Mountains and climate change

NATURE LOSING ITS BEARINGS

The case of the Mont-Blanc massif

CREA
-MONT-BLANC-

NATURE LOSING ITS BEARINGS MOUNTAINS AND CLIMATE CHANGE

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The Mont-Blanc massif as an example

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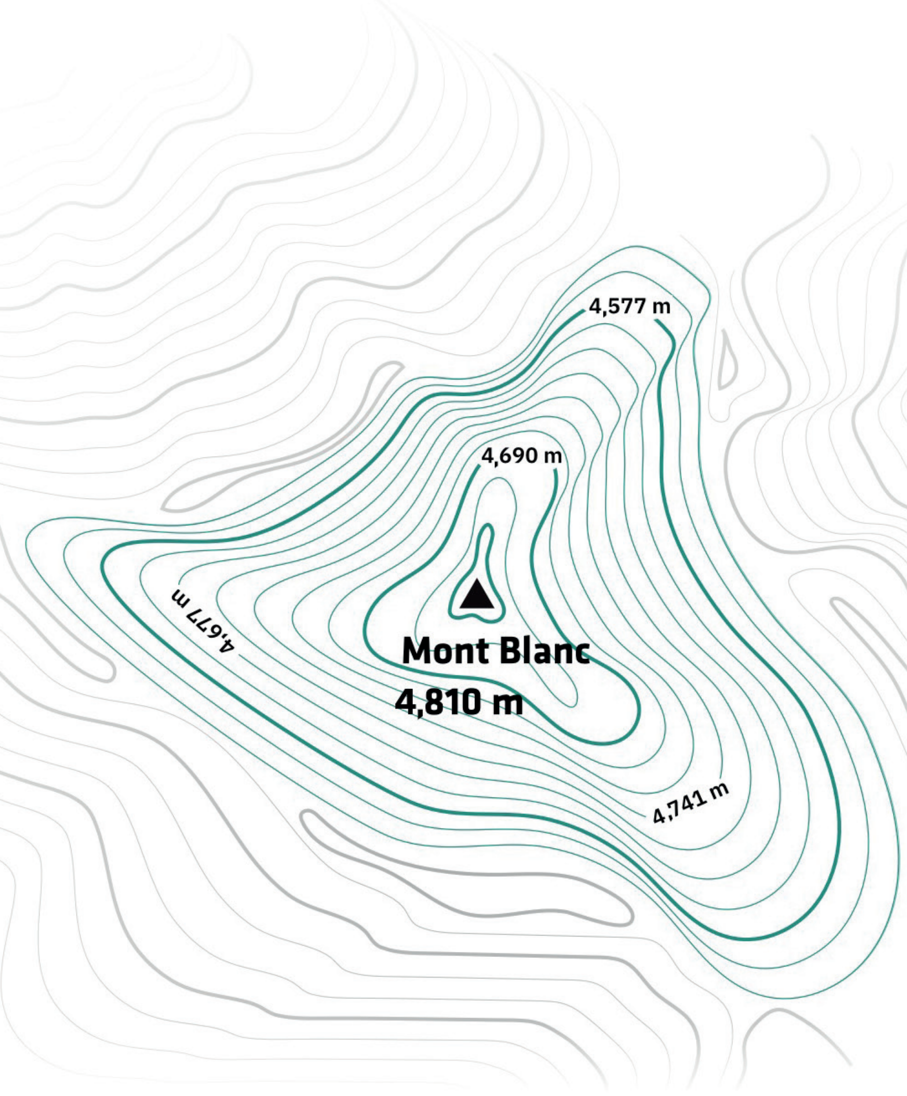


Climate change is affecting large mountain ranges two to three times faster than the rest of the planet. Even to the untrained and naked eye, the impact is now visible in the Mont-Blanc massif: the Mer de Glace and Argentière glaciers look tortured, rock fall so significant that it changes the how mountains look is becoming more and more frequent, snow cover is reduced in quantity and in duration...and alongside these changes, there are other upheavals that may be less visible, but are just as profound. Plant and animal species are subjected to rising temperatures, early snowmelt, and increasingly frequent heat waves and droughts. How do they react? How are the fauna and flora adapting to this disruption and how will the emblematic landscapes of the Mont-Blanc massif evolve? For over twenty-five years, CREA Mont-Blanc (the Research Center on Alpine Ecosystems) has been surveying the massif to monitor and study the effects of climate change on the mountains' biodiversity.

Mountains:
a unique natural environment

Climatic conditions vary with elevation: for every 100 meters of elevation gained, air temperature decreases by an average of 0.6 °C as a result of decreases in atmospheric pressure and absorption of solar radiation by the atmosphere. As you climb in elevation, solar radiation becomes more intense, generating strong temperature variations between day and night, but also seasonally.

