillaria michailovskyi***, Liliaceae), a bulbous plant from the mountains of the North-East of Turkey. Right,* **Tulipa turkestaniska** *(Liliaceae), is a tulip from the mountains of Turkestan and the North-West of China*

Around the garden: Plant life in the snow



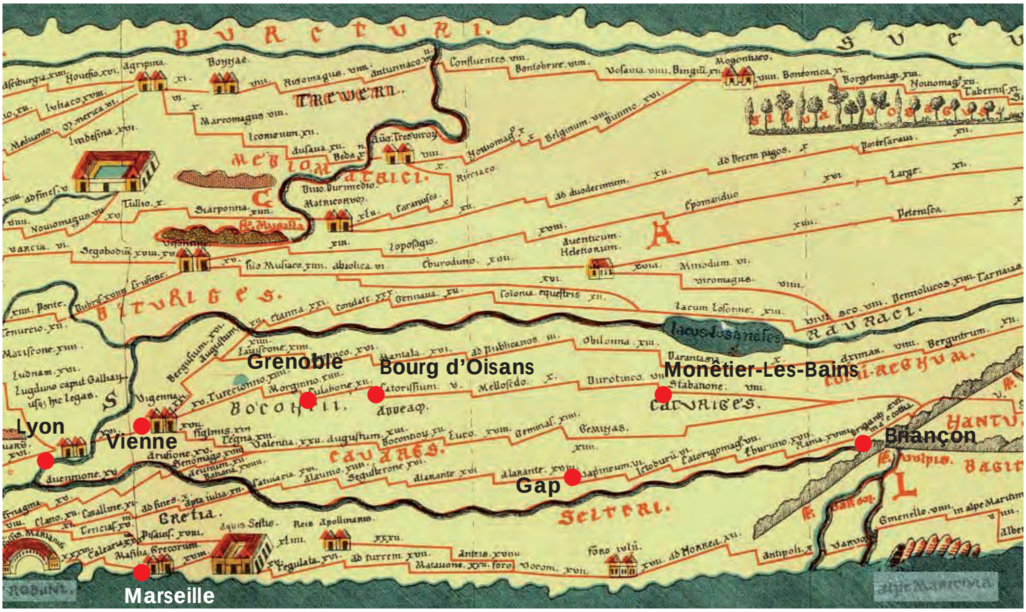
Snow is actually a living environment for certain algae. These organisms which live in hostile environments are called extremophiles. The sketch above shows the different phases of the life cyle of Chlamydomonas nivalis, *a microscopic unicellular alga which synthesises protective pigments (carotenoids) which give the surface of the snow on which they proliferate a red colour, a phenomenon which can be observed on spring snowdrifts and which gives it its common name "Watermelon snow". It was described and sketched by the Swiss botanist Robert Chodat in 1896 (Bull. Herb. Boissier. 4, p. 879-889).*

Man and the Pass

The history of the Pass

The Col du Lautaret is an ancient thoroughfare. The oldest traces of human activity go back as far as the Bronze Age (900 BC) and various objects from this period have been discovered at an altitude of 1900 m at "Casse Rousse" in the Lautaret region. In Roman times, the route linking Grenoble to Italy via Briançon was already in use, and in the 15th century the Dauphin created a refuge at the pass to shelter pilgrims and travellers. Other refuges, which have now disappeared or are in ruin, were situated either side of the Col du Lauteret (in Loche and La Madeleine). They offered poor travellers free food and lodgings. The Lautaret refuge belongs to the Villar d'Arène municipality and its management is put out to tender. Until the 1950s, the manager had to keep it open all year round.

Engraving of the Col du Lautaret and its refuge (Sabatier, in Nodier et Taylor, 1846). Unlike other engravings of this period, this is a very realistic image. Note here how much larger the Glacier de l'Homme was at the end of the Little Ice Age. Wooden markers were set up to indicate the route in winter. Today, these posts are made of metal (although on the road over the Col du Galibier they remain wooden) and are still used to help with snow clearance.



Part of the Peutinger Map. This document, dating from the beginning of the first millennium, shows the road network of the Roman Empire. The original document, a scroll around 7m long, is conserved in Vienna, Austria. The road from Briançon to Vienne, the French city which was a much more important town than Grenoble at that time, is marked in red.

One of the first photos of the Col du Lautaret taken in around 1890, with the old refuge (left) and the new Napoleonic refuge. The cows probably belonged to the manager of the Dauphin's refuge. Note the extent of the Glacier de l'Homme (see also the engraving above), as compared to the photo taken in the 1930s (p. 127) and today (p.167).

