Brown leaves in July: a warning signal or a defence mechanism?

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Brown leaves in July: a warning signal or a defence mechanism?

Brown and prematurely falling leaves are currently a common sight in many forests. Depending on the tree species, this may be either a defensive reaction to water shortage or an indication that damage has already occurred. Precise assessment is particularly crucial in the case of beech.

Fig. 1. Leaf browning and leaf shedding in high summer: many deciduous trees start shedding their leaves as early as July. Whether this is for protection or causes damage depends on the species of tree. This photograph, taken on 8 July 2026, shows a stand of trees severely affected by drought and heat above Herbetswil, Solothurn. Photo: Jan Ziegler (WSL)

An early autumn at the height of summer: in the forests of Switzerland and neighbouring countries in 2026, many deciduous trees were already showing brown or yellow or prematurely falling leaves as early as June and July. The species affected include beech, lime, cherry, birch and hornbeam trees, as well as oaks; on particularly exposed sites, practically all deciduous tree species are affected, including Norway maple, sycamore, field maple and whitebeam. Is this a defence mechanism enabling the trees to limit water loss through evaporation? Or are the falling leaves a symptom of irreversible damage already caused by the drought and heat? The answer depends largely on the tree species, and these differences have far-reaching consequences for the future of the trees in question.

Two processes, two meanings

We have seen premature defoliation in previous years, but it has been particularly evident since 2018/19 and 2022/23 at the latest, when widespread crown discolouration and defoliation were observed in August. The trend is similar in 2026, although in some regions it was even apparent as early as the end of June; in the Jura, many of the trees on shallow-soiled sites are showing signs of

severe to very severe water deficits and the associated leaf discolouration. Outwardly, the symptoms of discolouration may look similar; physiologically, however, we must distinguish between two different processes: premature senescence (premature leaf ageing, as an active process undertaken by the tree to recover nutrients); and leaf damage caused by heat and drought (leaf scorching). It is essential to distinguish between them in order to properly assess the causes and consequences of premature defoliation (Bergström *et al.* 2026).

Stress-induced premature senescence is an active and regulated process. Through hormonal signals (ethylene, abscisic acid), the tree recognises that the soil's water reserves are depleted and initiates the targeted breakdown of leaf tissue. It redirects nitrogen, phosphorus and other valuable nutrients back to the trunk; the leaf turns yellow, an abscission zone (separation line) forms at the petiole, and the leaf falls off in a controlled manner. The nutrients recovered in this way are then available for new growth the following spring. Unlike autumn leaf senescence, during which the recovery of nitrogen, phosphorus and potassium is almost complete, the recovery is incomplete under stress conditions, depending on the intensity and duration of the drought. If such stress-induced events recur, they deplete the tree's internal nutrient reserves over the years (Bergström *et al.* 2026).

Fig. 2. A bare beech crown, which has already shed almost all of its foliage by early July 2026 due to this prematurely induced senescence. The process of leaf shedding begins in the crown and progresses downwards, where a few green leaves can still be seen. Next to it are much more vigorous Norway maples and ash trees. Photo: Frank Krumm (WSL)

Heat damage and discolouration caused by drought stress (leaf scorching), on the other hand, constitute a passive, uncontrolled breakdown. Extreme heat and water deficiency lead to rapid cell death. The leaf usually withers from the edges and tips inwards; if the centre of the leaf is more exposed, it may also wither from the centre outwards; there is hardly any orderly recuperation of nutrients. The leaf dies before the tree can shed it in a controlled manner.

Fig. 3. a) An oak leaf drying out from the tip. b) A Norway maple with a different pattern of withering, starting from the veins and the tip of the leaf. c) Beech leaves drying out from the tip or also from the centre of the leaf in the case of the most exposed leaves on 5 July 2026. Photos: Frank Krumm (WSL)

And, as well as discoloured leaves, we can also see green, wilted leaves with no signs of browning whatsoever. This suggests that the leaves dry out very rapidly, before any biochemical degradation or transformation processes can begin (Fig. 4).