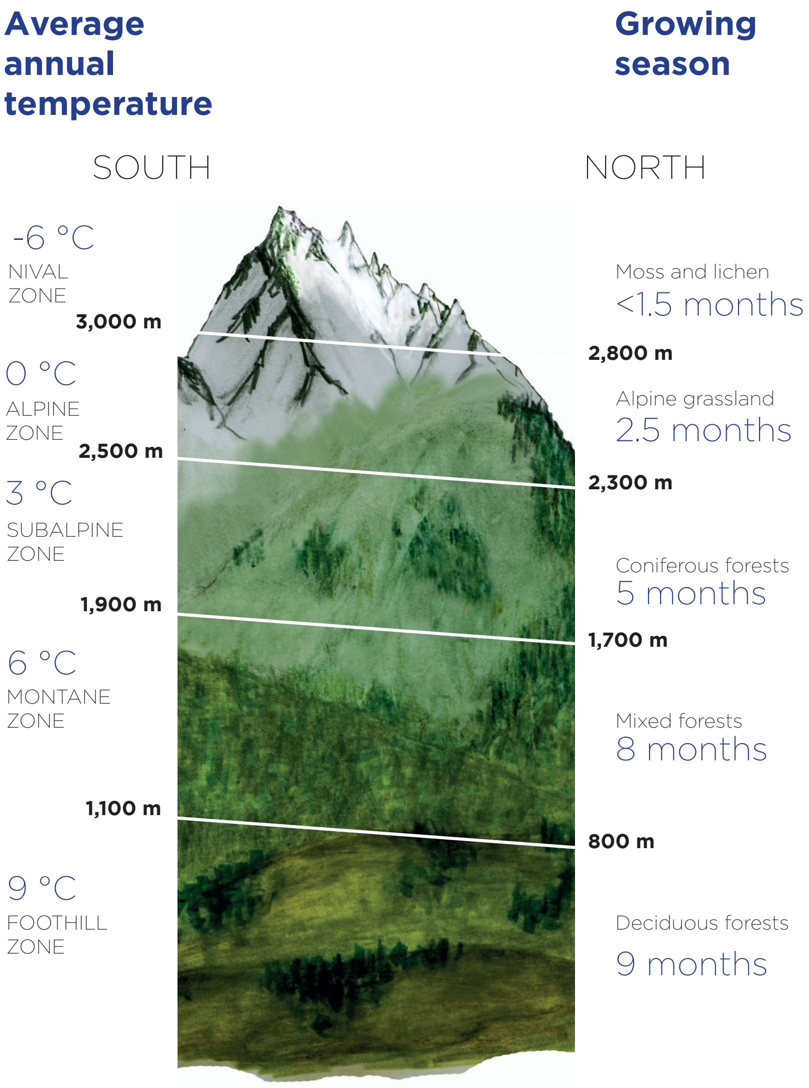
In addition, there is generally more precipitation at higher elevations. When air reaches the mountains, it rises and cools, increasing humidity and causing precipitation. When the temperature drops below zero, the precipitation falls as snow, covering the ground in a layer that gets increasingly deeper with elevation.

◀ *A chamois* (Rupicapra rupicapra) *at 2,400 meters.*
The lives of mountain species are shaped by precipitation (often as snow).

Elevation is not the only factor influencing climatic conditions: the shape of the terrain (also called topography) also plays a major role. Thus, a valley and a ridge located at the same elevation will experience very different snow conditions: while snow accumulates in the valley, the ridge may be entirely snow-free. Orientation also impacts the amount of sun an area gets: we can find nearly tropical conditions at plant-height on a steep south-facing slope, while conditions can be almost arctic on a north-facing slope which is in the shade most of the time. This phenomenon can be observed at the scale of a slope, but also on a micro-scale, on one side or the other of a bump or a rock, for example.

In summary, mountains are characterized by incredibly diverse environmental conditions on a relatively small scale (depending on elevation and topography). The result is that we can find, in a small area, a remarkable diversity of species which

◄ *Only a few meters away, and yet very different conditions: snow accumulation in depressions and snow-free ridges.*



have adapted to life in these unique conditions - a mosaic of different habitats juxtaposed within a few square meters.

Temperature acts as the major factor that limits the upper and lower ranges of a species. For example, treeline (perhaps the most visible ecotone), reflects the temperature at which conifers do not have enough heat to grow.

The temperature gradient is one of the most important factors shaping landscape, leading to different stages of vegetation: forest, shrubs and grassland. Mountains are also characterized by a strong seasonality. The most obvious sign of this is the presence of snow in the winter which disappears in summer, except at the highest elevations or in snowbeds.

◀ *The temperature gradient shapes the landscape and generates vegetation zones: forest, shrubs, grassland, etc. Plants' growing seasons decrease as you go up in elevation because most plants need temperatures above 5 °C to develop.*

Ranunculus glacialis

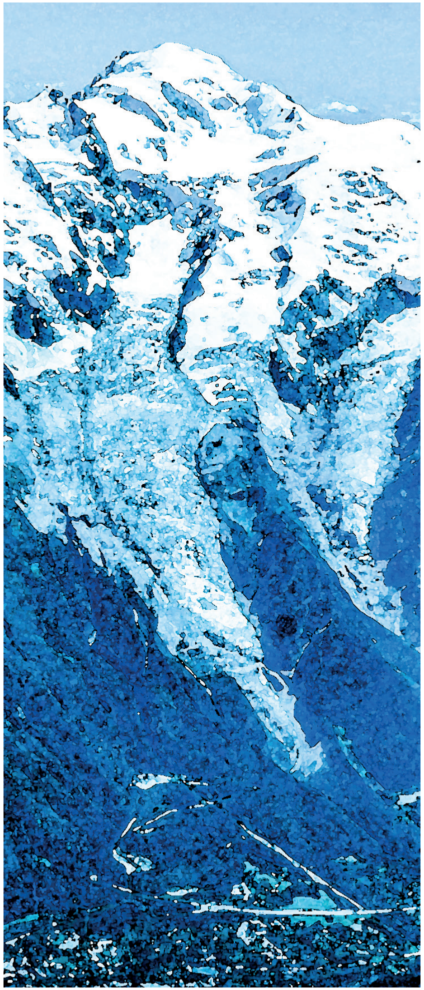
A specific biodiversity

To survive in these particular conditions, biodiversity has adapted and specialized: in the Mont-Blanc massif we find species with distinct adaptations that can only be found in this environment.

In general, they have an ability to develop quickly, and also to reduce their energetic expenditure (through hibernation or dormancy). They also are capable of resisting stress (frost or drought), and are characterized by a limited productivity (low reproduction rate per year).

Their morphologies are also specific. These plants and animals are smaller in size than their counterparts in the plains. Plants grow in cushion form to limit heat loss and animals have smaller limbs (like the mountain hare which has smaller ears and a rounder body).

