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Branch Orientation: A Potential Indicator of Stem Rehydration and Water Stress

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ABSTRACT

Spring rehydration in snow-covered temperate forests marks a key ecohydrological transition, influencing forest productivity and water balance. Tree water deficit is a key ecohydrological indicator about above ground water status and response to subsurface water availability. But simple measures of rehydration and water deficit are few and the relationship between stem rehydration and simple indicators like structural movement linked to branch orientation remains poorly understood. We investigated the coordination between stem rehydration, tree water deficit and branch movement in *Abies balsamea* using high-resolution dendrometer data and time-lapse imagery from early March to mid-May in Ontario, Canada. In this video and data, we showed that upward branch movement consistently aligned with stem radius expansion during snowmelt and after rainfall events, while downward branch posture corresponded with dry periods and increased tree water deficit. Freeze–thaw events caused abrupt stem shrinkage but had limited influence on branch position. These findings suggest that branch posture reflects stem water status, potentially offering a visual and qualitative indicator of subsurface water availability to trees. While this is not a substitute for physiological measurements, branch movement could support field-based monitoring of rehydration dynamics and further new opportunities to tree water relation studies. As climate change alters snowmelt timing and moisture regimes, integrating structural and physiological indicators may enhance our understanding of plant–water interactions in cold-region ecosystems.

1 | Introduction

Stem rehydration and water stress are key ecohydrological indicators (e.g., Zweifel et al. 2005; Zweifel 2016; Salomón et al. 2022; Hackmann et al. 2024; Peters et al. 2025). They are typically measured with dendrometers, which have become a key tool in monitoring seasonal transitions in tree water relations and transpiration phenology (Deslauriers et al. 2007; Turcotte et al. 2009; Nehemy et al. 2022, 2023). Stem shrinkage and swelling reflect changes in phloem and xylem tension and replenishment resulting from daily variations in transpiration and root water uptake. Transpiration drives internal water movement by creating tension (i.e., negative water potential) as water evaporates from stomata, pulling water upward from the roots and stem storage and transporting it through the xylem. Transpiration depletes internal water reserves (Perämäki et al. 2005; Cermak et al. 2007), resulting in measurable stem contraction (Zweifel and Hasler 2001; Steppe et al. 2006;

Magali F. Nehemy and Christina A. Hackmann contributed equally to this study.

