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Selected Browning of Conifer Cultivars in the 2021 Pacific Northwest Heat Wave

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A Port of Seattle park along Seattle's Duwamish River three months after the heat event. Many conifer varieties in public parks, along busy streets, and in private gardens suffered damage and, in many cases, death from the stress of the heat dome. The effects didn't always make immediate sense. Here, several conifers died while others growing right beside them escaped without apparent harm.

Despite our unusually cool, wet, and rainy springs in the Pacific Northwest the past few years, we still remember and cannot forget the record-breaking heat wave that blasted us in late June of 2021 elevating daytime temperatures 40 degrees higher than usual for early summer. This extraordinary event broke all-time records for the hottest temperatures in our region.

A nearly stationary, high-pressure system parked atop western North America for several days, blocking the easterly flow of weather systems typical for our region, forcing warm air downward and preventing surface heat from escaping into the upper atmosphere. This exceptional heat dome of parched, stagnant air remained trapped over northwestern North America for less than a week but pushed temperatures in Lytton, British Columbia, to 121°F, the highest temperature ever recorded in Canada, and to highs of 108°F in Seattle and 116°F in Portland, Oregon. These oven-like temperatures, in combination with profoundly low relative humidity, meant little evaporative cooling as well, further contributing to punishing high surface temperatures and desiccated soils. More than a year later, many of the scars and casualties of the daunting heat dome of 2021 remain.

Albers Marcovina Vista Gardens, a four-acre botanical garden in Bremerton, Washington, is just one hour west of Seattle by ferry across Puget Sound (the Salish Sea). In addition to hundreds of other types of trees, shrubs, and perennials, the garden is home to more than four hundred conifer cultivars, representing 130 conifer species, most from the diverse geographical regions of the Northern Hemisphere. The varied members of this special conifer collection felt the effects of 2021's heat wave in unison, providing a unique data set from which to evaluate the impact of sustained, punishing heat across a wide range of currently available conifer cultivars. All plants in the analysis herein were growing on a southwest-facing hillside above Puget Sound's Port Washington Narrows.

On the day immediately following the three most punishing days of intense heat, John briefly ventured out to see how the garden had fared and noticed that the leaves of a few conifers had already turned brown. However, it was still too warm to begin a painstaking, thorough inspection.

Three weeks passed before John and Dave could begin a systematic inspection of the conifers in the garden to evaluate and photograph the extent of the heat damage, quantifying the damage by visually estimating the percentage of wilted and browned conifer crowns using the following criteria:

- Modest (15%–39% browning)
- Moderate (40%–59% browning)
- Substantial (60%–79% browning)
- Severe (≥ 80% browning)

Surprisingly, most of the conifers (nearly 90%), including all the conifers shaded from the hot afternoon sun, had little (< 10% browning) to no apparent foliar damage. John had grown those that did sustain damage in native clay soil amended with compost or top-dressed with mulch in full sun, and he did not irrigate them after their initial planting and establishment.

A follow-up examination of the conifers about three months after the heat wave showed that most of the conifers which had suffered moderate to more severe browning during the heat wave showed little additional browning after this initial three-week, post-heat inspection. However, some of the conifers that had initially appeared undamaged at week three had begun to exhibit noticeable browning at the three-month inspection, particularly at the branch tips. Interestingly, the browning pattern appeared more evenly distributed on these conifers. Additional browning occurred as the months passed, and twig dieback became evident on some conifers, particularly those with substantial or severe browning within three weeks after the heat wave.

Cultivars of seven different fir species exhibited modest or more substantial browning (Table 1). Four fir cultivars, 'Rumburk', 'DuFlo', 'Mt. Si', and 'Kristallkugel', had severe browning and extensive twig and branch dieback (Figure 1 and 2). Note that the original, correct name for 'Kristallkugel' is 'Grübele HB'. 'Rumburk' and 'DuFlon' have subsequently died. Although 95% of the crown of the California red fir cultivar 'Mt. Si' had turned brown, and over 90% of its branches died (Figure 3a, pictured on July 15, 2021), this fir exhibited a flush of new growth on a small portion of its branches, and it has managed to survive (Figure 3b, same specimen pictured on Oct. 19, 2021). The Korean fir

Table 1. Effect of the heat wave on fir cultivars as expressed by percent browning