◀ *The glacier buttercup* (Ranunculus glacialis)*, one of the flowering plants growing at high elevations, develops flower buds two years in advance. This adaptation mechanism developed in response to a very short growing season due to the climate.*



4,810 m -8 °C

4,000 m -3 °C

3,000 m 3 °C

2,000 m 9 °C

1,000 m 15 °C

The Mont-Blanc massif, an open-air laboratory

For an ecologist, the Mont-Blanc massif, with its impressive vertical gain - the most extreme in the Alps - constitutes a life-size laboratory. From an elevation of 500 meters in the valley to 4,810 meters at the summit of Mont-Blanc, in only 20 kilometers of distance, the massif rises 4,300 meters. The result is that the massif is home to a very strong temperature gradient (the amount temperatures vary with elevation, expressed in °C/100 m) and a wide range of microclimates all within an extremely concentrated area, as a function of altitude and exposure. Starting from Swiss or Italian valleys and climbing to the top of Mont Blanc is like making a great climatic journey - similar to going from the Mediterranean all the way to Greenland.

◀ *Gradient of average summer temperatures from Chamonix to the summit of Mont Blanc. Temperatures decrease 0.6 °C every 100 meters.*

Temperature gradient

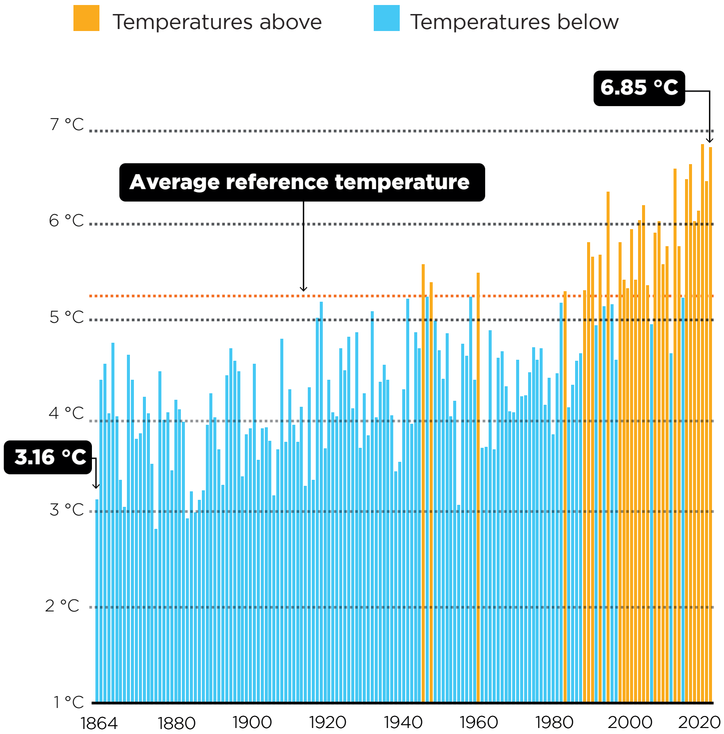
Researchers can just go up progressively in elevation to observe how a species, plant or animal, reacts when subjected to different temperatures and climates. This allows us to study a wide variety of conditions in a small area representative of the climates that prevail between southern Europe and the Arctic.

The Mont-Blanc massif thus constitutes a unique and invaluable subject for scientists who study the reactions of fauna and flora to global climate change and try to predict how landscapes will evolve. Because climate change occurs approximately twice as fast in the mountains as in the plains, the studies conducted there offer a strong potential for extrapolation to other areas in the world.

◀ *Over 1,000 meters of difference in elevation, the climatic variation is equivalent to that which we observe over 1,000 kilometers of distance in latitude.*

Temperature change
in Switzerland

Compared with the average reference temperature (1981-2010)



Sources : MTO Suisse

Faster climate change in mountainous regions

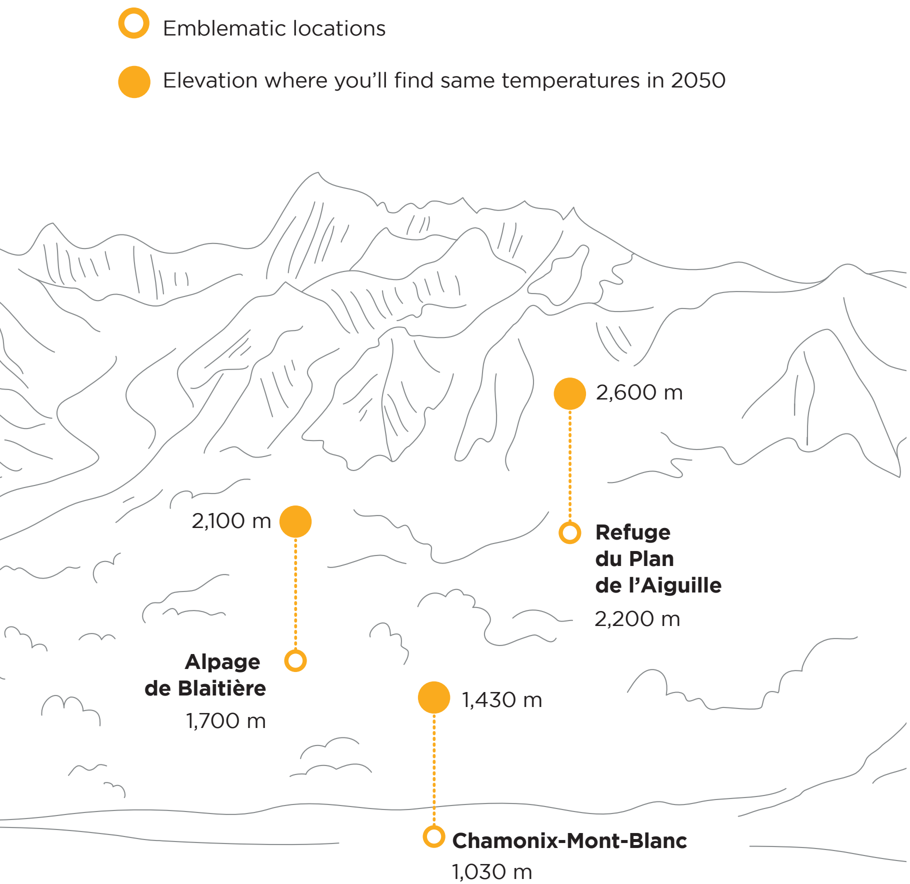
The rise in temperatures observed since the beginning of the industrial era increased globally during the 1980s and will continue to intensify in the future. However, in the Mont-Blanc massif, like in the rest of the Alps, we've observed a clear acceleration in warming.

