1 **Climatic influences on summer use of winter precipitation by trees**

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19 **Key points**

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21 We determined the representation of water originating from winter versus summer precipitation

22 in the xylem of common Swiss trees.

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24 Water originating from winter precipitation was observed in trees at most sites, even at the height

25 of summer, but varied among species.

26

27 Climate and species appear to be key controls over spatial and inter-annual variations in the

28 seasonal origins of water used by trees.

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30

Abstract

Trees in seasonal climates may use water originating from both winter and summer precipitation. However, the seasonal origins of water used by trees have not been systematically studied. We used stable isotopes of water to compare the seasonal origins of water found in three common tree species across 24 Swiss forest sites sampled in two different years. Water from winter precipitation was observed in trees at most sites, even at the peak of summer, although the relative representation of seasonal sources differed by species. However, the representation of winter precipitation in trees decreased with site mean annual precipitation in both years; additionally, it was generally lower in the cooler and wetter year. Together, these relationships show that precipitation amount influenced the seasonal origin water taken up by trees across both time and space. These results suggest higher turnover of the plant-available soil-water pool in wetter sites and wetter years.

Plain Language Summary

In the middle of a hot and dry summer, we often think that a large rain event can "rescue" a forest from drought. However, it is not clear whether trees can or do consistently use the water from summer rains. A growing body of research indicates that over the course of the summer growing season, trees take up significant amounts of water that originated as winter snow or rain. We studied the seasonal origins of the water taken up by three common tree species (beech, oak and spruce) in forest sites across Switzerland in two different years. Our results demonstrate that trees at most sites use some water from winter snow and rain, even at the height of summer, although there were differences among species and sites. The water sources used by trees likely reflect a combination of the amount and timing of winter and summer precipitation, the rate at which that precipitation moves through the soil, and the distribution of the tree roots that take up the water. Determining the seasonal origin of water used by trees, as well as why it may vary over time and space, can help us better anticipate the effects of global climate change.

Introduction

In ecosystems with seasonal growth, it could be expected that growing season precipitation should serve as the primary water source for plants when their water demand is high. However, many stable isotope studies have shown that the water used by trees during the growing season often originates primarily from winter rather than summer precipitation (Phillips & Ehleringer, 1995; Hu *et al.*, 2010; Kerhoulas *et al.*, 2013; Martin *et al.*, 2018; Allen *et al.*, 2019b; Berkelhammer *et al.*, 2020). For instance, using an index of the seasonal origins of water taken up by trees, we previously found that common tree species from 182 sites across Switzerland mostly used water from winter precipitation at the height of a dry summer (Allen *et al.*, 2019b). In that study, however, trees in more humid sites used relatively less winter precipitation, and the proportions of summer versus winter precipitation in tree xylem varied by species (see also Williams & Ehleringer, 2000; Guo *et al.*, 2018). These differences must reflect an interplay between root distributions, soil-water storage, and recharge dynamics. Resolving the controls over such patterns can improve our understanding of the vulnerability of vegetation to hydroclimatic disturbances.

The consistency, over space and time, in the seasonal origins of water used by trees, as well as how they are shaped by weather and climate, remain unresolved. We used stable isotopes of hydrogen and oxygen as tracers to study the seasonal origin of water in three common tree species in 24 long-term forest monitoring plots in Switzerland, bringing together observations made on the same trees in two different summers. Our objectives were 1) to determine whether the seasonal origins of water in trees varies consistently among species and across sites during two different growing seasons and 2) to test how variation in weather and climate factors may explain the observed differences. We hypothesized that our original observations demonstrating less reliance of trees on winter precipitation at wetter sites (Allen *et al.*, 2019b) would also apply to wetter years, and thus that the hot and dry conditions in which we made our original observations may have resulted in atypically high use of winter precipitation. Our results provide insights relevant for a number of important questions, including how to reconstruct climates in the past, how water resources are partitioned within ecosystems in the present, and what sources of water may be critical for plants in the future.

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Methods

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95 *Field sampling:* Our study was carried out in the context of a long-term forest health monitoring
96 program that includes nearly 200 sites (Braun *et al.*, 2017, 2020). Each site contains at least one
97 of three key tree species: beech (*Fagus sylvatica* L.), spruce (*Picea abies* (L.) H. Karst.), and oak
98 (*Quercus robur* L.). General site characteristics are described in Allen *et al.*, (2019b) and shown
99 in **Figure S1**. Summer temperature and precipitation at the field sites during the years in which
100 we sampled are described in **Table S1**.