Fig. 4. The two photographs were taken in the same stand on a north-west-facing slope near Laupersdorf in the canton of Solothurn. The leaves in this young beech stand have fallen whilst still green. The green colour of the leaves suggests that the normal, visible senescence process had barely begun, and that the trees were unable to recover nutrients, or were only able to do so to a limited extent. The process began here in the understorey and then progressed towards the crown, in contrast to the processes shown in Figure 2 on the south-west-facing side of the valley. The top picture shows a few remaining green leaves in the upper part of the crown. Photos: Frank Krumm (WSL)

Within the stand, these different processes often occur in combination, on the same tree and sometimes on the same branch. It is therefore the overall appearance that counts, rather than any single feature.

Field guide

More likely to be premature senescence: relatively uniform yellowing; leaf tissue initially still intact; controlled detachment at the base of the petiole (leafstalk).

→ an active process that allows for the partial recovery of nutrients.

More likely to be leaf scorching: brown, dry leaf tips or leaf edges; sharply defined areas of necrosis alongside tissue that is still green; irregular or rapid dieback.

→ a passive process and a combination of heat, atmospheric dryness (high vapour pressure deficit, VPD), intense solar radiation and a lack of soil water, which together lead to excessively high leaf temperatures and a breakdown of the water cycle. A large proportion of the nutrients is lost in this case.

Importance of timing

In the case of a leaf that is completely brown or has already fallen, it is often no longer possible to determine the underlying process with certainty, as the decomposition processes set in rapidly. In order to distinguish between the causes, it is necessary to assess the leaf while it is still partly green.

A safety valve in the leafstalk

Why some trees cope well with premature defoliation whilst others do not depends on their water transport system. The tree transports water through fine conduits from the roots to the leaves; via xylem vessels in deciduous trees, and tracheids in conifers. This flow is driven by evaporation: it draws the water upwards as if through a straw. If the suction forces become too great – because the soil dries out or the air is too hot and dry – air bubbles (embolisms) form in the conduits, interrupting the flow of water. This process is known as **cavitation**.

To assess the severity of the damage, it is crucial to know in which part of the tree an embolism first occurs. According to the hypothesis of hydraulic segmentation, in species well-adapted to drought, the ‘less valuable’ and easily replaceable organs – namely the leaves and leafstalks – undergo cavitation significantly earlier than the ‘more valuable’ structures such as the branches and trunk (Tyree and Ewers 1991). The leafstalk then acts like a fuse: the leaf is sacrificed before the trunk sustains any damage. From an energy perspective, losing a leaf costs very little; a branch or trunk with permanently blocked vascular conduits has serious consequences.

All three processes described – premature senescence, leaf scorching, and the withering of green leaves – depend primarily on the duration and intensity of the drought and the heat. Symptoms of withering in the leaves therefore do not indicate that the safety mechanism is not working properly.

A comparison of the vulnerability curves and critical water potentials of different organs makes it possible to determine whether a tree species employs a strategy of hydraulic segmentation. The P_{50} value indicates the water potential at which 50% of the vascular conduits cease to function. A value exceeding P_{50} does not mean that the organ dies; it marks a significant loss of hydraulic conductivity. Only when nearly 90% (P_{88}) of the conduits are affected is the water transport considered to be permanently interrupted. This strategy depends on the order in which the different organs are affected by cavitation: If P_{50} and P_{88} are reached in the leafstalk at a less negative water potential than in the rest of the tree, the safety mechanism is working. If the values fall within the same range, this protective function no longer exists. If the leaves show symptoms of damage at this stage, it must be

assumed that cavitation is also affecting other parts of the hydraulic system, in the branches and trunk. This segmentation is particularly pronounced in species native to arid regions; in species from humid forests, it is often weak or non-existent (Zhu *et al.* 2016).