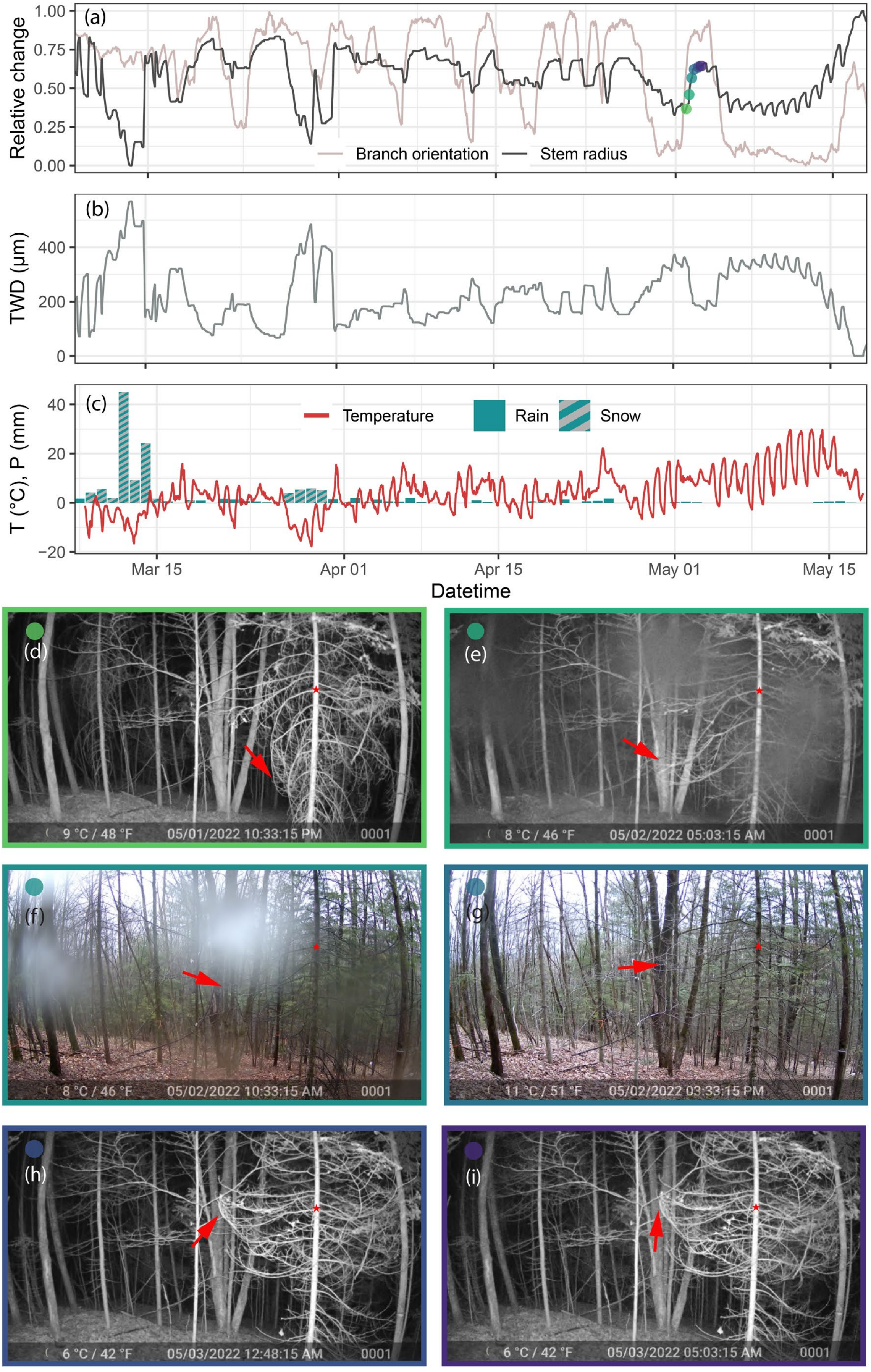


FIGURE 1 | Legend on next page.

FIGURE 1 | Branch movement, stem radius dynamics and environmental conditions during late winter and early spring. (a) Relative change in branch orientation (black line) and stem radius (brown line), each normalised to their observed maxima. Coloured points highlight selected time steps shown in (d–g), exemplifying upward branch movement. (b) Tree water deficit (TWD) derived from dendrometer measurements, illustrating periods of stem shrinkage and rehydration. (c) Environmental conditions over the same period, including air temperature (red line), rainfall (solid teal bars) and snowfall (hatched teal bars). (d–g) Time-lapse images captured by a trail camera showing diurnal and multi-day branch repositioning (red arrows) in relation to the reference point (red star) and weather conditions. Coloured frames correspond to the time points marked in (a). Temperature at the time of each image is shown in °C/°F.

Zweifel 2016). As transpiration rates start to decline after midday, root water uptake also begins to replenish internal water storage, continuing through the night, restoring hydration for the next day and promoting stem expansion.

In the winter and early spring, freeze–thaw cycles can result in stem contraction and expansion (Zweifel and Häsler 2000; Améglio et al. 2001; Charra-Vaskou et al. 2016; Maruta et al. 2020). Upon freezing, an abrupt decrease in diameter is observed, and on thawing, the initial diameter is restored (Zweifel and Häsler 2000; Améglio et al. 2001; Ball et al. 2006; Charra-Vaskou et al. 2016). Recent studies have linked the onset of transpiration, detected with stem radius change measurements, to also the onset of photosynthetic activity (Pierrat et al. 2021) and net carbon uptake (Nehemy et al. 2023), highlighting stem radius dynamics as a proxy for ecophysiological function.