101

102 Between 22 July and 3 August 2019, we collected samples from 8 individuals of each species at
103 24 sites (*n* = 258 trees in total; one site has 10 individuals of a species). Fully sunlit branches
104 were collected, using pole pruners, by a technician suspended below a helicopter. Samples were
105 returned to the ground, immediately enclosed in a black plastic trash bag to suppress
106 transpiration, and left in a refrigerated cooler until further processing (< 24 h). Sites were
107 selected to be broadly representative of the ranges of temperature, precipitation, elevation, and
108 longitude included in the monitoring network as a whole. Here we compare our observations in
109 2019 to observations in the same 24 sites from our original sampling in 2015, where we collected
110 samples using the same methodology from 3-8 of the same individuals of each species (*n* = 147
111 trees in total); this sampling was conducted between 27 July and 10 August 2015. A smaller
112 subset of these sites was sampled in 2018 (*n* = 42 trees in total), as discussed in the supporting
113 information.

114

115 *Sample processing:* For each sample, the bark and vascular cambium were removed from a fully
116 suberized piece of the branch, the remaining xylem was sealed in a glass vial, and the vial was
117 frozen until water extraction. Water extraction was carried out via cryogenic vacuum distillation
118 at the Paul Scherrer Institute (2015) and at ETH Zurich (2019) on manifolds with an identical
119 design as described in Orlowski *et al.* (2013). Branch samples were extracted under a 0.03 hPa
120 vacuum for 2 h at 80 ºC and the evaporated water was frozen in a liquid nitrogen trap. Samples
121 were then analyzed for $\delta^{18}O$ and δ^2H by TC/EA-IRMS at the Paul Scherrer Institute (2015) and
122 at ETH Zurich (2019). All values are presented per mil (‰) relative to V-SMOW. The standard

123   deviation of an independent quality control standard used for analysis at the Paul Scherrer

124   Institute was ≤ 0.2 ‰ $\delta^{18}O$ and ≤ 0.4 ‰ δ^2H. The standard deviation of an independent quality

125   control standard used for analysis at ETH Zurich was 0.17 ‰ $\delta^{18}O$ and 0.62 ‰ δ^2H.

126

127   ***Analytical approach:*** To determine the seasonal origin of the precipitation in trees, we used an

128   index of the isotopic signature of plant xylem water relative to seasonal cycles of isotopes in

129   precipitation (Allen *et al.*, 2019b). This seasonal origin index can be described as follows:

130

131    $$SOI = \begin{cases} \dfrac{\delta_x - \delta_{annP}}{\delta_{summerP} - \delta_{annP}}, & if\ \delta_x < \delta_{annP} \\[2em] \dfrac{\delta_x - \delta_{annP}}{\delta_{annP} - \delta_{winterP}}, & if\ \delta_x < \delta_{annP} \end{cases} \qquad\qquad Eq.\ 1$$

132

133   where δ_x is the fractionation-compensated δ^2H isotopic signature of xylem water, and $\delta_{winterP}$,

134    $\delta_{summerP}$, and δ_{annP} are the δ^2H isotopic signatures of winter, summer, and volume-weighted

135   annual precipitation at each study site. The δ_x values in Eq. 1 were compensated for evaporative

136   fractionation by projecting dual-isotope measurements of xylem water to local meteoric water

137   lines along theoretical evaporation-line slopes, using the method described in detail in Allen et

138   al. (2019b). Projecting the xylem water values onto the meteoric water line means that the SOI

139   values reported here are based on both the δ^2H and $\delta^{18}O$ of the xylem samples, and thus that Eq.

140   1 would yield similar results for either isotope. Isotopic signatures of precipitation were

141   estimated using data from the two years prior to sampling (i.e., August 2013-July 2015 for the

142   2015 xylem samples, and August 2017-July 2019 for the 2019 xylem samples), as inputs to a

143   previously described and validated model (Allen *et al.*, 2018). The seasonal origin index (SOI)

144   provides a measure of the overrepresentation of a season's precipitation in xylem relative to the

145   representation of that season's precipitation in the annual precipitation amount. Negative values

146   of SOI suggest an overrepresentation of winter precipitation in xylem and positive values suggest

147   an overrepresentation of summer precipitation in xylem. The SOI will be near -1.0 for soil and

148   plant water samples derived entirely from winter precipitation and near 1.0 for samples derived

149   entirely from summer precipitation.