Species differences in deciduous trees

A direct test of segmentation in the leaves, branches, trunks and roots of four deciduous and four coniferous tree species confirmed the basic tendency: leaves and roots are generally more susceptible to embolism than branches and trunks (Johnson *et al.* 2016). However, this finding does not answer the question of whether a particular species has a hydraulic safety mechanism. This can only be determined on a species-by-species basis, and the current status of knowledge varies considerably for central European tree species:

Table 1. Hydraulic segmentation, significance of premature leaf fall, and long-term prognosis for six central European deciduous tree species. Directly measured P50 values (rounded) are available only for beech and sycamore (seedlings, Losso *et al.* 2019); the remaining entries are estimates of variable reliability.

Tree species	**Hydraulic segmentation**	**Significance of defoliation**	**Long-term prognosis**
Common beech *(Fagus sylvatica)*	No – leafstalk and trunk exhibit cavitation at similar potentials (~−2.3 vs. −2.7 MPa)	Damage symptoms: trunk and branches already affected	Increased mortality over 3+ years, bark-boring insects, slime flux
Sycamore *(Acer pseudoplatanus)*	Pronounced in seedlings (leafstalk ~−1.1 MPa, trunk ~−2.5 MPa); not tested on mature trees	Probably protective; symptoms of desiccation do not rule this out	Regeneration following summer defoliation not investigated
Pedunculate/sessile oak *(Quercus robur/petraea)*	Probably yes – cavitation-resistant trunk (−4.6 to −4.7 MPa) (Lobo *et al.* 2018)	Primarily protective under moderate stress	Ring-porous anatomy renews earlywood vessels annually, permitting efficient water transport the following year. Depending on site however, mortality may also occur the following year (Vitasse *et al.* 2023)
Silver birch *(Betula pendula)*	Unclear/opposite effect – midrib more resistant than branches	Ambiguous; more likely symptom of stress	Premature defoliation is a warning signal
Common ash *(Fraxinus excelsior)*	Probably yes – progressive protection: trunk > leafstalk > leaflet	Leaflets are first to be sacrificed	Already weakened by ash dieback; drought is additional stress factor
Hornbeam *(Carpinus betulus)*	Unknown	Uncertain	Considered to be more resistant to drought stress than beech; insufficient precise data available

Premature signs of discolouration and defoliation do not indicate whether a tree species has a hydraulic safety mechanism, nor whether the defoliation is a sign of protection or damage, as the symptoms are identical. The distinction can only be made in subsequent years: an absence of damage despite leaf symptoms in the previous year then indicates the effectiveness of the protective mechanism. To carry out a thorough assessment of the key native tree species, it would be necessary to determine their susceptibility to cavitation at the leaf, branch and trunk levels. It is a key task to understand the long-term consequences of these effects on the various tree species. Long-term monitoring is essential for this.

The beech: an evolutionary compromise

The European beech presents a particularly critical case. It is no coincidence that this species lacks a safety mechanism. This is the flip side of its fundamental survival strategy: intense shading of competitors through a complete, closed canopy. A tree that outcompetes its rivals by shading them cannot afford to shed its leaves prematurely. Over the course of evolution, the beech has abandoned its hydraulic safety mechanism in favour of its competitive strategy (Losso *et al.* 2019).

This means that if a beech tree sheds its leaves in July, it is not a defensive reaction. Premature defoliation is therefore a serious sign of stress and a clear warning signal, associated with an increased risk of long-term damage to the crown and mortality. By the time the leaves are falling, the water potential in the trunk is already as low as that in the leafstalk: the embolism has already reached the trunk.

The point at which this threshold is reached is well documented for the common beech: leaf water potentials measured before sunrise and ranging between −2.1 and −2.8 MPa mark the onset of crown damage; below −2.8 MPa, transpiration ceases and crown thinning exceeds 20% (Walthert *et al.* 2021). Measurements taken in July 2026 on severely damaged beech trees confirm the trend observed in the summer of 2018.