Since 1964, the average annual temperature has risen about 2 °C, which is nearly twice as much as the warming measured globally (+ 1.1 °C) or in France (+ 1.4 °C). Since the 1980s, we have seen in the Alps an increase in temperatures from 0.2 °C to 0.5 °C per decade. This change is equivalent to the difference in temperatures that we typically observe between two different spots on a mountain located 100 meters of elevation apart. At this rate, in order to stay in the same temperature

◀ *Compared with the average temperatures established during the reference period (1981-1990), since the 1980s, the rise in temperature is particularly pronounced.*

Projections of climatic conditions

Summer temperatures in 2050



Sources : WSL-Chelsa

conditions, an organism would have to climb 100 meters in elevation every 10 years!

Why are we seeing this increase in warming? One reason is albedo, or the fraction of solar radiation which is reflected or diffused by a surface. Rising temperatures cause reductions in the size of zones covered by snow or ice (which reflect solar radiation) in exchange for dark rocks which, in contrast, absorb heat. Combined with higher concentrations of water vapor in the atmosphere near large mountains, the albedo effect amplifies the greenhouse effect on a local scale.

However, this does not fully explain such a significant increase in the rate of warming at elevation. Climatologists and glaciologists are attempting to identify other contributing factors.

◄ *In summer, the rise in temperatures will be even more pronounced. To find the same climatic conditions, we'll have to go up 130m in elevation every 10 years.*

Decrease in snow cover duration by 2050

In any case, this accelerated increase in temperature has a significant impact on the duration of snow cover (the snow-free season is longer) and the spatial extent (the snow cover has been reduced at lower and middle elevations). Since the 1970s in the Northern Alps, the duration of the snow cover at 1,100m and 2,500 m has been reduced by five weeks. By 2050, snow cover duration on the valley floor and on south-facing slopes below 2,000 m may be further reduced by 4-5 weeks, compared with the current duration, and by 4 weeks at 2,500 meters. Above 4,000 m, the length of the snow season should not change much.

◀ *The shrinking of the snowpack will continue and will become more pronounced on south-facing slopes.*

Looking ahead to 2050

+ 3 °C

Increase in summer temperatures
in the high mountains
Above 2,000 meters

+ 15 to + 20 days

Increase in the number of extremely hot days at the valley floor
“extremely hot days” = maximum temperature above 32 °C
Today: 2 extremely hot days

+ 30 days

Increase in the number of summer days in the mid-mountains
“summer days” = temperatures above 25 °C
Today: 5 summer days

+ 400 m

Rise in the 0 °C isotherm
Elevation above which the temperature is below 0 °C in the summer
Today: 3,800 m

- 150 mm

Reduction of the water balance
in the summer at mid elevations
Soil moisture

Climate change affects each season differently. In the Mont-Blanc massif, the summer season is experiencing the greatest rise in temperature, accompanied by the appearance of droughts and heatwaves which are becoming both more frequent and longer. These phenomena have become increasingly common, particularly since 2000. By 2050, heat waves will become more frequent, severe, and long-lasting. Nonetheless, the season most affected by climate change is the spring: the increase in temperature directly impacts snowmelt. And the spring is a crucial season for animals and plants: plants begin to emerge, animals become more active as they are able to access resources previously covered in snow, etc.

Flora and fauna and their adaptations to climate change

Not all species respond to climate change in the same way or at the same rate. We sometimes observe that even for the same species, different types of disruption (warmer temperatures, decreased snow cover, heat waves, etc.) produce contradictory effects.

◀ *Moss campion* (Silene acaulis) *is a plant which lives in rocky areas at high elevation and grows close to the ground and forms a cushion-like structure. Thanks to this structure, it is more resistant to cold and dry conditions.*

Changes in seasonal cycles

The most commonly observed response, for both animals and plants, is a significant shift in certain seasonal events.
A literature review of studies in the Alps shows that insects, butterflies and reptiles - the animals that can't regulate their body temperature and are therefore very dependent on the temperature of their environment - have responded the most to the changes in temperature of the last decades: their life cycle is beginning earlier by an average of 6 days every decade.
The European spruce bark beetle is a good example. This small insect from the order coleoptera makes its way under spruce bark to feed on tender wood, rapidly killing the tree. Yet, like many parasites, it develops much faster in warmer temperatures.

◀ *Developmental phases of a budding ash (Fraxinus excelsior) and a coal tit hatchling* (Periparus ater).

The species used to produce one or sometimes two generations of many tens of thousands of insects per year. With warmer temperatures, winters that are less severe, mild springs, and hot summers, the beetles have proliferated and now can produce three or even four generations in a year. Their attacks cause the decline and death of spruce trees. Among animal species, birds and mammals appear to have the most limited response, with an average change in their seasonal cycle of about one day per decade. They are more dependent on the seasonal changes in the photoperiod (the length of the day) than they are on seasonal changes in temperature.

◀ *European spruce bark beetles* (Ips typographus), *parasitic insects which benefit from rising temperatures, attack spruce trees* (Picea abies), *resulting in their death.*

Pyrrhocorax graculus

In the Mont-Blanc massif, we have nonetheless observed that the Alpine chough breeds earlier and earlier in the season. From 1988 and 2018, chicks left the nest three days earlier each decade. This adaptation, which is linked to the increase in spring temperatures, provides the birds with a longer favorable season before winter.

The seasonal cycles of plants have also shifted earlier by an average of two to three per decade. The most pronounced shifts in cycles have been observed in trees and shrubs. Results from Phénoclim, a program which studies alpine trees, indicates that, among the six different species in the study, all but the spruce exhibited earlier budburst over the course of the last ten years. Birch and the ash demonstrated significant shifts: 4-6 days earlier per decade.