150   To study how the seasonal origin of water in trees varies as a function of mean annual

151   precipitation amount between years, we used analysis of covariance. To study how variation in
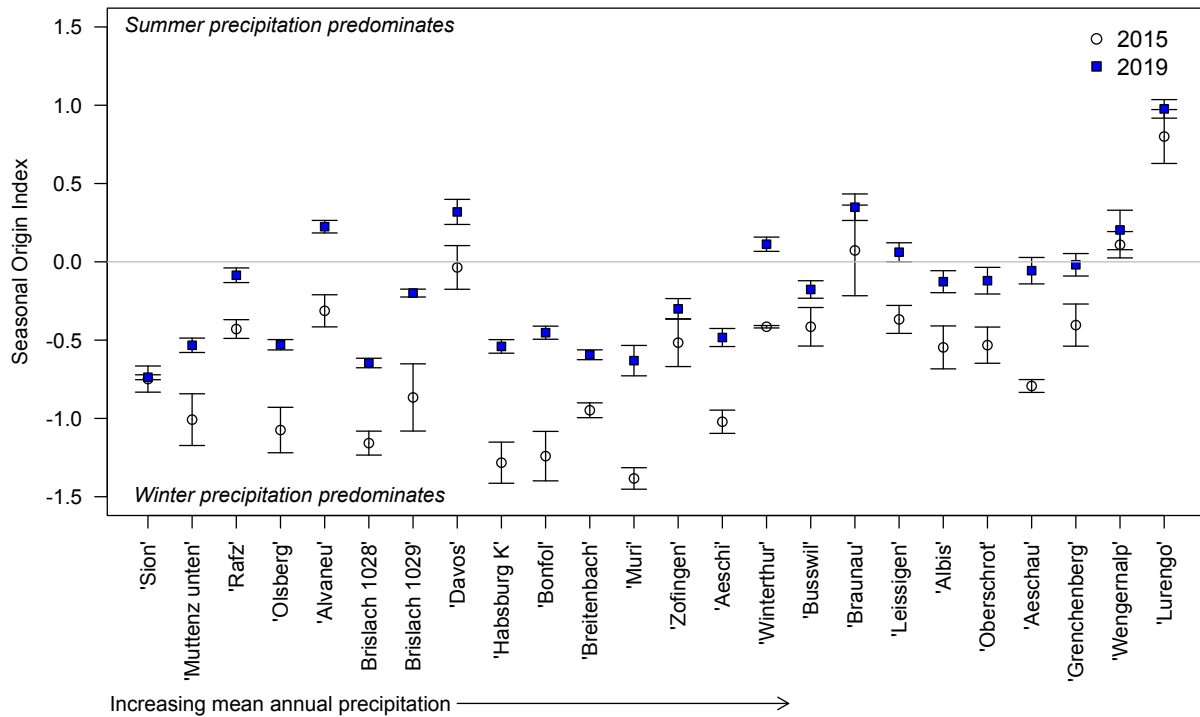
152 summer precipitation amount and other meteorological factors may contribute to the observed
153 differences in the seasonal origin of water in trees between the sample years, we determined the
154 change in SOI between years as a function of the change in temperature, precipitation, vapor
155 pressure deficit and potential evapotranspiration at each site in the month prior to sampling and
156 compared the mean of these slopes to zero using one sample t-tests. Similarly, we determined the
157 magnitude of the difference in SOI at a given site between years and the magnitude of the
158 differences in the same weather variables in the month prior to sampling at that site and
159 correlated the measures using Spearman's Rank Correlations. Daily climate data were generated
160 from a geospatial model using weather station data (Meteotest, Bern, Switzerland).

161

162 **Results and Discussion**

163

164 The mean δ^2H xylem water isotope ratios of all three tree species were more positive (7.1 to
165 14.3‰ enriched) in 2019 compared to 2015 (**Figure S2; Table S2**). In contrast, the mean δ^{18}O
166 xylem isotope ratios of all three species were similar in 2019 compared to 2015 (from -0.1‰
167 depleted to 1.1‰ enriched). Summer precipitation across our sites averaged 86 mm more in 2019
168 than in 2015. Xylem water also plotted closer to the meteoric water line in 2019 than in 2015
169 (**Figure S2**), suggesting greater soil surface evaporation in 2015 from a pool that contained less
170 summer precipitation. Given that these measurements resulted from similar sample handling and
171 analysis, analytical errors would likely apply similarly and thus not explain this difference.