The Col du Lautaret in around 1910 with the Napoleonic refuge on the right (and its annexes) and opposite, on the other side of the road, the two buildings of the Hôtel des Glaciers, belonging to the Bonnabel family. On the left, we can see the chalet which has been shored up, and which was destroyed in 1930 as a result of a legal technicality (the other chalet burned down in 2000 and was replaced by a four-star hotel). In the foreground is the Alpine Garden, created in 1899 by Jean-Paul Lachmann with funding from Alexandre Bonnabel. It was located just next to the road at the point from which the Gabilier road now joins. The Garden had to be moved to its current site when the road was built. Picture from Agency Chusseau-Flaviens, one of the first press agencies created in Paris at the very beginning of the 20th century.

Between 1859 and 1862 the new Napoleonic refuge was built at the Col du Lautaret and a new national road was built alongside it (a project was initiated by the préfet Joseph Fourier at the beginning of the 1800s.) This building completed the older refuge and was used to welcome in travellers and provide lodgings for a road-mender responsible for maintaining the road.

From the 1890s, the road-mender Alexandre Bonnabel started to develop tourist accommodation at the pass. He built annexes all around the Napoleonic refuge and a Swiss-style chalet. The chalet was soon extended and a second one built. In a matter of just a few years, Alexandre Bonnabel had become a hotel manager with 200 rooms to let to the tourists, who arrived in ever-increasing numbers with advent of motor transport. The promotion of the Route des Alpes, an initiative of the Touring Club de France, lead to the construction of the Galibier road and ensured a steady stream of tourists to the Col du Lautaret, ideally situated at the crossroads of the Grenoble-Briançon and the Evian-Nice roads.

Trips organised by the newspaper Le Petit Dauphinois *started out from the Place Grenette in Grenoble and visited sites of interest in the Dauphiné. Shown here at the Col du Lautaret in the Hôtel des Glaciers car park opposite the Dauphin's refuge (left) and the annexes of the Napoleonic refuge (right). Photograph Augustin Michel (?), Radisaw Tomitch fund. Inv. N° C72.314, © Coll. Musée dauphinois.*

The Napoleonic refuge in around 1930 with its numerous annexes: two in front, two on either side and others behind (see p.124). In the background, on top of the slope, is the PLM Chalet-Hotel and garage (right). On the left, a sign on the wall of the Dauphin's refuge points visitors towards the PLM and gives them the price for lunch (20-25 francs). Photograph Martinotto Frères. Inv. N° C88.740, © Coll. Musée dauphinois.

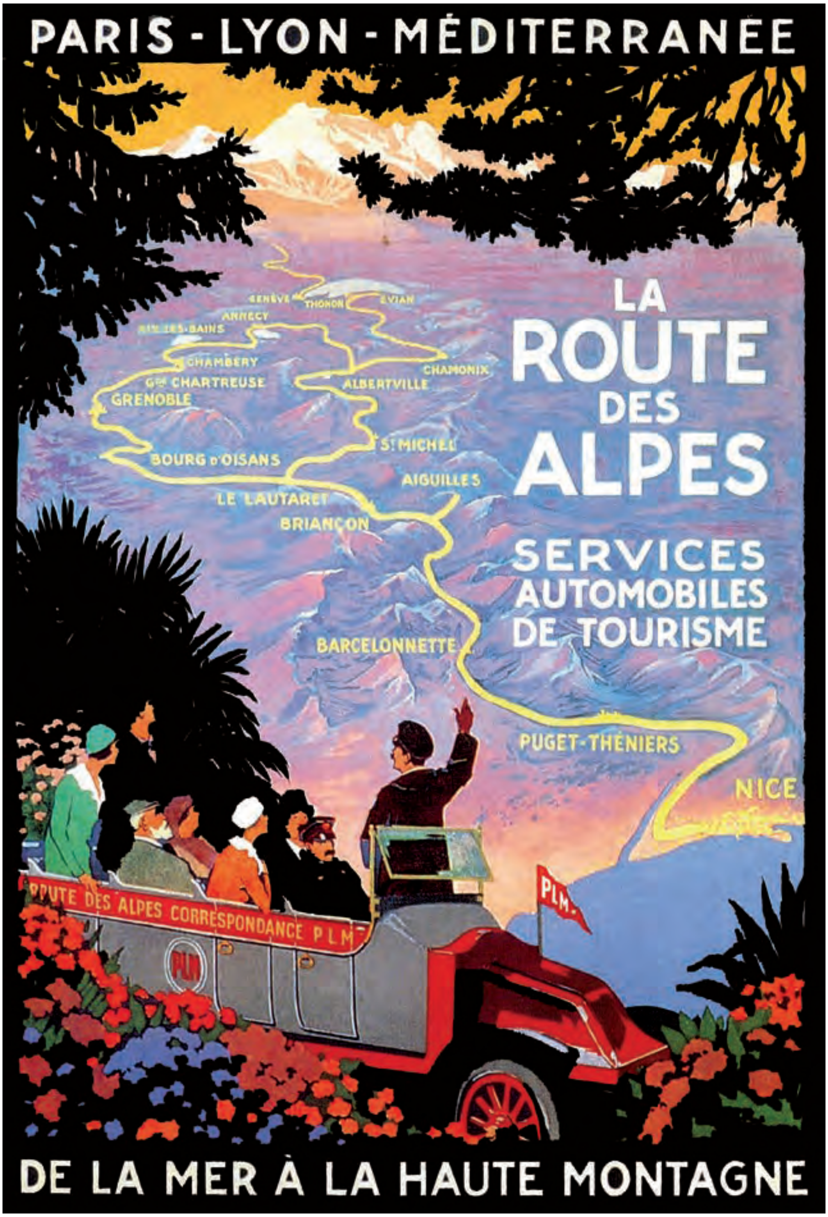
Painting by Pierre Comba showing the Col du Lautaret around 1900 and the arrival of an alpine horse-drawn carriage. The buildings shown here belong to the Hôtel des Glaciers (in the foreground) and the Napoleonic refuge (in the background).