Name	Cultivar	Age (years)	Percent Browning
Abies koreana (Korean fir)	'Kristallkugel'	12	95%
	'Blue Magic	9	60%
	'Silberperle'	10	40%
	'Golden Traum'	11	25%
	'Oberon'	11	20%
	'Wellenseind'	9	15%
Abies veitchii (Veitch's fir)	'Rumburk'	12	95%
	'Heddergott'	16	65%
Abies alba (European silver fir)	'Pancake'	3	65%
Abies cephalonica (Greek fir)	'Minitip'	4	60%
Abies concolor (white fir)	'Ostrov nad Ohří'	9	45%
	'Jack'	6	25%
Abies lasiocarpa (subalpine fir)	'DuFlon'	12	95%
	'Prickly Pete'	3	50%
Abies magnifica (California red fir)	'Mt. Si'	12	95%

'Kristallkugel' has also survived severe browning. Four other fir cultivars, 'Blue Magic', 'Heddergott', 'Pancake', and 'Minitip' (Figure 4a, pictured on July 15, 2021), had substantial damage. Veitch's fir 'Heddergott' subsequently died, but the other three fir cultivars with substantial browning recovered well (Figure 4b, the same specimen of 'Minitip' but this time photographed on April 25, 2022).

Fig. 1: *Abies koreana* 'Kristallkugel' on July 15, 2021

Fig. 2: *Abies veitchii* 'Rumburk' on July 15, 2021

Fig. 3a: *Abies magnifica* 'Mt. Si' on July 15, 2021

Fig. 3b: *Abies magnifica* 'Mt. Si' on October 19, 2021

Fig. 4a: *Abies cephalonica* 'Minitip' on July 15, 2021

Fig. 4b: *Abies cephalonica* 'Minitip' on April 25, 2022

Cultivars of six spruce species also exhibited moderate or more severe browning in response to the heatwave (Table 2). Three cultivars of Norway spruce, including a five-year-old 'Gold Drift', suffered severe browning. All three cultivars also had extensive dieback of their branches, but all three survived (Figure 5). Interestingly, a second older cultivar of 'Gold Drift' shaded from the afternoon sun by a woodland to the west did not suffer from the heat wave (Figure 6). Both were photographed on the same day, July 15, 2021. The two Norway spruce cultivars, 'Anita's Golden Cloak' and 'Pusch' showed modest browning and recovered well with minimal branch dieback (Figures 7a and 7b: 'Anita's Golden Cloak' photographed on July 15, 2021 and April 25, 2022). The white spruce 'Goldilocks' had 85% of its needles turn brown, while other white spruce cultivars experienced no browning. Conifer experts have speculated that 'Goldilocks' may be a cultivar of Norway spruce. The Serbian spruce cultivar 'Kuschen' suffered severe browning and branch dieback and subsequently died, while the Serbian spruce cultivar 'Treblitzsch' had modest browning and it recovered. The Caucasian spruce 'Schovenhorst' had substantial browning, and the cultivar 'Smee WB' had moderate browning, while other cultivars had no browning. The only Colorado spruce which suffered substantial browning was 'Mrs. Cesarini'.

Four mugo pine cultivars had moderate to substantial browning (Figure 8: *Pinus mugo* 'Gordon Bentham' photographed on July 15, 2021), while other Mugo pine cultivars had little or no browning. The Korean pine

Table 2. Effect of the heat wave on spruce cultivars as expressed by percent browning

Name	Cultivar	Age (years)	Percent Browning
Picea abies (Norway spruce)	'Gold Drift'	5	95%
	'Clanbrassiliana'	12	90%
	'Humilis'	4	90%
	'Pusch'	13	30%
	'Anita's Golden Cloak'	11	35%
Picea glauca (white spruce)	'Goldilocks'	11	85%
Picea omorika (Serbian spruce)	'Kuschen'	11	95%
	'Treblitzsch'	13	30%
Picea orientalis (Caucasian spruce)	'Schovenhorst'	12	60%
	'Smee WB'	7	40%
Picea pungens (Colorado spruce)	'Mrs. Cesarini'	8	65%
	'A.S.'	9	15%
Picea rubens (red spruce)	'Pocono'	8	50%

Fig. 5: *Picea abies* 'Gold Drift' growing in direct afternoon sun on July 15, 2021

Fig. 6: *Picea abies* 'Gold Drift' growing in afternoon shade on July 15, 2021

Fig. 7a: *Picea abies* 'Anita's Golden Cloak' on July 15, 2021

Fig. 7b: *Picea abies* 'Anita's Golden Cloak' on April 25, 2022

Fig. 8: *Pinus mugo* 'Gordon Bentham' July 15, 2021

(*Pinus koraiensis*) cultivars 'Blue Ball' and 'Variegata' experienced approximately 40% browning. However, the browning was minimal in an older Korean pine species. Two Douglas fir cultivars, 'Green Orca' and 'Logger Head', and all the hemlock cultivars, including Canadian hemlock (*Tsuga canadensis*), mountain hemlock (*T. mertensiana*), northern Japanese hemlock (*T. diversifolia*), and southern Japanese hemlock (*T. sieboldii*), encountered modest browning of their needles, particularly at the tips of the branches. The fact that most conifers recovered despite considerable damage emphasizes their resilience against foliar scorch and drought-induced mortality.