172

173 The within-plot and species-within-plot variation in xylem water isotopes can be evaluated using
174 data from 2019. For plots with 2 different tree species (*i.e.,* 8 plots with 16 individuals), the
175 average standard deviation within plots was 7.61 ‰ δ^2H and 1.22 ‰ δ^{18}O. Average standard
176 deviation within species within plots was generally smaller, ranging from 2.91 to 4.90 ‰ δ^2H
177 and 0.83 to 1.02 ‰ δ^{18}O (**Table S2**). Estimates of variation within tree crowns, among trees, and
178 across plots are limited and can be used to better inform study design (Goldsmith *et al.*, 2018;
179 von Freyberg *et al.*, 2020).

180

181 *First-Order Controls on Seasonal Origins of Water in Plants*

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Figure 1. The seasonal origin index of water in xylem at sites sampled in both 2015 and 2019.
Sites are ordered left to right from lowest (690 mm yr^{-1} at Sion) to highest (1791 mm yr^{-1} at
Lurengo) mean annual precipitation. In all sites, the mean seasonal origin index is greater in
2019, indicating a consistent spatial pattern of increased use of summer-sourced water compared
to 2015. Nevertheless, the predominant pattern remains that water used by these trees in the
summer mainly originates from winter precipitation. Data represent means ± *SEM.*

Mean site SOI was significantly more positive in 2019 compared to 2015, indicating an increase
in the overrepresentation of water from summer precipitation in trees (paired t-test; t = -10.2, df
= 23, *p* < 0.0001, **Figure 1**). However, the SOI of water in trees was <0 in both 2015 (mean of
sites = -0.60) and 2019 (mean of sites = -0.17), indicating that winter precipitation was
overrepresented in late-summer tree xylem water in both sample years. Data from seven of these
same sites sampled and analyzed in 2018 (which was another drought year) using the same
approach also show overrepresentation of winter precipitation (**Figure S3**). The use of winter
precipitation has been inferred in other temperate ecosystems using water isotopes for individual
years (Hu *et al.*, 2010; Kerhoulas *et al.*, 2013; Martin *et al.*, 2018) and using tree ring cellulose
isotopes over decadal scales (Berkelhammer *et al.*, 2020).

201

202   The SOI of water in trees increased linearly as a function of precipitation in both years at a

203   common slope, but with different intercepts ($f_{2,45} = 22.2$, $p < 0.0001$, $r^2 = 0.50$). Previous

204   research in temperate semi-arid ecosystems has also observed that vegetation in wetter sites

205   consistently uses more summer precipitation (Williams & Ehleringer, 2000; Guo *et al.*, 2018).

206   Collectively, these observations indicate that precipitation amounts impose a first-order control

207   on the seasonal origin of water used by plants. We hypothesize that greater inputs to a given

208   volume of soil water storage should drive greater turnover of the water in that volume, and thus

209   increase the proportion of recent precipitation within it. However, this mechanism assumes that

210   the incoming precipitation either displaces existing soil water or re-fills depleted soil storage. If,

211   alternatively, summer precipitation bypasses soil water storage in summer when those pores are

212   filled (e.g., Brooks *et al.*, 2010), then we would expect the driest soils to show more

213   responsiveness to changes in summer precipitation. The effects of precipitation amount on soil

214   water turnover should apply across both time and space, which is consistent with our observation

215   of higher representation of summer water in trees at wetter sites in both years and the generally