But while changes in stem diameter through dendrometers have been shown to track water potential in leaves and stems (Offenthaler et al. 2001; Dietrich et al. 2018; Peters et al. 2025), the relationship between stem rehydration and structural movement, such as branch positioning, remains poorly understood (Zlinszky et al. 2017). Turgor-driven elasticity and water-related changes in stem stiffness (Ciruzzi and Loheide II 2019) may influence branch posture. Recent work using terrestrial laser scanning (TLS) has found consistent overnight drooping of branches during rehydration in species such as *Betula pendula* (Junttila et al. 2022), as well as *Populus*, *Quercus* and *Acer* (Hallmark et al. 2021). The movement patterns observed thus far appear to vary by season and environmental conditions.

Here, we document stem rehydration and branch movement in balsam fir (*Abies balsamea*) in a snow-dominated temperate forest during early and late spring, from early March to mid-May. We combined stem radius measurement with timelapse photography to observe synchronously the stem expansion and contraction, along with branch movement, in the spring, before, during and after snowmelt. This brief observation and video document strong evidence for our site that the branch position may indeed be an indicator of stem rehydration and water stress.

2 | Study Site and Methods

This study was conducted in the Harp-4 catchment of the Muskoka River Watershed, Ontario, Canada. The site is a mixed forest on shallow, sandy soils with ~1000 mm of annual precipitation (~30% snow). Snowmelt occurs from mid-March to early May and represents the main recharge period of subsurface storage and streamflow events (McDonnell and Taylor 1987). We installed circumference dendrometers (DC3, Ecomatik) on hemlock (*Tsuga canadensis*) and collected 15-min stem radius data through spring 2022. The *T. canadensis* diameter at breast height (DBH) was 14.4 cm. Time-lapse imagery of nearby *A. balsamea* and *Fagus grandifolia* trees was recorded using a trail camera (Model SL122M Pro; Zopu Trail Camera) at 24-MP resolution with a 15-min shooting interval, and subsequently compiled into a video. Although the monitored species (*T. canadensis*) is not visible in the video, both *A. balsamea* and *T. canadensis* are conifer species growing less than 5 m apart. The DBH of the *A. balsamea* (9.8 cm) is smaller but similar to the *T. canadensis*. We obtained air temperature and precipitation from the Dorset Environmental Science Centre.

We processed dendrometer data using *treenetproc* package (Haeni et al. 2020) and conducted the visualisation with the R package *gganimate*. Stem radius measurements were normalised relative to the observed maximum to provide direct observation against branch position. Additionally, we computed the tree water deficit (TWD), a proxy for tree water status (Zweifel 2016) to compare with changes in branch position. TWD is a key ecohydrological indicator about above ground water status and response to subsurface water availability. When TWD is zero, the stem's water storage tissues and cambial zone are fully hydrated and stem water potentials are near zero. Positive TWD values indicate that the stem has lost water, meaning its storage is no longer saturated and stem water potential has dropped below zero.

We used the time-lapse image sequence to build a video and quantified relative changes in branch orientation (vertical displacement of a defined fork) using the Tracker software (Brown et al. 2025). Briefly, we then normalised the quantified branch displacement relative to its maximum value, such that a value of one represents the observed maximum deflection and zero corresponds to the lowest position. Next, we combined the time-lapse video with the environmental data and the normalised change in stem radius and branch position data using the DaVinci Resolve software. Finally, we used the diel cycle approach to identify the onset of transpiration in the spring (Nehemy et al. 2023; Flynn et al. 2025). The video, data and code for this work are available in Nehemy et al. (2025).