Extreme temperatures can severely damage leaf structures and functions. The extreme temperatures during the heat wave experienced by those conifers on a southwest-facing hillside exposed to the afternoon sun during the hottest part of the day on the longest days of the year exhibited foliage scorch relatively quickly, in just a few days and weeks, usually with more browning on their south and west sides and less browning on their north and east sides. These observations suggest that heat *per se* played a major role in the initial damage. In contrast, conifer desiccation and hydraulic damage likely played a major role in the longer-term impacts of this heat wave exhibited by additional leaf browning in a more evenly distributed pattern at the branch tips in the months following the heat wave, twig and branch dieback, and conifer mortality. Leaf scorch, be it due to extreme heat or a combination of heat and hydraulic damage, would impair photosynthesis and weaken the conifer, making it more likely to succumb to other stressors.
Leaf scorch in conifers may occur when their leaves lose water faster than they can replace it via transpiration. Usually, water evaporation at a leaf's surface creates negative pressure. This tension pulls water up through the water-conducting system of the plant, the xylem, like sucking on a straw. During dry and hot periods, this negative pressure can become excessive to the point that the water column breaks (a process called cavitation), causing an embolism, where air bubbles form, breaking the sustaining flow of water and interrupting hydraulic conductivity. The concurrent embolism of numerous water conduits impedes or shuts down water flow to conifer leaves, twigs, and branches. This leads to leaf browning and desiccation and is often associated with branch dieback. This desiccation and subsequent browning are not always fatal to the plant, but they do stress it.

Conifers differ in their sensitivity to drought and ability to avoid embolism. Evaporation creates a negative pressure within the conifer, expressed in MPa (Megapascal) units. A 50% loss of water conductivity in the xylem is referred to as P50, a key physiological parameter that reflects a conifer's ability to withstand sensitivity to drought. Thus, conifers with higher P50 negative pressures would likely have less embolism and be more drought-tolerant than those with lower P50 negative pressures. Indeed, together with two colleagues, we recently reported that conifer species at Vista Gardens with P50 negative pressures greater than -6 MPa, such as Deodar cedar (*Cedrus deodara*) and cedar of Lebanon (*C. libani*) with P50 of -6.69 MPa and -7.71 MPa, respectively, did not undergo any observable leaf browning in response to the heat wave. However, species with P50 negative pressures between -6 MPa and -5 MPa, such as black spruce (*Picea mariana*) 'Normanna Rd' (P50 -5.21 MPa) and single-leaf pinyon (*Pinus monophylla*) 'Blue Jazz' (P50 -5.55 MPa), had modest needle browning. In comparison, species with P50 negative pressures less than -5 MPa, such as two cultivars of Veitch's fir (P50 -3.52 MPa) and some cultivars of the Norway spruce (P50 -3.66 MPa), had moderate to severe browning up to 95% of the canopy (Klein et al.).

Although *P*50 appears to be a valuable metric of drought sensitivity among conifer species, trees with a given *P50* had significant variations in leaf browning.

Fig. 9: John Albers in the conifer garden during our survey of the heatdome damage

For example, among the 15 Norway spruce cultivars (*P*50 -3.66 MPa), three had severe leaf scorch, two had modest leaf scorch, and the remaining ten cultivars had little or no leaf scorch. Among the 14 Colorado spruce cultivars, one had substantial browning, another modest browning, while the others had little or no browning. Similarly, among the fifteen cultivars of the Korean fir in full sun, one had severe leaf scorch and subsequently died, one had substantial browning, and the others had modest or moderate leaf browning. In contrast, the other cultivars, including the species, had no leaf browning . Among the eight cultivars of white fir (*P50* -4.76MPa), one had moderate browning, two had modest browning, and the others had little or no browning. It is clear, therefore, that some cultivars of a given species appear to be more sensitive to leaf scorch than others.

What accounts for the differences in the sensitivity of cultivars to leaf scorch? Together with my colleagues, we previously reported that younger conifers at this site tended to be more vulnerable to leaf browning than older, better-established conifers (Klein et al.). Younger or smaller conifers would have less rooting depth and less developed associations with mycorrhizae, leaving them more sensitive to drought and leaf scorch. Also, many of the conifer cultivars with substantial or severe browning were quite small, while the larger and older cultivars and species generally had little or no browning. The temperature close to the ground may be higher, thereby increasing the likelihood of heat damage to the leaves.