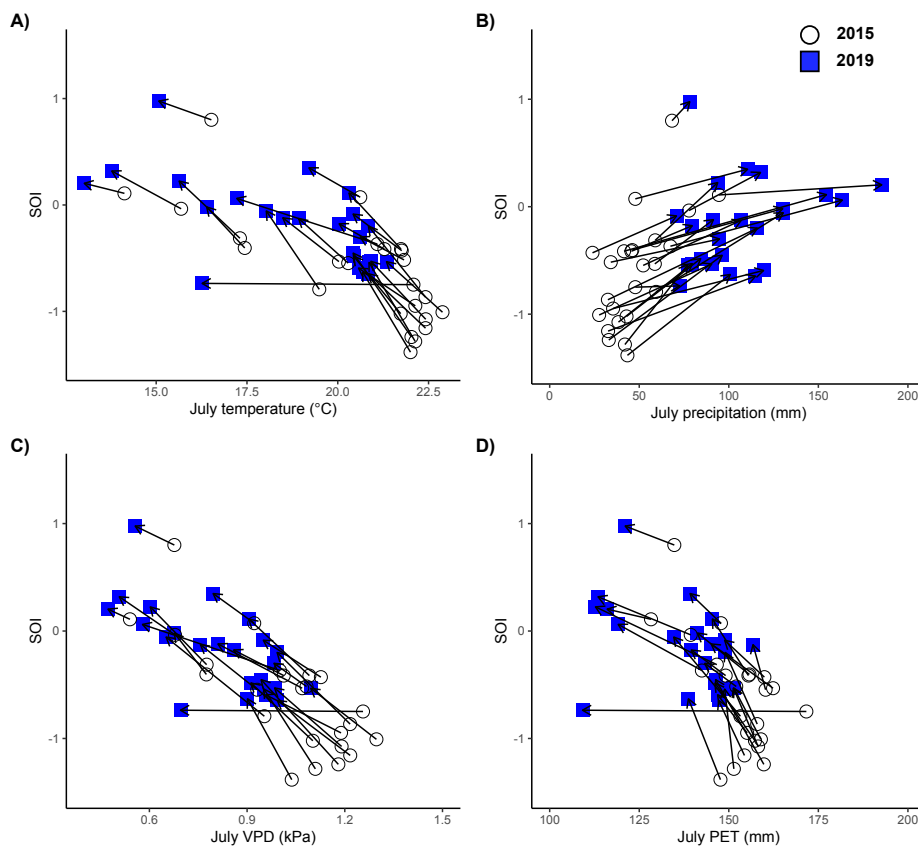216   higher representation of summer precipitation in the wetter year.

217

218   Interpreting our findings in the context of our previous research lends further support for the

219   hypothesis that summer droughts drive higher relative use of winter precipitation. The strong

220   overrepresentation of winter precipitation in xylem in 2015 (Allen *et al.*, 2019b) prompted us to

221   hypothesize that winter precipitation might be under-represented in annual streamflow in

222   Switzerland (i.e., if it was disproportionately transpired, then it would not be proportionally

223   represented in streamflow). Instead, we observed that roughly equal proportions of summer and

224   winter precipitation become streamflow (Allen *et al.*, 2019a). For this finding to be consistent

225   with our new observations, where winter precipitation is overrepresented across three (drought)

226   years, we hypothesize that summer precipitation must be recharging soils and supplying

227   evapotranspiration when and where it is wetter. Again, this hypothesis may seem to conflict with

228   the hypothesis of Brooks *et al.*, (2010) that bypass flow dominates infiltration in wet conditions;

229   however, summer precipitation inputs at wet sites in Switzerland are concurrent with plant draw-

230   down of soil water storage that create deficits that can be recharged by summer precipitation.

231   While the flow processes involved remain unclear, our new findings make it clearer that dry

232   conditions result in higher relative use of, and perhaps reliance on, stored winter precipitation.

233

234   *Second-Order Controls on Seasonal Origins of Water in Plants*

235

236   While trees at most sites demonstrated an overrepresentation of precipitation originating from

237   winter in both years, we also observed compelling differences in the representation of winter

238   versus summer precipitation in trees between years. The general positive shift in SOI from 2015

239   to 2019 corresponded with a general positive shift towards more humid conditions in July, but

240   the magnitudes of those SOI shifts by site were not well explained by the magnitudes of weather

241   changes by site.