3 | Results and Discussion

Overall, we observed an alignment between branch movement and stem hydration status (Figures 1 and 2; Video 1). The upward branch movement coincided consistently with stem

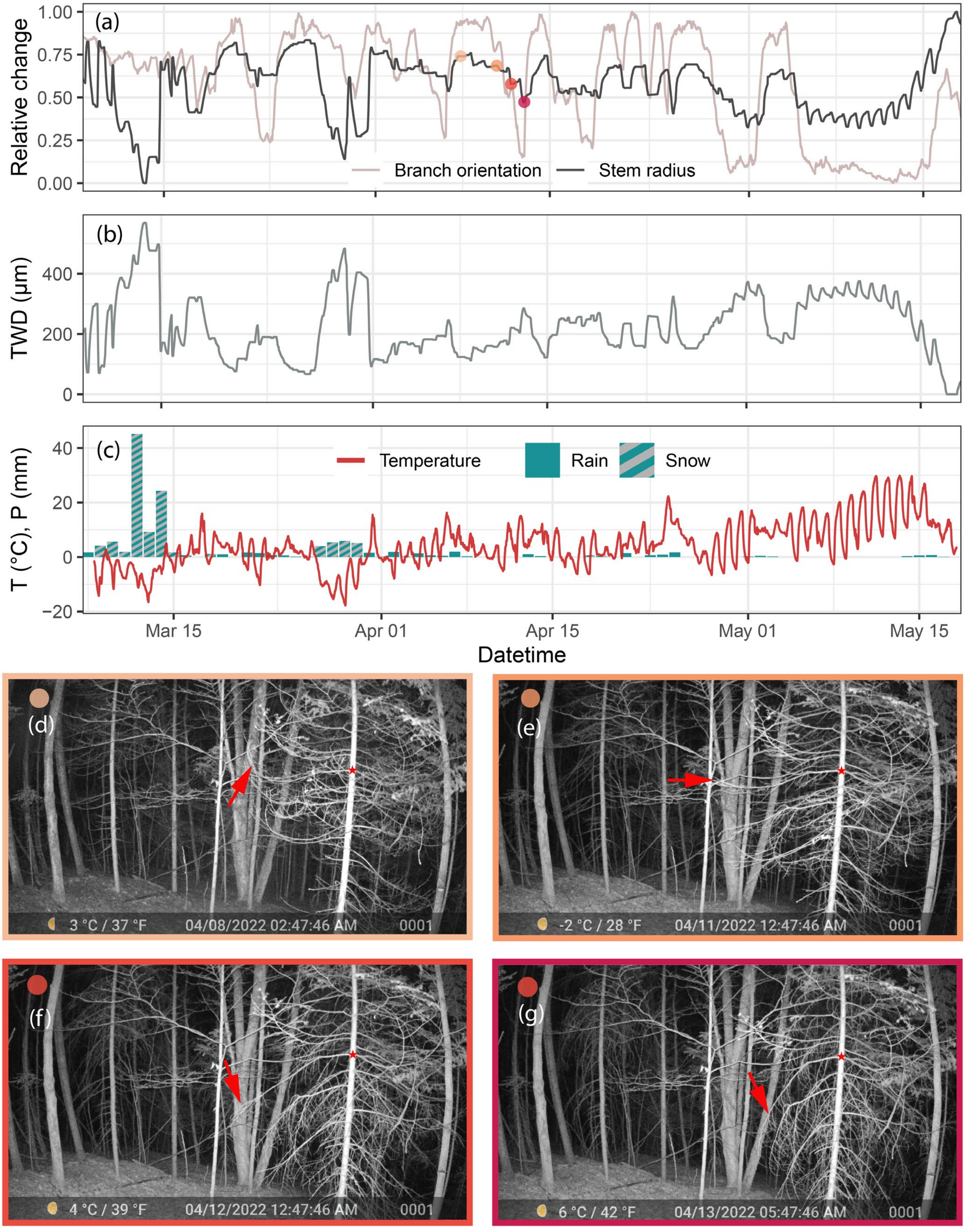
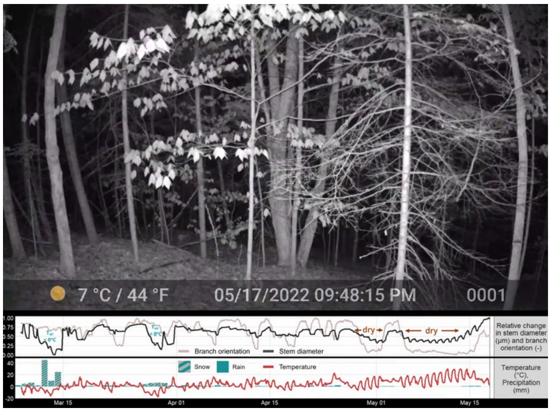