In 1914, the railway company Paris-Lyon-Méditerranée (PLM) opened a chalet-restaurant at the Col du Lautaret. Coach companies carried passengers between Grenoble, Briançon and St Michel de Maurienne. Very quickly the building was expanded to become a luxury hotel and restaurant, a stopover on the Route des Grandes Alpes, which crossed the main passes between Menton and Lake Geneva (Aubert and Bignon 2013). In 1919, the PLM company provided a new (the current) site for the Alpine Garden and topped up the subsidy offered by the Touring Club de France to fund the move. The PLM hotel continued to do business until it was burnt down by the German army in 1944.

PLM posters drawn by Hugo d'Alesi (left) and by Eugène Bourgeois (right, press Ateliers F. Hugo d'Alesi), showing the Col du Lautaret, the Hôtel des glaciers, the Napoleonic refuge and the Meije; the ®PLM/Paris- Lyon-Méditerranée brand belongs to the Accor group. © Wagons-lits diffusion SA 1999 © ADAGP, Paris 1999.

The PLM Chalet-Restaurant, at its opening in 1914, with PLM coaches for different destinations in the car park. On the right, is the kitchen building; on the left, the dining room and the entrance hall. Photograph G. Oddoux, photographer from Grenoble.

The PLM Chalet-Hotel at the height of its popularity in the 1930s, with PLM coaches in the carpark on the left and private vehicles in the car park on the right. The Meije glaciers, in the background, are now retreating. Photograph A. Mollaret, photographer from Grenoble.



Roger Broders PLM poster showing the Route des Alpes. Note the strategic position of the Col du Lautaret, on both the road from Grenoble to Briançon and the Route des Alpes between Evian and Nice. The ®PLM/Paris-Lyon-Méditerranée brand belongs to the Accor group. © Wagons-lits diffusion SA 1999 © ADAGP, Paris 1999.

Today, hundreds of thousands of vehicles cross the Col du Lautaret Pass, mostly transporting tourists. The Alpine Garden and the Ecrins National Park (created in 1973) are the pass's two main attractions. In the winter, the pass has become a hospot for ski touring and, more recently, snow-kiting.

The Rock Gardens

The Southern Alps

This region includes the French and Italian Maritime Alps as far as the Trentino region in Italy. It has a high species diversity and many of these species are endemic, which is connected to its geographical isolation, the presence of significant limestone areas and the overlap between the Alpine and Mediterranean regions.

European or common peony (*Paonia officinalis*) and mountain pine (*Pinus mugo*)

Allium insubricum

Rhaponticum heleniifolium

Lilium pomponium

Paederota lutea

Linaria alpina

Saxifraga retusa ssp. *augustana*

Bupleurum longifolium

Fritilaria meleagris

Leontopodium alpinum

Sempervivum grandiflorum

The Eastern Alps

At the time of post-glacial re-colonisation, this part of the Alps benefited from botanical influences from the Balkans and the Carpathian Mountains. Massifs that are renowned for the diversity of their flora include the Dolomites (3343 m), Triglav (2864 m), the Karawanken (2237 m) and the Hohe Tauern (3798 m).