242

243

244   **Figure 2.** The change in the seasonal origin index of water at sites sampled in both 2015 and

245   2019 as a function of the change in A) temperature, B) precipitation, C) vapor pressure deficit

246   (VPD) and D) potential evapotranspiration (PET) in the month (July) prior to the sampling. The
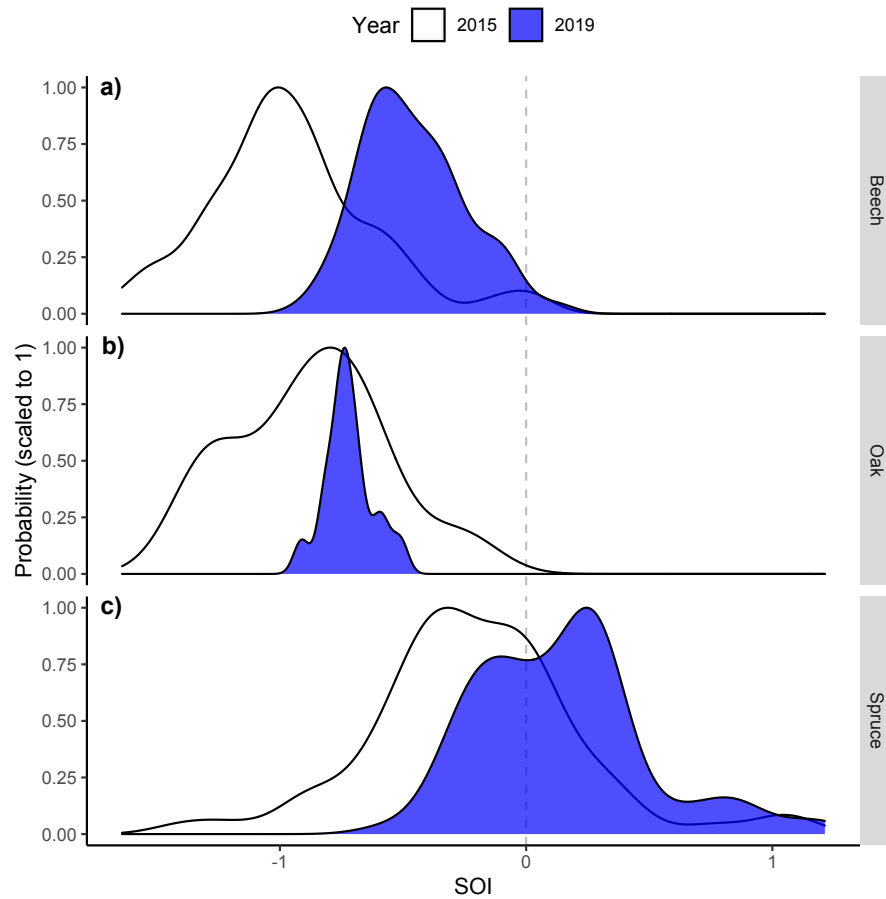
247   mean of the slopes (change in SOI per change in weather) significantly differed from zero for all

248   four of the weather metrics.

249

250   All sites showed a lower temperature, higher precipitation, lower VPD, and lower PET in the

251   month (July) prior to sampling in 2019, compared to the month prior to sampling in 2015,

252   whereas all sites showed higher SOI values in 2019 compared to 2015 (**Figure 2**). Consequently,

253   the mean change in SOI per change in July precipitation between years had a significant positive

254   value (i.e., the mean of site slopes significantly differed from zero; $p < 0.0001$); this also held

255   true for changes in SOI per change in other July weather indices, including temperature, VPD,

256   and PET ($p < 0.0001$). Interestingly, these statistically significant relationships did not hold true

257   when the changes in any of the four weather indices were calculated for the two months (June +

258   July) prior to sampling, nor was there a statistically significant relationship with the year-to-year

259   difference in annual precipitation (p = 0.92).

260

261   However, in spite of the consistent direction of the changes in weather with the change in SOI,

262   the magnitude of the difference in SOI among sites between 2019 and 2015 was not correlated

263   with the magnitude of the difference in temperature ($\rho = -0.15$, $p = 0.5$), precipitation ($\rho = 0.18$,

264     $p = 0.4$), vapor pressure deficit (VPD; $\rho = -0.33$, $p = 0.1$), or potential evapotranspiration (PET; ρ

265     $= 0.2$, $p = 0.3$) in the month (July) prior to sampling (**Figure S4**). In other words, a greater

266   difference in temperature, precipitation, VPD, or PET between the two years was not correlated

267   with a greater difference in SOI. All three species exhibited similar correlations between year-to-

268   year SOI differences and year-to-year differences in weather indices, although spruce exhibited a

269   significant correlation ($\rho = -0.61$, $p = 0.02$) between SOI differences and VPD differences. The

270   correlation between SOI differences and precipitation differences was not strengthened by

271   excluding small precipitation events (< 5 mm), which probably would not have infiltrated into

272   the soil. Finally, we found no evidence for a significant correlation of by-site slopes (change in

273   SOI per change in weather metric) with site mean annual precipitation ($p > 0.1$). Thus, we were

274   unable to explain the relative magnitudes of changes in SOI among sites, even if the average

275   change in SOI per change in (only) previous-month weather differences was highly significant.