◀ *The Alpine chough* (Pyrrhocorax graculus) *lives year round at high elevation. Skilled fliers, they take advantage of ascending currents to move without effort and reach great heights.*

The limitations of this response

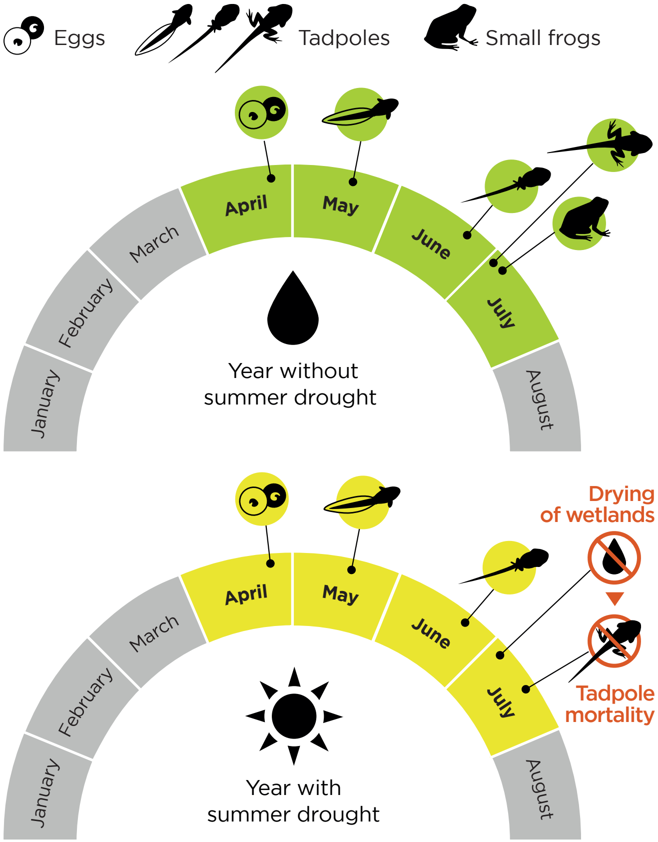
A beneficial effect... Until now, traditionally short seasons in the mountains have constituted an important constraint for living organisms. Longer growing seasons provoked by warming could therefore be beneficial to all species by facilitating their development and their reproduction.

However... rising temperatures are not the only impact of climate change; it has other effects including summer droughts. The negative impact of droughts can contradict the beneficial effect of the longer growth season.

◀ *The European common frog* (Rana temporaria) *is able to live at high elevations up to 2,800 m. They lay their eggs in wetlands as soon as there is open water, making this species very dependent on the date of snow melt.*

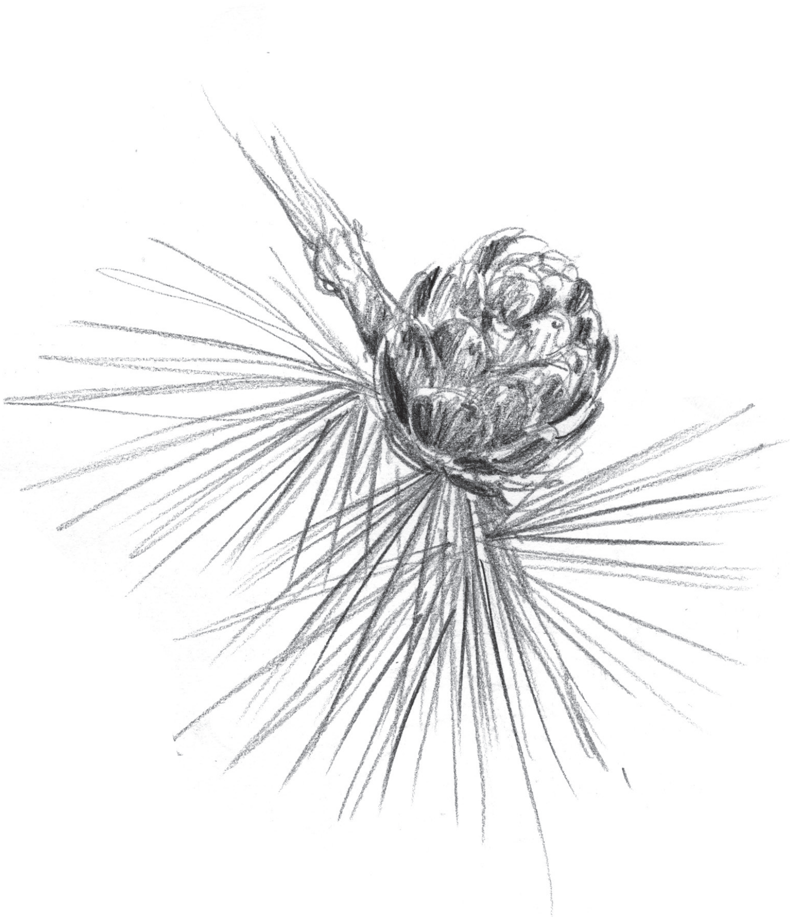
Summer droughts and the European common frog

Risks related to wetlands drying out



In the Mont-Blanc massif, the life of the common frog depends directly on the date of snow melt, which allows them to access wetlands where they reproduce. The rise of temperatures and a longer season could be beneficial for this species because they have more time for development. Nonetheless, summer droughts, which are becoming more and more frequent, can cause wetlands to dry out too early, preventing tadpoles from completing their development. What will become of the common frog?