FIGURE 2 | Legend on next page.

FIGURE 2 | Branch movement, stem radius dynamics and environmental conditions during late winter and early spring. (a) Relative change in branch orientation (black line) and stem radius (brown line), each normalised to their observed maxima. Coloured points highlight selected time steps shown in (d–g), exemplifying downward branch movement. (b) Tree water deficit (TWD) derived from dendrometer measurements, illustrating periods of stem shrinkage and rehydration. (c) Environmental conditions over the same period, including air temperature (red line), rainfall (solid teal bars) and snowfall (hatched teal bars). (d–g) Time-lapse images captured by a trail camera showing diurnal and multi-day branch repositioning (red arrows) in relation to the reference point (red star) and weather conditions. Coloured frames correspond to the time points marked in (a). Temperature at the time of each image is shown in °C/°F.



VIDEO 1 | This video summarises high-frequency observations of changes in stem diameter and branch orientation, together with associated environmental drivers. The top panel shows a time-lapse sequence of the study tree (the individual located on the right side of the frame and closest to the viewer), along with the air temperature and date/time (EST) information, providing a visual record of branch movement. The middle panel displays the relative changes in stem diameter and branch orientation, illustrating their strong temporal synchronisation. The bottom panel presents the environmental conditions, including air temperature (°C) and precipitation (rain and snow, mm). Together, these panels highlight the tight coupling between environmental forcing, stem diameter dynamics and branch orientation. Video content can be viewed at https://onlinelibrary.wiley.com/doi/10.1002/hyp.70389.

radius expansion (Figure 1a) and reduced TWD (Figure 1b); downward branch movement was aligned with stem shrinkage (Figure 2a) and increased TWD (Figure 2b). We note that branch upward movement usually started a few hours (< 3–8 h) prior to the stem expansion (Figures 1a and 2a). We suggest this pattern could arise because the water-potential gradient is steeper towards the branch tips, where water potential is most negative near the needles, drawing water first into branch storage before replenishing the stem. Although, further measurements are required to test this hypothesis. In contrast, during drier periods (i.e., TWD closer to 400 um) when stem expansion was minimal and below the previously observed stem maximum, branches remained in a downward position (Figure 1b,d; Video 1).

Several rehydration events occurred in mid-to-late March (15, 19–20 and 24–25 March) and early April (1–2 April), before the complete end of the snowmelt period and onset of transpiration (8 April). These events were characterised by a synchronised increase in stem radius and upward branch movement, suggesting that snowmelt likely contributed to recharge of root-zone water and supporting the rehydration of the stem and branches (Nehemy et al. 2022). Importantly, these responses occurred on days when air temperatures rose above 0°C and remained above freezing temperatures. In early March (8–14 March), prior to the onset of transpiration, freeze–thaw diel cycle events were evident, during which the stem radius exhibited abrupt fluctuations (Figure 1a). Air temperatures dropped below 0°C at night and reached near 0°C during the day (Figure 1c). After the first rehydration response on 15 March, another air temperature below 0°C event occurred between 28 and 31 March leading to a sharp decline in stem diameter, followed by recovery with thawing and rehydration on 1 April. These rapid changes in stem radius reflect well-documented frost shrinkage in trees, typically occurring when temperatures fall between −2°C and −6°C, and subsequently the stem expands above freezing (Davis et al. 1999; Zweifel and Häsler 2000). Spring 'frost events' such as these are known to interrupt stem rehydration, delay the onset of transpiration and suppress photosynthetic activity (Pierrat et al. 2021; Nehemy et al. 2023). During these events, when air temperature was below 0°C for more than 24 h, branch movement was subtle and inconsistent, with limited amplitude, suggesting that branch movement is less sensitive to freeze–thaw cycles than to rehydration.