276

277   Understanding how inter-annual differences in SOI vary with differences in precipitation and

278   other weather metrics across sites can provide insights that add to our observations of first-order

279   controls on the seasonal origins of water in trees. Second-order controls on the source of

280   precipitation used by trees may relate to interactions between climate and rooting depths. For

281   instance, if plants in wetter environments have shallow rooting depths, then the available storage

282   for plant-available water would be smaller and we would have expected greater SOI sensitivities

283   to precipitation in the wetter environments; we did not observe that. An alternative second-order

284   control may relate to differences in how precipitation infiltrates and percolates through soils in

285   wetter versus drier conditions. If all of July precipitation entered the soil profile and became

286   available to roots, we would expect the drier soils in drier environments to have been more

287   sensitive to increased inputs, resulting in greater changes in SOI per changes in July precipitation

288   amount; however, we also did not observe this to be the case. While inter-annual differences in

289   weather and SOI were widespread across sites, changes in magnitude in SOI were not well

290   explained by any variable across the sites, which may suggest that the second-order controls over

291   the seasonal origins of plant-water are inconsistent among sites.

292

293   *Species Differences in Seasonal Origins of Water in Plants*

Figure 3. Probability density functions (scaled to maximum of 1) of the seasonal origin index (SOI) of water in the xylem of A) beech, B) oak and C) spruce in summer 2015 (white) and 2019 (blue). In 2019, the distributions for beech and spruce were shifted positively, indicating increased use of summer-sourced water compared to 2015. Use of predominantly winter-sourced water in oak does not appear to differ between 2015 and 2019. Sample sizes are in Table S1.

300   The mean SOI values were shifted significantly higher in 2019 compared to 2015 for beech (t-

301   test; t = -10.4, df = 89, p < 0.0001, difference of mean SOI = 0.50) and spruce (t-test; t = -6.0, df

302   = 124, p < 0.0001, difference of mean SOI = 0.35), but not oak (paired t-test; t = -1.7, df = 13, p

303   = 0.1, difference of mean SOI = 0.15) (**Figure 3**). The distributions of SOI values also

304   significantly differed between years for beech and spruce (Kolmogorov-Smirnov tests, p <

305   0.0001). In both sample years, we observed that beech had the highest, and spruce the lowest,

306   overrepresentation of winter precipitation, with oak showing intermediate use. Both beech and

307   spruce demonstrated an increase in the overrepresentation of summer precipitation in the wetter

308   compared to the drier sampling year. Results from oak must be interpreted cautiously as they are

309   from only two sites.

310

311   Previous research has demonstrated that plant species differ in their use of winter versus summer

312   precipitation (Williams & Ehleringer, 2000; Guo *et al.*, 2018), as well as differ in the elasticity of

313   their use of summer precipitation when more becomes available (West *et al.*, 2007). The

314   differences observed among beech, spruce, and oak are likely to partially result from how the

315   predominant climate conditions shape root distributions and therefore the ability for species to

316   exploit summer precipitation events (Fan et al., 2017). Spruce occurs in wetter environments in

317   Switzerland and has more shallow roots (Schmid & Kazda, 2002), which may enable them to use

318   small episodic summer precipitation events. Beech occupies intermediate environments and oak

319   the driest environments in Switzerland. Our results indicate that the mean change in SOI per

320   change in July precipitation between years was higher in spruce (0.008) and beech (0.010) than

321   oak (0.003), which lends some support to the idea that spruce and beech rooting patterns may

322   make them more sensitive to summer precipitation than oak. We also previously posited that the

323   strong overrepresentation of winter precipitation in beech in 2015 may have been because those

324   trees used water from soil layers that were not recharged during dry summer conditions because

325   any new summer precipitation bypassed those soil layers due to preferential flow (Allen *et al.*,

326   2019b). Our new findings show that even the beech forests at drier sites increase in their use of

327   summer precipitation when more is available.