Long-term data from northern Switzerland show the seriousness of the consequences: following the extreme summer of 2018, 963 mature beech trees were monitored there over a three-year period.

Beech trees in northern Switzerland – three years on from the summer drought of 2018

- → With premature defoliation in 2018: 7.2% of trees dead by 2021 – without premature defoliation, only 1.3%.
- → Defoliation of crowns of affected trees: 29% on average by 2020.
- → 24.6% showed signs of slime flux (bleeding wounds in the bark) in 2019.
- → 22.8% showed signs of bark beetle infestation in 2021 – three years after the drought year.

Source: Frei *et al*. 2022

Why do the effects of the damage continue to be felt for years?

Four mutually reinforcing mechanisms explain why the damage continues to have an impact for years:

- **Carbon deficit:** Leaf loss in July shortens the photosynthesis season by 8 to 12 weeks and has a negative impact on shoot formation for the following year. The tree enters autumn with reduced carbohydrate reserves. It is precisely these reserves that it needs in spring for new growth and the formation of new root hairs.
- **Loss of nutrients:** In the event of heat damage, nitrogen and phosphorus remain in the fallen leaves. Although they do reach the soil via the litter and are partially reabsorbed after decomposition, this process is slow and involves losses. As a lack of these two nutrients limits leaf development, repeated losses weaken the tree's ability to develop its crown over several years (Bergström *et al.* 2026).
- **Permanently reduced conductivity:** Cavitated xylem vessels do not regain their function in the season following the drought. The tree compensates for the prolonged disturbance by reducing its leaf area. This is precisely what manifests itself the following year as thinning of the crown (Hunziker *et al.* 2025; Arend *et al.* 2022). The tree thus enters the next dry year with a weakened vascular system, a smaller leaf area and, consequently, lower

photosynthetic potential, as well as a narrower safety margin – the latter being a key factor in drought-induced mortality (Torres-Ruiz *et al.* 2024).

- **Secondary pests:** Weakened trees no longer produce adequate resin barriers or wound callus tissue. Bark-boring insects such as jewel beetles and bark beetles, as well as fungi, take advantage of this window of opportunity, often only one to three years later (Frei *et al.* 2022).

These mechanisms – whether considered individually or in combination – have an impact that extends far beyond a single event. The extreme years of 2003, 2015, 2018/2019, 2022 and 2026 have a cumulative effect: on critical sites, it is often the same trees that are affected again and again, and this combination accelerates processes such as the dieback of beech trees, which unfolds over several years. However, the full extent of this cumulative effect has not been quantified.

Conifers: brown needles as a late warning signal

Conifers react in a fundamentally different way, which alters how the damage is assessed. Their primary line of defence does not involve the shedding of needles, but often consists of a drastic reduction in transpiration. They do not exhibit distinct areas of abscission on individual needles.

It is therefore the year in which the needles were formed that is crucial. If needles formed in previous years turn yellow and fall off, this may be a defensive reaction. If the current year's needles have turned brown, damage has already occurred. Furthermore, the visible symptoms lag behind the damage: the stress triggering the damage may have occurred weeks or months before. The speed at which this critical condition is reached depends primarily on the depth of soil accessible to the roots and the water supply available to the plants; damage sustained the previous year also plays a role. In conditions of extreme drought, spruce trees, for example, can suffer hydraulic collapse and die within a single summer, without having previously been attacked by harmful organisms (Arend *et al.* 2021).