We observed stem expansion and upward branch movement (Figure 1) in response to rainfall events following snowmelt and the onset of transpiration, notably on 13–14, 21, 23, 25–26 April, 2–3 May (Figure 1) and 15 May. In contrast, during drier periods, of at least four consecutive days without rain, such as 28 April to 1 May and 6–14 May, branches remained downward (e.g., Figure 1a,d; *Note:* branch orientation timeseries), and stem expansion was minimal (Figure 1a; Video 1). A notable recovery in branch upward position and stem radius occurred between 2 and 3 May after two rainfall events (Figure 1) and after three small rainfall events on 15–17 May, following the prolonged dry period (Video 1). The described upward movement aligned with stem expansion following opportunities to rehydrate after rainfall periods suggests that increased stem water content enhances branch turgor and stiffness, allowing branches to resist gravitational pull during rehydration. We also note that the *F. grandifolia* tree in the video (tree cantered) does not show similar branch movement during the observed period, as it also did not have leaves until 13 May. This provides additional evidence that stomatal opening and transpiration are required to generate the water potential gradient that results in stem shrinkage and expansion after spring thaw (Nehemy et al. 2023; Flynn et al. 2025), and, respectively, branch upward movement.

4 | Relevance

Our observations highlight a previously overlooked branch movement in temperate forests, underlying water uptake and