328

329   Our study was not designed to understand how much water trees use from particular precipitation

330   events, although this is of interest given projected changes in event size (Vautard *et al.*, 2014)

331 and the greater likelihood that high precipitation intensities correspond with greater recharge

332 (Jasechko & Taylor, 2015) or preferential flow through the subsurface (Buttle & McDonald,

333 2002). Pairing fine temporal resolution sampling with a large spatial domain that spans climates

334 may be key to building upon our working first-order hypothesis – that SOI differences reflect

335 different turnover times of root-zone soil water – and identifying how soil water transport,

336 recharge, and root-abstraction processes vary over time and space.

337

338 *Considerations of Key Uncertainties*

339

340 In addition to environmental influences on SOI, our interpretation may be confounded by

341 methodological artifacts associated with cryogenic vacuum distillation. By comparing the δ^2H of

342 plant xylem water obtained by cryogenic vacuum distillation and the δ^2H of steady-state

343 transpiration of a known source water, Chen et al. (2020) identified a δ^2H extraction bias that

344 they attributed to some combination of isotopic exchange of hydrogen in wood tissue with water

345 in wood tissue and/or water stored in the xylem that is not participating in transpiration. We

346 recalculated SOI, following the procedures of Allen and Kirchner (2022), by assuming that δ^2H

347 was biased by -6.1‰, based on the average cryogenic extraction offset identified among 30

348 species in 6 different studies (Goldsmith & Allen, 2021; **Figure S5**). Applying this offset shifts

349 the mean SOI among sites from −0.60 to −0.25 in 2015 and −0.17 to 0.16 in 2019. It is not clear

350 how this extraction bias varies among species, and if it arises from water stored in xylem that is

351 not participating in transpiration (Barbeta *et al.*, 2020), then it may also differ between the two

352 sample years. Re-interpreting plant xylem source water in light of a potential extraction bias

353 must be done with caution, as its magnitude and its causes (and therefore its application to

354 specific species in specific contexts) remain unresolved.

355

356 *Conclusions*

357

358 During midsummer many plants use water that originated during winter, implying that winter

359 precipitation may play an important role in governing growing season dynamics, particularly in

360 the context of shifting seasonal precipitation inputs projected to occur with climate change

361 (Zeppel *et al.*, 2014). Thus, projected changes in precipitation amount, the seasonal distribution

362   of that precipitation, or the event sizes could all change the seasonal sources of water used by

363   trees. Resolving the seasonal origins of water used by plants, as well as their controls, therefore

364   has relevance for plant function ecology, (isotope) dendrochronology, and ecohydrology. We

365   conclude by highlighting a few key examples:

366

367   *Functional ecology:* Identifying the seasonal origins of water used by different plant species, and

368   in particular, the ability for a species to exploit summer precipitation when it becomes available,

369   has implications for understanding plant function in the context of global change (West *et al.*,

370   2007). Of particular interest is whether species can shift between winter and summer

371   precipitation sources over inter-annual timescales, (e.g., Roden & Ehleringer, 2007) and

372   therefore keep pace with a changing climate.

373

374   *Isotope Dendrochronology:* Accurate reconstruction of past climate using stable isotopes of

375   oxygen in tree rings depends on understanding the isotopic values of source water incorporated

376   into the tree rings (Treydte *et al.*, 2014). Studying the seasonal origins of water used by trees can

377   better constrain estimates of source water, particularly when multiple chronologies are brought

378   together from different sites (Saurer *et al.*, 2008), as well as prevent misinterpretation of climate

379   signals.

380

381   *Ecohydrology:* Partitioning the water sources that provision streamflow, evaporation,

382   transpiration, and groundwater depends on our ability to develop models of how water transits

383   through the critical zone (Brooks *et al.*, 2010; Kirchner & Allen, 2020). Studying the seasonal

384   origins of water used by trees provides an important means for source-water partitioning, and for

385   inferring the transit, mixing, and use of water in critical zones.

386

387   By sampling the same trees at the same forest sites in two different summers, we were able to

388   observe how weather and climate influence the seasonal origins of water used by three common

389   tree species. Our results indicate that water from winter precipitation was consistently

390   represented in tree xylem at the peak of summer. However, the representation of winter vs.

391   summer precipitation varied consistently as a function of species, site characteristics, and year-

392   to-year weather differences.

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