Primula clusiana in front of Mountain Pine and the peaks of Combeynot


Campanula thyrsoides ssp. *carniolica*


Cirsium carniolicum


Gentiana pannonica


Hesperis matronalis ssp. *nivea*


Lilium martagon var. *cataniae*


Dianthus alpinus


Hacquetia epipactis


Scorzonera rosea


Senecio abrotanifolius


Rhododendron hirsutum

The Massif Central

Geologically the Massif Central is very ancient and mainly composed of granite. It was rejuvenated by the uplift of the Alps and by intense volcanism. The mountains are of medium altitude and their flora is similar to that of the Alps and the Pyrenees.

View of the Chalet - Laboratory

Adonis vernalis

Centaurea pectinata ssp. *pectinata*

Genista tinctoria

Hieracium aurantiacum

Pulsatilla vulgaris var. *costeana*

Tulipa australis

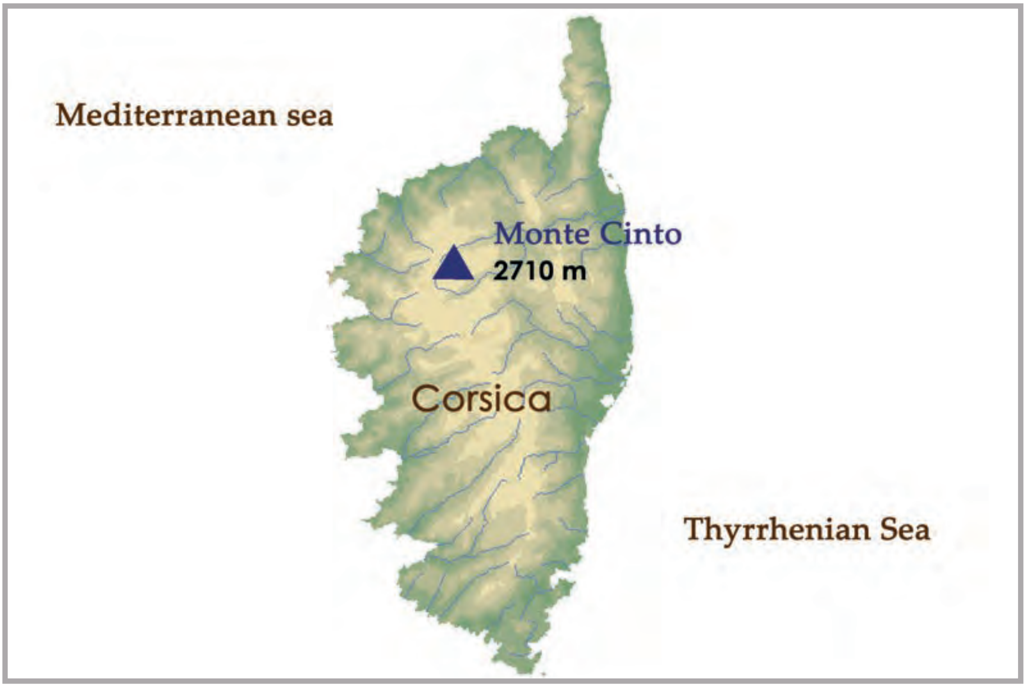
Sempervivum arvernense

Iris lutescens ssp. *lutescens*

Persicaria bistorta

View of the Meije

The Corsican Mountains



Very mountainous terrain means that Corsica has higher precipitation than other Mediterranean islands. The high summits are home to very rich Alpine flora (10% endemism). Some species can also be found in Sardinia, at lower altitude (1834 m).

The rock garden before it was moved to its current position in 2012

Asperula gussonei

Doronicum corsicum

Euphorbia myrsinites

Aquilegia bernardii

Potentilla corsica

Paeonia coriacea

Cymbalaria hepaticifolia

Aconitum corsicum

Thymus herba-barona

Stachys corsica

The Pyrenees

The Pyrenees separate France from Spain and stretch for about 400km. The range continues to the Basque-Cantabrian Mountains. The geological and climatic diversity means the flora is highly varied (2,500 species), with a notable contrast between the Spanish (dry) and French (wet) slopes.