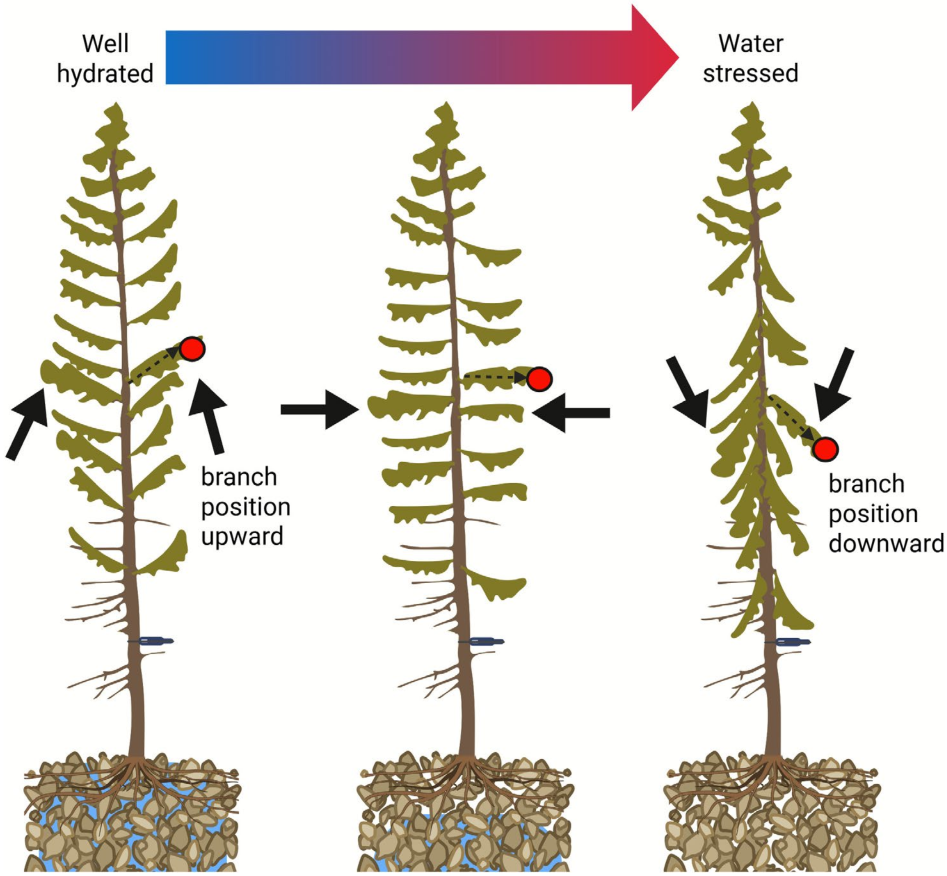


FIGURE 3 | Perceptual model illustrating how branch position responds to tree hydration status. This perceptual model depicts the expected shifts in branch orientation of conifer trees across a continuum from well-hydrated (left) to water-stressed conditions (right). When trees are well hydrated, branches tend to maintain a more upward or horizontal position due to higher stem water content and turgor pressure. As hydration decreases, branches gradually move downward, reflecting reductions in water availability and increasing water stress. The red circle marks the point on the branch used to observe and quantify positional changes. This also highlights a potential improvement to the method: affixing a lightweight marker (e.g., a ping-pong ball) to the branch tip can enhance visibility and precision of movement detection when using time-lapse trail cameras (Hallmark et al. 2021). This low-cost refinement can support more accurate monitoring of branch displacement as an indicator of tree water status. The timing of spring onset in seasonally snow-covered forests has a strong influence on annual forest productivity and water balance (Black et al. 2000; Richardson et al. 2013; Nehemy et al. 2023). As snowmelt timing shifts under climate change, so too does the availability of water for vegetation, making the detection of key phenological transitions increasingly important (Chen et al. 2015). Unlike deciduous species, evergreen conifers can take up water and even photosynthesize during winter (Sevanto et al. 2006), with spring rehydration and photosynthetic activity commencing earlier than in deciduous species (Pierrat et al. 2021). This figure was created in https://BioRender.com.

storage dynamics. In snow-dominated systems where stem rehydration marks the onset of spring physiological activity, visual cues such as branch posture may serve as a low-cost, field-based indicator of subsurface water availability. Note that this is not a means to substitute dendrometers or other physiological tools (i.e., psychrometers, microtensiometers), but rather a way to observe the ecosystem and trees' response in the spring and summer, as one would observe the stream bed expansion after snowmelt or rainfall events.

We are not the first to be intrigued by branch movement and position (for more details, see Puttonen et al. 2016; Zlinszky et al. 2017; Hallmark et al. 2021; Junttila et al. 2022), and there are early records of vegetative movement inquiry by Darwin on 'The power of movement in plants' (Darwin 1880). Our observations indicate that there is still much to investigate regarding plant-water relations and how branch movement specifically behaves across different species. For instance, within our short observational window, dormant broadleaf species, although experiencing the same environmental conditions, showed no detectable branch movement, whereas conifers exhibited clear changes in branch orientation. Addressing these gaps will require additional work to determine whether branch movement is driven primarily by tree hydration dynamics (Figure 3) or whether it also reflects co-occurring external factors, such as vapour pressure deficit and relative humidity, as suggested by (Hallmark et al. 2021). It also remains unclear whether the underlying response mechanisms are consistent across species. Future studies should incorporate explicit tracking markers on branches and pair movement observations with concurrent physiological measurements on the same individuals. Low-cost approaches, such as trail cameras combined with lightweight markers like ping-pong balls (Figure 3; Hallmark et al. 2021), offer one pathway, while more advanced methods, including TLS (Junttila et al. 2022), can provide higher-resolution structural data. Although our observations are simple, they provide compelling evidence that branch movement is a real and measurable phenomenon in temperate forests and follows changes in plant water status, warranting deeper investigation. As climate change alters snowmelt timing and amount, integrating structural (e.g., branch position) and physiological observations can aid field observations and improve our understanding of vegetation–hydrology feedback in cold-region ecosystems.

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Data Availability Statement

The data that support the findings of this study are openly available in Zenodo at https://zenodo.org/records/18371436

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