For any given species, whether plant or animal, the responses vary according to their location, as a function of elevation and exposure. In the Mont-Blanc massif, larch trees offer a striking example. At high elevations, larch budburst has been observed earlier in the year because of the rise in temperatures in the spring. But lower in the valley,



Larix decidua

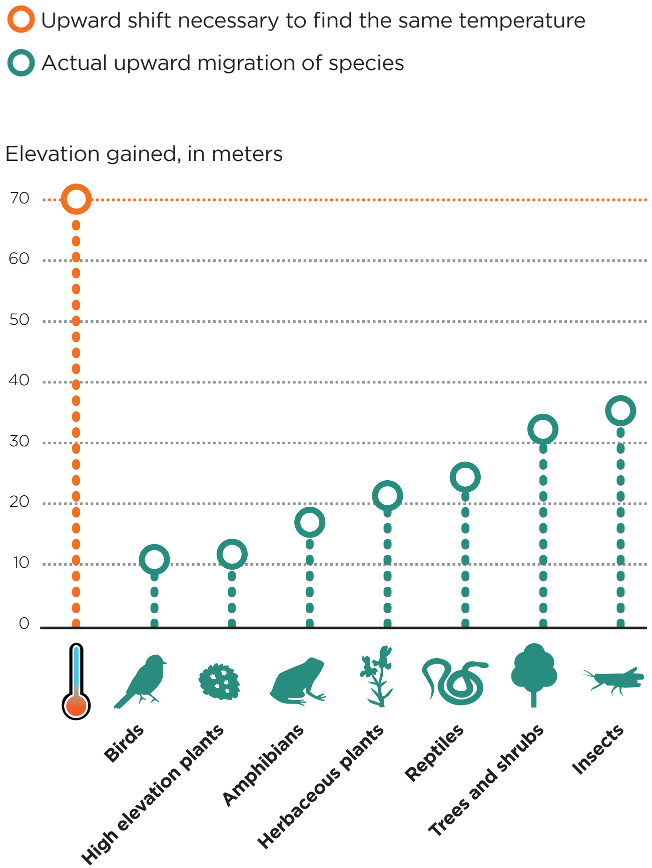
the budburst does not happen much earlier than before. This can be explained by another impact of climate change: warmer winters. Budburst depends not only on spring temperatures, but also on the intensity of the cold during plants' dormant season. Even if the physiological mechanisms at play are not yet well understood by researchers, a lack of cold during the winter clearly delays the development of vegetation.

Larch trees located at high elevations that still receive sufficient cold in winter have experienced a greater shift in the onset of their budburst than those at lower elevations , where winter temperatures are no longer cool enough to allow dormancy to break in the spring.

◀ *Larch* (Larix decidua) *needles and cones. Their budburst depends both on the amount of accumulated warmth in the spring and on the amount of cold they are exposed to during the winter.*

Vertical migration of species

in 10 years



Sources : Vitasse et al. 2021

Moving higher to escape the heat

Over the last few decades in the Alps, we have observed a general trend of organisms moving upwards in order to find optimal living conditions. On average, plants, fungi and animals are migrating about 20 m upslope. To date, the most significant shift that has been observed is for insects, which have seen a rise of 36 meters per decade. Once again, the response is stronger for species that do not regulate their temperature and depend directly on external conditions. Among plant species, trees and shrubs "climb" to higher elevations the most quickly.

The most visible elevational migration is the rise of treeline. In the Mont-Blanc massif, the median elevation of the forest rose by 60 meters between 1952 and 2006. Simulations predict that treeline will continue to rise and could reach 100 meters

◀ *In order to find favorable climatic conditions, species will need to shift upslope 70 m per decade.*

by 2050, depending on the configuration of the environment. The surface area occupied by forest is growing, with an 85% increase between 1952 and 2006. This increase is not only the result of climate change; it is also due to changes in land-use over the years, most notably the decrease of grazing and general move away from agricultural activities. As a consequence, we can expect a significant increase in the surface area occupied by the forest, growing from 90 km² in the 1950s to 230 km² in 2050 (mainly on the Swiss and French sides of the massif).

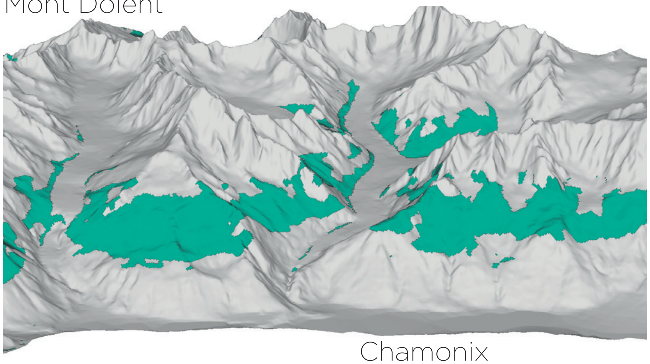
◄ *The Argentière village and glacier and the evolution of the landscape between 1890 and 2010. The forest has colonized most of the area.*

The limitations of this response

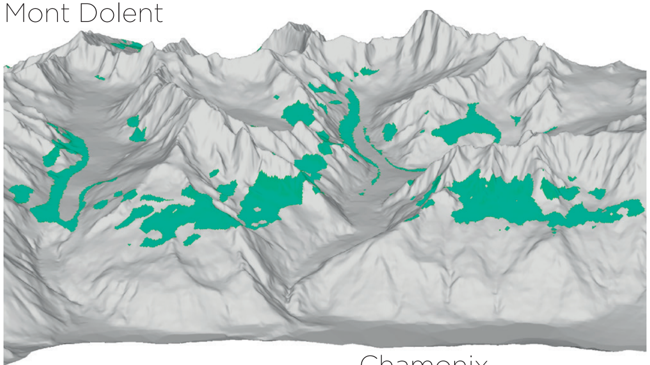
It is likely that some species will not be able to keep up with this pace and will not manage to climb as quickly as the mercury in the thermometer! What's more, given the conic shape of mountains, as you go higher in elevation, there is less available surface area. The sheer steepness of the Mont-Blanc massif leads to a significant reduction of the surface towards the top. There is half as much surface area available between 3,000 and 4,000 meters of elevation as between 2,000 and 3,000 meters.

Anticipated changes in Rock ptarmigan habitat

Today



2050



■ suitable habitat

Sources : LECA / CNRS

The race to higher ground is therefore complicated by a loss of favorable habitat for alpine species to colonize. The rock ptarmigan, an Arctic-alpine species and a relic of the glacial periods, is a mountain bird that needs cold to grow and reproduce. In the Mont-Blanc massif, the species may lose 60% of its habitat by 2050 and 100% of its habitat by the end of the century due to rising temperatures and the reduction of snow cover.