View of the Combeynot Massif

Achillea pyrenaica

Allium moly

Allium pyrenaicum

Fritillaria pyrenaica

Aster pyreanicus

Papaver lapeyrousianum

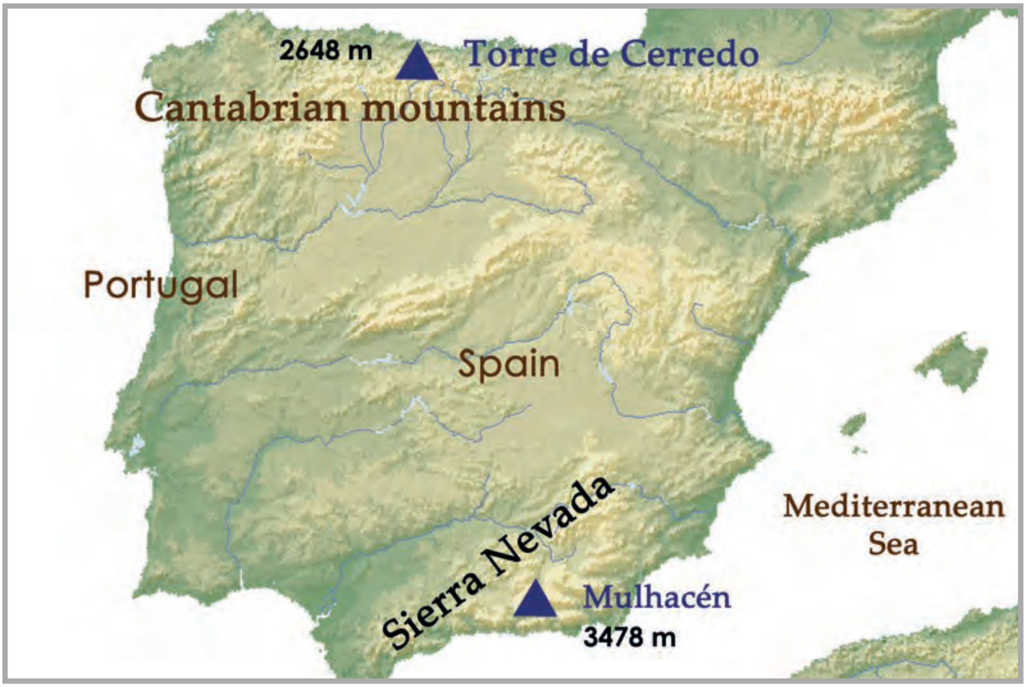
Rhaponticum centaurioides

Saxifraga longifolia

Lilium pyrenaicum

Saxifraga aquatica, Lilium pyrenaicum and the Combeynot Massif

Spanish mountains



The Cantabrian range is located in the north of the country and is an extension of the Pyrenees. It has an oceanic climate and its flora has an affinity with the Pyrenean flora. The Sierra Nevada, in the south of Spain, is an "island" in the middle of the semi-arid region of Andalusia, and its flora has an affinity with that of the North African Atlas.

The rock garden is covered in shale, which dominates the landscapes of the Sierra Nevada

Arenaria agregata

Anemone pavoniana

Chaenorrhinum glareosum

Gentiana occidentalis

Plantago nivalis

Vella spinosa

Pulsatilla rubra

Ptilotrichum spinosum

Linaria aeruginea

Panoramic view towards the Galibier Pass

The Apennine Mountain Range

These mountains run the length of Italy for over 1,000 km. The central Apennines are made up of high massifs, such as the Abruzzo. Alpine flora has developed above the beech forest and pines. It includes species adapted to life on cliffs or on the white sandstone scree which dominates the landscapes.

Linaria purpurea and *Cerastium tomentosum*

Phyteuma scheuchzeri ssp. *collumnae*

Achillea oxyloba

Erysimum majellense

Linaria purpurea var. *montana*

Cymbalaria pallida

Centaurea parlatoris

Geranium argenteum

Cynoglossum majellense

Armeria majellensis

The new scree in the Apennine Rock Garden (see p. 29)

Balkan Peninsula

This peninsula in South East Europe includes the following mountain ranges: Stara Planina, Rila, Pirin and Rhodope (Bulgaria), the Pindus (Greece, Albania) and the Dinaric Alps (the former Yugoslavia). These mountains are subject to a strong Mediterranean influence that includes plants adapted to dry summers.