All the conifer cultivars evaluated in this study came from cuttings (scions) taken from plants with dwarf or miniature growth rates. They were grafted onto rootstocks of the same or related species of the witch's broom. The branching and leaves of most cultivars derived from witch's broom are more congested than those of the original species. Consequently, this tends to reduce air circulation and evaporative cooling at the leaf surface, which could contribute to higher temperatures at the leaf surface. Also, witch's broom cultivars may have altered shape, size, and distribution of the leaves, which could change other tree physiological metric differences, such as stomatal conductance and water use efficiency, thereby adversely impacting a cultivar's sensitivity to heat and drought.

John Albers (left) and David Perry (right) in John's garden

The heat and drought tolerance of the rootstock and the compatibility between the witch's broom scion and rootstock could also affect the cultivar's ability to withstand heat and drought. For example, it is known that fir scions grafted onto Japanese fir (*Abies firma*) rootstock do better in the American Southeast. More studies are needed on the impact of conifer cultivar grafting on heat and drought tolerance.

Our study, while useful, has obvious limitations. We collected our data from the conifers at a single site under the heat, moisture, and soil conditions at this specific site (Figure 9). Thus, it is impossible to extrapolate these data to the impact of the heat wave on conifer cultivars over the broader region and exposed to varying conditions. It would have been more desirable to obtain data from all over the broad region exposed to the heat wave. Additionally, we measured and recorded tree crown browning at only one time point, approximately three weeks after the heat wave. It would also have been helpful to have complete data on the changes in leaf browning over time, in addition to our initial estimates of maximal browning of the trees' crowns.

Despite these limitations, our observations are worth considering as we continue to experience the consequences of our changing climate in the continental United States. We are sure that we can expect warmer average temperatures, dryer summers, and longer and more intense heat waves in conjunction with increasing wildfires, insect outbreaks, and tree diseases. We will also experience greater extremes in temperature and precipitation and, thus, shifts in plant and animal life cycles.

Indeed, in the past few years in the Pacific Northwest, we have experienced extremes in temperature and precipitation. Given the negative impact of more severe drought and heat waves on conifers, we must alter our practices and conifer choices. One significant finding of our study was that all conifers shaded during the hottest part of the afternoon escaped any significant leaf browning. Thus, the best way to protect conifers sensitive to future heat waves is to provide them with afternoon shade. Placing shade cloth over dwarf conifers before an impeding heat wave is a practical solution. Also, the long-term impact of the heat wave will be lessened by providing supplemental water and mulching the conifer's roots to retain moisture before the heat wave. Selecting conifers that are more heat and drought resistant is the ideal approach. Thus, we need sound data to determine which species and cultivars will likely withstand higher temperatures and reduced precipitation.

Physiological parameters that predict drought tolerance may be available on economically important forest tree species, but data are not yet available for many ornamental species important to the landscape and nursery industries. Furthermore, few studies compare conifer species' physiological metrics to their cultivars. In view of our surprising data that cultivars of the same species differed significantly in their sensitivity to leaf scorch, hopefully, tree researchers will begin to compare the physiological metrics of tree species with their cultivars. Our studies show that fir, spruce, pine, and hemlock cultivars were susceptible to leaf scorch and twig dieback during the heat wave. However, the affected cultivars were highly selective. By contrast, the genera cypress (*Cupressus*), juniper (*Juniperus*), cedar (*Cedrus*), false-cypress (*Chamaecyparis*), and Japanese-cypress (*Cryptomeria*) at this site exhibited minimal or no leaf browning in response to this heat wave.

There are no adequate known physiological parameters to predict heat tolerance in conifers. What temperature for what length of time is required to elicit leaf damage, and what role does leaf desiccation and hydraulic damage play in this process? What are the physiological or structural parameters that determine a conifer's heat tolerance? These are some of the key questions that need to be addressed.

As conditions continue to evolve climatically, we will need better knowledge of those conifer species and cultivars most vulnerable to heat and drought-induced damage and mortality and those most tolerant. We will also need to determine which physiological parameters best predict these vulnerabilities. Such critical information will allow the nursery, landscape, and gardening communities to better select those conifers most appropriate for a given region and better prepare them for the realities of the warming climate.

For a complete, updated, illustrated guide to growing and caring for conifers, see John J. Albers's *Growing Conifers: The Complete Illustrated Gardening and Landscaping Guide*, New Society Publishers, 2021.

References

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