Lepus timidus

Species interactions shaken up

Even if different species respond differently to change, in terms of time and space, all species live and grow in constant interaction with others. Some species will be threatened by the effects of climate change, while others may fare better.

Notably, we've observed more competition from species from lower elevations. For example, the mountain hare is increasingly exposed to competition from the European hare, which is migrating to higher elevations and beginning to encroach on the lower part of the mountain hare's range.

The same situation may occur for plants. A study conducted in Switzerland between 1989 and 2009

◀ *The mountain hare* (Lepus timidus) *is an Arctic-alpine species specially adapted to cold environments. Its large and furry paws allow it to stay on the surface of the snow, even in powder, like snowshoes. It is camouflaged in order to hide from predators: brown in the summer; it can hide among rocks. White in the winter, and it becomes invisible in snow.*

showed that, among 1,334 plant species, those which are not native to the Alps migrate to higher elevations twice as fast (72 meters per decade) as alpine plants (32 meters per decade). For now, this is actually a positive effect: it means an increase in biological diversity on mountain summits. But for how long?

These differences in adaptation and response to climate change can result in a dangerous desynchronization. This is the case for certain extremely specialized species, such as the mountain hare, the rock ptarmigan, and the ermine. In the winter, to better blend into the landscape and thus escape from predators, these animals change color, becoming white by molting their summer plumage or coat. Molting is more dependent on photoperiod (the length of the day) than on temperature. While the date when the animals molt has seen little change, snowmelt is occurring earlier

◄ *Two rock ptarmigans* (Lagopus muta) *in October at different stages in their molt.*

Capra ibex

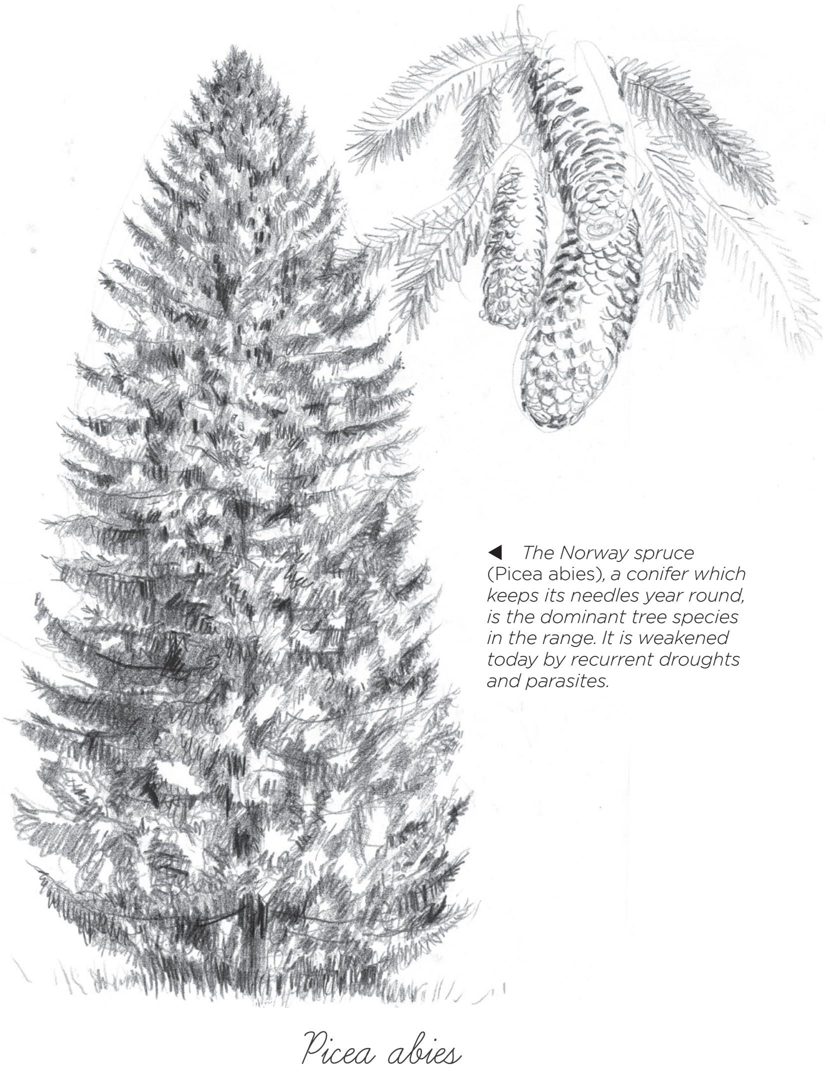
and earlier in the year. Consequently, animals are "desynchronized" with their environment: they stay white in a landscape which has turned brown. Their "camouflage" becomes counterproductive and leaves them vulnerable as they are more visible to their predators.
The ibex provides another example. The date that they give birth to their young depends on the timing of the mating season, which takes place in the autumn. During years with unusually warm winters or springs, there is an offset between peak production of vegetation, which occurs earlier, and the time when ibexes have the highest nutritional needs. As a result, higher mortality rates of young ibexes have been observed in the Grand Paradiso national park in Italy in years following early springs.

◀ *Warm springs cause vegetation growth to begin earlier, shortening the length of time when the vegetation provides the best nutritional value, and disrupting seasonal cycles of large herbivores like the Alpine ibex* (Capra ibex).

Changing landscapes: the greening of the Alps

Over the last thirty years, the Mont-Blanc massif has transformed. A band of vegetation is gaining ground over areas typically covered with snow: the Alps are getting greener. Satellite images show that high mountain areas (around glaciers, névés and cliffs) are experiencing the most significant greening trend. The composition of forests is also changing. In the future, there will be more deciduous trees and fewer conifers. These tangible changes are already underway.