Visit of the biology department of Grenoble university in 2003, under the direction of J-G Valay

Anthemis cretica

Asperula nitida

Iris pallida

Degenia velebitica

Geranium macrorhizum

Geum bulgaricum

Knautia macedonica

Lilium carniolicun

Wulfenia carinthiaca

Thymus doerfleri and *Geum coccineum* at their peak flowering at the beginning of July

Mountains of the Middle-East

In the north, there are the Turkish Pontic mountains, the Taurus in Iran, and the Alborz mountain range. The Zagros range is in the south, which is far more arid. The Lebanon Mountains separate Lebanon from Syria. Most of these mountains have a cold dry climate, where thorny cushions are abundant.

A "wild garden" (meadow left) and man-made garden for plants from very dry zones

Coluteocarpus vesicaria

Erodium absinthoides

Aethionema saxatile ssp. *oreophilum*

Silene caryophylloides

Helichrysum compactum

Hordeum violaceum

Muscari armenum

Stachys byzantina

Verbascum phoeniceum

Verbascum olympicum (yellow) and *Geranium ibericum* ssp. *jubatum* (purple)

The Carpathian Mountains

The Carpathians form a mountain range in the centre of Eastern Europe (Romania, Slovakia, Poland, Czech Republic, Hungary, Ukraine and Serbia). The flora of this range has strong affinities with that of the Eastern Alps and, to a lesser extent, with that of the Himalayas.

The rock garden at day break, dominated by *Alchemilla mollis* and *Pinus mugo.*

Alyssum repens

Arabis ferdinandi-coburgii

Delphinium oxysepalum

Dianthus capitatus ssp. *andrzevitschianus*

Jurinea glycacantha

Saxifraga marginata

Dianthus spiculifolius

Gentiana phlogifolia

Silene hayekiana

Pulsatilla halleri

The Caucasus

This range is made up of the Lesser Caucasus (in the south) and the Greater Caucasus (to the north, the higher of the two ranges). The western part of the range is listed as a UNESCO World Heritage Site due to its biodiversity which, as yet, has been largely unaffected by man. The range is home to over 5,000 species.

Papaver lateritium (orange), *Anthemis biebersteiniana* (yellow), *Nepeta grandiflora* (blue)

Androsace lehmaniana

Chrysanthemum coccineum

Arabis flaviflora

Campanula biebersteiniana

Centaurea macrocephala

Paeonia wittmanniana

Inula glandulosa

Daphne caucasica

Lilium monadelphum

View of the Mirande Chalet and the Cerces Massif

The Himalayas & Tibet

The Himalayas are the highest mountain range in the world (14 summits over 8,000 m high, 2,400 km long). The high altitude Tibetan plateaus extend to the north. The southern slopes, subject to monsoons, are more humid than the northern slopes. The Alpine zone, above the tree line, starts at around 4,000 m.

Primula rosea around a small artificial lake at the very beginning of the flowering season