There are significant differences between the main tree species. The **spruce** *(Picea abies)* is the most vulnerable: its shallow root system only reaches into the topsoil, and its stomata remain open for longer than those of other conifers. In this species, reddening of the needles and browning of the crown are frequently associated with an active bark beetle infestation *(Ips typographus)*: the resinous defence mechanism requires turgor pressure and carbohydrate reserves, which are lacking following drought stress. The 'point of no return' comes early. The fact that crown damage in spruce often starts at the top is explained by a hydraulic phenomenon: the young shoots at the crown tip are inherently more vulnerable (P_{50} −1.5 MPa) than the older trunk wood at the base (−4.0 MPa) (Zambonini *et al.* 2024).

The **Scots pine** *(Pinus sylvestris)* is considerably more robust: it closes its stomata early and conservatively, reaches deep into the soil thanks to its taproot, and retains its needles for several years. If the needles from previous years turn yellow in late summer, it is a stress reaction, but not yet a sign of lasting damage. The situation only becomes critical when the current year's needles are also affected.

Fig. 5. Dead pine trees in the Pfyn Forest, Valais, as a result of extreme drought. Photo: Marcus Schaub (WSL)

What does this mean for forestry practice?

Premature defoliation or leaf discolouration in beech trees in June and July is a warning signal to be taken seriously: it is not a defensive reaction, but a symptom of damage (Frei *et al.* 2022; Losso *et al.* 2019). It is worth marking these trees and monitoring them for at least three - or preferably more - consecutive years, particularly to see whether and how they recover. The capacity to carry out this monitoring may be limited if the damage occurs over extensive areas. In this case, advantage should be taken of the fact that dieback occurs over several years. This time can be used to promote site-appropriate regeneration and avoid putting additional pressure on the timber market.

The likelihood of recovery varies considerably depending on the tree species:

- Beech: increased risk of mortality over a three-year period; monitoring of damage in subsequent years.
- Oak: comparatively resilient, as predetermined breaking points limit the spread of damage, and young, ring-porous earlywood vessels enable efficient renewal of the water conduits. Sessile oak and downy oak tolerate dry sites better; the latter is however heavily infested by secondary pests in drought years (Sallé 2014).
- Maple: the outlook is more favourable if defoliation begins early in the stress period; however, the ability of maples to recover following summer defoliation has not yet been investigated (Losso *et al.* 2019).
- Lime: recovers significantly better from early defoliation.
- Spruce: a brown crown is a signal that urgent action is required; the presence of bark beetles should be checked immediately. The urgency increases with the proportion of spruce trees and the proximity to the next spruce stand.

Decisions on which tree species to promote where: Beech-dominated stands on sites with low water-retention capacity – that is on shallow soils, exposed slopes and sandy substrates – must be reassessed in the long term. As extreme summers become more frequent, the evolutionary compromise of the beech is becoming a recurring issue (Frei *et al.* 2022).

It remains to be seen where and to what extent thinning measures improve water availability for the remaining stand. In beech stands, such measures may well be a difficult balancing act (Gessler *et al.* 2026), as shade tolerance is a key feature of the beech's strategy; if favourable growing conditions prevail immediately after a thinning measure, the remaining beech trees will invest their resources in rapid canopy closure, before forming new roots. This makes them all the more vulnerable to the next drought period.

The bottom line

The brown leaves and needles of summer 2026 do not all tell the same story, but they do convey an important message. For the beech, the defining tree species of central Europe, the picture is clear: the shedding of its leaves at the height of summer is not a defence mechanism, but a symptom of stress. Other tree species, such as lime or oak, are better able to protect themselves, whereas with the sycamore the picture is less clear. Even the tolerance of species equipped with a hydraulic safety mechanism has its limits: on the driest, most extreme sites, even these species are now also under stress. Finally, when it comes to conifers, visible signs appear late - too late for preventive intervention on individual trees, but not too late for a reassessment of the choice of tree species on a site-by-site basis. Knowledge of these species-specific differences is not just academic detail, but one of the most important foundations on which to base forestry decisions in the coming decades (Hunziker *et al.* 2025; Torres-Ruiz *et al.* 2024).

Translation: Tessa Feller

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