◀ *A changing landscape around the Mer de Glace. Above: in 2015, below: in 2050. Watercolors by Claire Giordano.*



◀ *The Norway spruce* (Picea abies), *a conifer which keeps its needles year round, is the dominant tree species in the range. It is weakened today by recurrent droughts and parasites.*

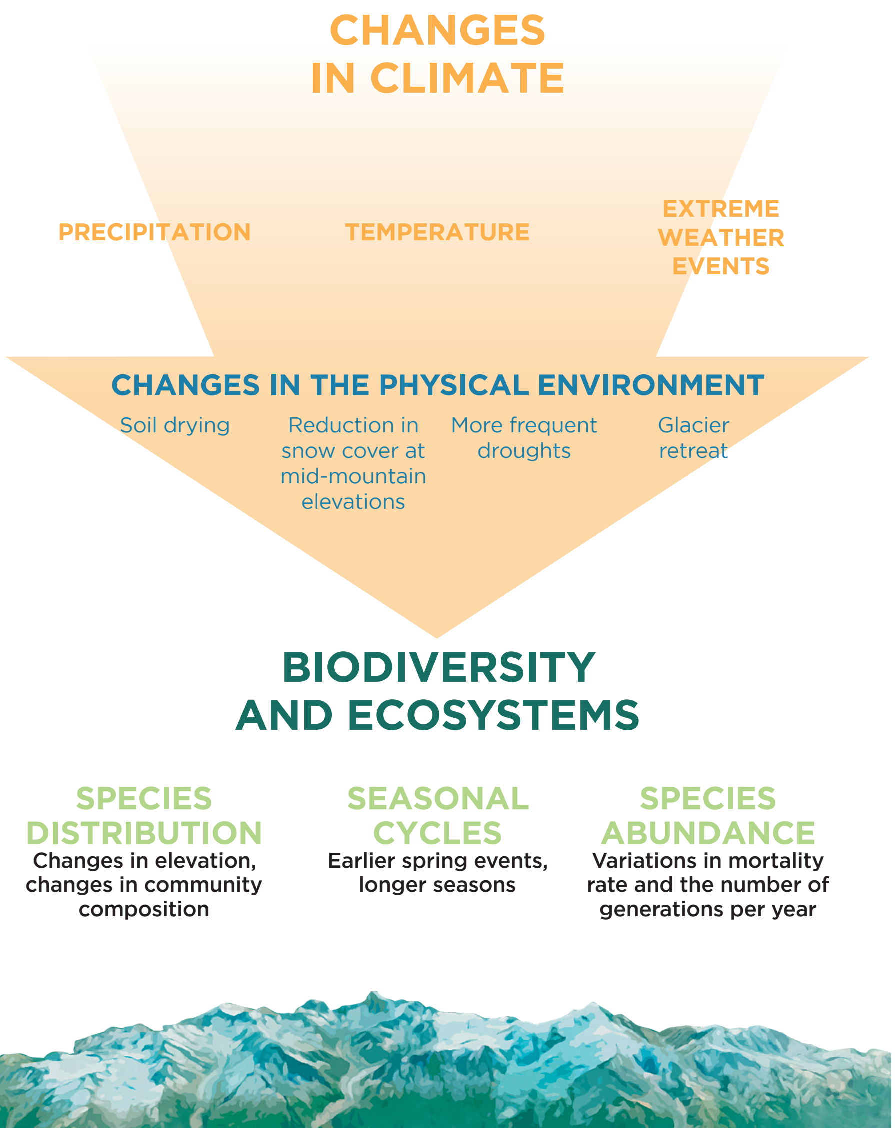
THE NORWAY SPRUCE

An iconic species of the Mont-Blanc massif in peril

While the Norway spruce is the dominant species in the forests of Mont-Blanc today, its future is uncertain. Due to the effects of a global increase in temperatures, the spruce can be found at higher elevations. The upper limit of its distribution - like that of all of the forested area in Mont-Blanc - is climbing. This is beneficial in some ways.

But this expansion is limited or offset by repeated droughts and heat waves in the summer, which deprive the trees of water. When water-stressed, spruce are even more vulnerable to the parasite the European spruce bark beetle. In contrast, these beetles benefit from hot weather, which provides a perfect atmosphere for the proliferation of parasitic insects. These pests attack the tree trunks, causing decline and dieback among the already weakened trees.

The spruce will thus lose its dominance of the Mont-Blanc massif's landscape, while other species of trees, mostly deciduous, will become more common and visible.



In conclusion. . .

Mountain landscapes are undergoing profound changes. Even if mountain species have demonstrated an impressive capacity for adaptation to harsh environments, their ability to adapt to new changes is being tested. In comparison with typical evolutionary mechanisms, which take many generations to produce adaptations to environmental conditions, the rapid acceleration of climate change in the Alps allows very little time to respond.

In addition, the combination of climate change with other pressures on natural environments (soil sealing, degradation of natural habitats, overcrowding and increases in visitation, etc.) can impede the ability of species to move to new territories in response to their climatic needs.

However, mountain environments have advantages too, including the diverse range of habitats that are found extremely close to each other. While a lowland species may need to move hundreds of kilometers to find favorable conditions, in the mountains, a species sometimes only needs to move a few meters to find

the optimal temperature. Furthermore, in contrast to non-mountainous regions, in the Mont-Blanc massif, there are many areas which are relatively undisturbed by humans.

With glacier retreat and reduced snow cover, new areas will be accessible to plants and animals and could become refuges for biodiversity, provided they remain preserved from human development. Flora and fauna, when protected and given space and time to adapt (like they've had in the past), have the potential to evolve for these new conditions.

Our activities and practices can either help or hinder these adaptations. But in any event, humans will also have to adapt to the changes in more ways than we can imagine. If forests continue to climb in elevation, if spruces become more scarce, and if alpine environments experience recurring droughts, what will become of, for example, summer tourism and agriculture? Or more broadly, how will the image of the mountains, that we currently value and celebrate, need to change?

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ATLAS MONT-BLANC

Tracking the effects of climate change online
CREA Mont-Blanc's researchers have developed a digital tool for students, instructors, journalists, decision-makers and mountain professionals. The Mont-Blanc Atlas focuses on how mountain ecosystems function and how they are changing as a result of global climate change. Based on the visualization of scientific data and the results of research conducted in the field, it allows you to project yourself into the heart of the Mont-Blanc massif, and see its present and future, inviting us to reflect on shifts in alpine ecosystems due to climate change.

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