Allium macranthum

Androsace sempervivoides

Aquilegia fragans

Primula vialii

Cremanthodium ellisi

Delphinium cachmirianum

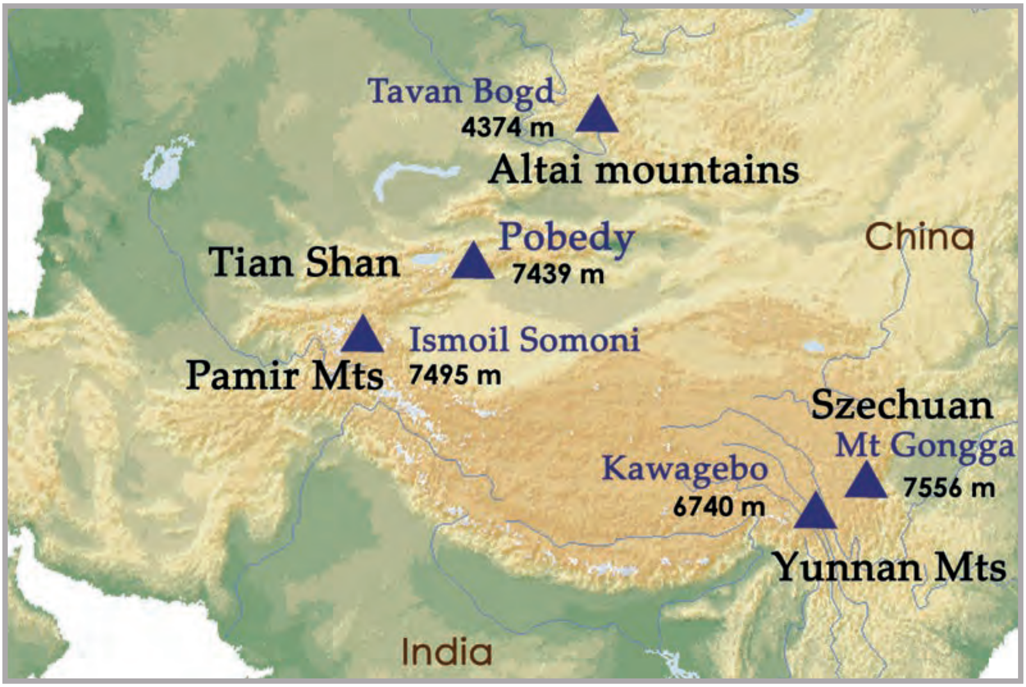
Nardostachys jatamansi

Potentilla atrosanguinea

Codonopsis clematidea

Meconopsis grandis

Central Asia & China



Central Asia is home to several mountain ranges, including the Altai, Pamir and Tian Shan mountains. The flora of Szechuan and Yunnan should also be included. The centre for the diversification of several European alpine genera such as Gentians, Primroses and Rhododendrons is located in these mountains.

View of the Mirande Chalet at sunset

Corydalis nobilis

Paeonia delavayi

Incarvillea mairei var. *grandiflora*

Iris albertii

Iris forestii

Ligularia przewalskii

Lonicera tatarica

Erigeron aurantiacus

Rheum wittrockii

Trollius sibiricus

Siberian plains

The Siberian plains, in the north of Russia, have a cold, dry, continental climate with an annual temperature range of 40 to 50°C. The south of Siberia, too dry for forests, is dominated by the steppe. Further north, conifer forests (taigas) take over and then give way to arctic tundra.

Dracocephalum grandiflorum, Papaver nudicaule and *Iris bloudowii*

Aquilegia viridiflora

Ligularia siberica

Iris sibirica

Saussurea frolowii

Hedysarum austrosibiricum

Sedum kamtschaticum

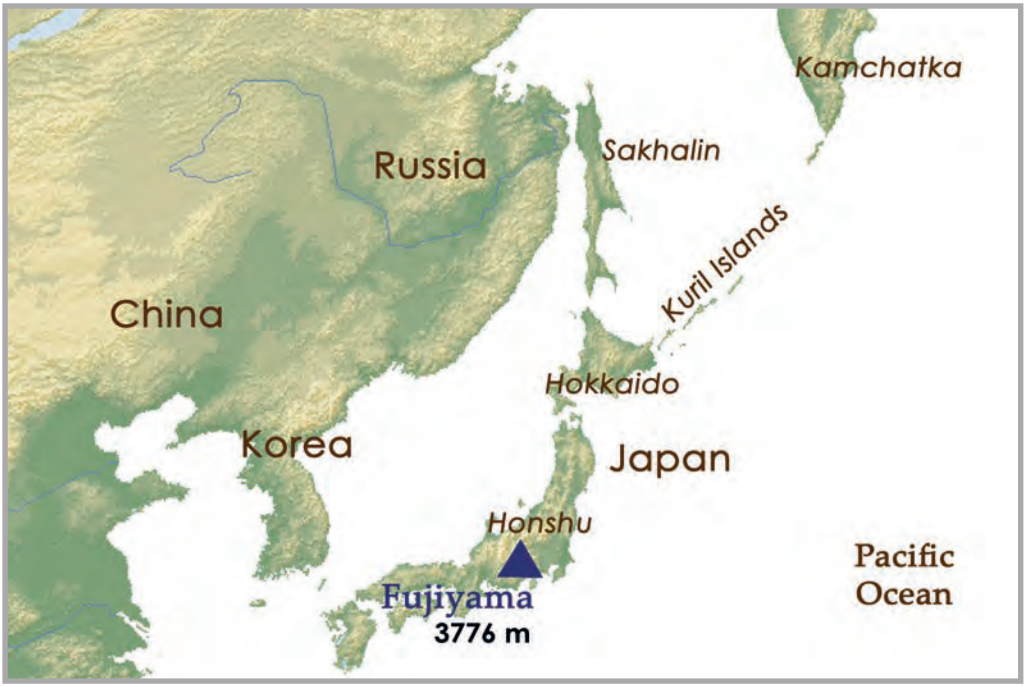
Viola dissecta

Leontopodium kamtchaticum

Paeonia tenuifolia

The Siberian Rock Garden at the end of June, the beginning of the growing season

Japanese Mountains



Hokkaido Island has a cold, oceanic climate, similar to that of the Sakhalin islands and the Kamchatka peninsula (Russia). Its rich flora has affinities with that of the Siberian regions, with certain particularities because it receives much more rain than Siberia.

A beautiful panoramic view of the Meije from the artificial lake


Arnica sakkalinense


Leontopodium hayachinense


Papaver myabeanum


Primula japonica


Spiraea japonica var. *decumbens*


Anaphalis margaritacea


Hosta sieboldiana


Hypericum kamtchaticum


Iris laevigata


Hemerocallis yezoense

Arctic regions

The Arctic regions are located north of the Arctic Circle at the North Pole. Arctic flora is found at low altitude due to proximity to the North Pole and is homogeneous across all arctic regions. Cold is the main constraint, and the soil is permanently frozen at depth throughout the year (permafrost).

Rays of sunlight catch *Geum rivale* ssp. *islandica* after snow on the 10 July 2007

Castilleja miniata

Dodecatheon pulchellum
ssp. *pauciflorum*

Lupinus arcticus

Thymus praecox
ssp. *arcticus*

Potentilla
hyparctica

Rubus arcticus

Saxifraga cespitosa

Saxifraga hieracifolia

Campanula rotundifolia
var. *alaskana*

Papaver lapponicum

North America

The Rocky Mountains stretch from Alaska to New Mexico across over 4,500 km. To the east the Appalachian Mountains are ancient, eroded mountains at a lower altitude. Amongst the purely American genera grown at Lautaret you can find *Eriogonum*, *Castilleja*, *Penstemon* and *Phlox*.

The North-American Rock garden in August

Clematis hirsutissima

Dodecatheon redolens

Dryas drummondii

Eriogonum ovalifolium var. *depressum*

Towsendia rothrockii

Heuchera rubescens var. *glandlosa*

Dicentra oregana

Tradescantia ohioensis

Penstemon whipleanus

Aquilegia elegantula

Andes & Patagonia

The Andes extend over more than 10,000 km. Patagonia and Tierra del Fuego are found to the south of this mountain range (Chile and Argentina), as well as the cold Patagonian Steppe (South Argentina). There is a great diversity of climates along the Andes, hence the rich and brightly coloured flora, rarely seen in Europe.

A guided tour run by ecology students from Grenoble University

Deschampsia antarctica

Calceolaria corymbosa

Calandrinia caespitosa

Oxalis adenophylla

Thlaspi magellanicum

Tropaelolum polyphyllum

Mimulus cupreus

Hordeum comosum

Mimulus depressus

The rock garden has been created using volcanic rock from the Massif Central

Southern mountains

The flora of the Australian and New Zealand mountains has affinities with that of the Southern Andes. This dates back to the Mesozoic Era when these land masses formed a single continent. The flora in the mountains of South Africa (Drakensberg, 3482 m) evolved more recently and so does not have these affinities.

The Southern Mountains rock Garden in August

Crassula milfordiae

Craspedia maxgrayi

Delosperma congestum

Geranium sessiliflorum

Celmisia coriacea

Kniphofia caulescens

Raoulia hookeri

Cotula potentillima

Felicia natalensis

Helychrisum milfordiae whose flowers close every night

Serge Aubert is a Professor of plant biology at the Joseph Fourier University (Grenoble 1), a member of the Laboratory of Alpine Ecology and Director of the Joseph Fourier Alpine Station, the structure created in 2005 by the University of Grenoble 1 and CNRS. This Mixed Service Unit includes the Alpine Botanical Garden and the Chalet-Laboratory at the Col du Lautaret and the Robert Ruffier-Lanche Arboretum and glass-houses on the Grenoble campus.

The photo was taken in August 2012 in the tropical Andes (páramo El Angel, Ecuador).

The first edition of this guide was published in 2000 based on the work of Patrice Fernandez who carried out his national service at the Lautaret Alpine Research Station, supervised by the team which led the site's scientific revival through the 2000s: Serge Aubert, Philippe Choler, Rolland Douzet and Richard Bligny (Director from 2000 to 2004). When the second edition was written in 2005 (a total of 5000 copies were sold, requiring several reprints), Serge Aubert worked with Alain Bignon (1944-2012) to include a chapter on local history. This latest edition has been largely rewritten, corrected and extended to twice the original length.

Unless otherwise indicated, most of the illustrations come from the author's collection of images. Most of the older images come from the Alpine Garden's archives and the Bignon and Aubert collections. Some documents are from the collections housed at the Dauhpinois Museum and the MuCEM (the Museum of European and Mediterranean civilisations) to whom we would like to extend our thanks.

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