

Supporting Information. Bose AK, Rigling A, Gessler A, Hagedorn F, Brunner I, Feichtinger L, Bigler C, Egli S, Etzold S, Gossner MM, Guidi C, Lévesque M, Meusburger K, Peter M, Saurer M, Scherrer D, Schleppi P, Schönbeck L, Vogel ME, von Arx G, Wermelinger B, Wohlgemuth T, Zweifel R, Schaub M. Lessons learned from a long-term irrigation experiment in a dry Scots pine forest: Impacts on traits and functioning. Ecological Monographs.

Appendix S1

Table S1. Start and end date of the irrigation treatment received by the experimental forest from 2003 to 2018.

Year	Irrigation period	
	Start date	End date
2003	19th June	21st October
2004	15th May	26th October
2005	23rd April	4th October
2006	6th May	25th October
2007	4th May	2nd October
2008	15th May	14th October
2009	14th May	12th October
2010	17th June	1st October
2011	14th May	16th October
2012	11th May	2nd October
2013	17th May	23rd September
2014	19th May	1st October
2015	12th May	5th October
2016	30th May	26th September
2017	19th April	9th October
2018	8th May	27th September

Table S2. List of vegetation parameters (traits and functions) considered in this study and their respective measurement period, number of observations, and experimental design. The measurement protocols for each parameter are provided in Section S1 of the supplementary materials.

Parameters	Measurement years	Number of years since onset of irrigation	Number of observations	Experimental design and associated random effect structure	References
Needle length	Three periods: 2003 - 2005, 2008 - 2012, and 2013 - 2016	1-3 years, 6-10 years, and 11-14 years	12, 32, and 22 trees at 1st, 2nd, and 3rd periods, respectively	12 (6 control and 6 irrigated), 32 (16 each from control and irrigated), and 22 trees (12 irrigated and 10 control) at 1st, 2nd, and 3rd measurement periods, respectively were nested within 8 independent sampling units	Data of 1 st period and 3 rd are published in Dobbertin <i>et al.</i> (2010) and Zweifel et al. (2020), respectively, but the 2 nd part of the data is unpublished
Shoot length	Three periods: 2003 - 2005, 2008 - 2012, and 2013 - 2016	1-3 years, 6-10 years, and 11-14 years	12, 32, and 22 trees at 1st, 2nd, and 3rd periods, respectively	12 (6 control and 6 irrigated), 32 (16 each from control and irrigated), and 22 trees (12 irrigated and 10 control) at 1st, 2nd, and 3rd measurement periods, respectively were nested within 8 independent sampling units	Data of 1 st period and 3 rd period were published in Dobbertin et al. (2010) and Zweifel et al. (2020), respectively, but the 2 nd part of the data is unpublished
Tree ring width	2003 - 2014	1-12 years	41 trees	20 control and 21 irrigated trees were nested within 8 independent sampling units	Timofeeva et al. 2017
Tree ring $\delta^{13}\text{C}$	2003 - 2014	1-12 years	10 trees	5 control and 5 irrigated trees were nested within 5 independent sampling units	Timofeeva et al. 2017

Percentage of ray parenchyma in tree trunk	2003 - 2012	1-10 years	40 trees	20 control and 20 irrigated trees were nested within 8 independent sampling units	von Arx et al. 2017
NSC in tree trunk	2003 - 2012	1-10 years	40 trees	20 control and 20 irrigated trees were nested within 8 independent sampling units	von Arx et al. 2017
Leaf Area Index	2004 - 2018	2-16 years	8 plots	3 hemispherical photographs taken from each plot and were nested within 4 control and 4 irrigated plots	Parts of the data is published in Dobbertin et al. (2010)
Crown transparency	2003 - 2017	1-15 years	622 trees	325 control and 297 irrigated trees were nested within 8 independent sampling units	Parts of the data is published in Dobbertin et al. (2010) and in Schönbeck et al. (2018)
Stand-level basal area of live trees	2003-2017	1-15 years	622 trees	325 control and 297 irrigated trees were nested within 8 independent sampling units	Unpublished data
Probability of tree survival	2003 - 2017	1-15 years	622 trees	325 control and 297 irrigated trees were nested within 8 independent sampling units	Unpublished data
Fine root biomass	2003 – 2005, 2012, 2014, and 2016	1-3, 9, 11, and 13 years	23 trees	12 control and 11 irrigated trees were nested within 8 independent sampling units	Herzog et al. 2014; Brunner et al. 2019
Ingrowth root biomass density, root length density, root tissue density, and tip frequency	2005 and 2016	3 and 14 years	21 trees in 2005 and 12 trees in 2016	12 control and 9 irrigated trees in 2005 and 6 control and 6 irrigated trees in 2016 were nested within 8 independent sampling units	Brunner et al. 2009, 2019

Litterfall	2014	11 years	56 litter traps	56 litter traps were nested with 8 independent sampling units (7 within each sapling unit)	Unpublished data
Foliar decomposition rates	2014	11 years	96 litter bags	Litters of 3 tree species and 2 types of mesh size for each species. 8 litter bags were nested within 2 independent sampling units for each mesh size of each species	Unpublished data
Root decomposition rates	2014 - 2016	11-13 years	40 litter bags	20 litter bags were placed (nested) within 4 control plots while another 20 litters bags were placed (nested) in 4 irrigated plots	Herzog et al. 2019
Regeneration abundance	2019	16 years	32 plots	16 control and 16 irrigated plots were nested within 8 independent sampling units	Unpublished data
Fungal fruit body abundance and biomass	2003 - 2007	1-5 years	96 trees	48 control and 48 irrigated trees were nested within 8 independent sampling units	Unpublished data
Abundance of galls	2007 and 2008	4 years and 5 years	113 trees in 2007 and 153 trees in 2008	58 control trees and 55 irrigated trees in 2007 and 76 control trees and 77 irrigated trees in 2008 were nested within 8 independent sampling units	Unpublished data
Species richness and abundance of spiders	2007 and 2008	4 years and 5 years	24 plots	12 control and 12 irrigated plots were nested within 8 independent sampling units	Unpublished data
Species richness and abundance of ground beetles	2007 and 2008	4 years and 5 years	24 plots	12 control and 12 irrigated plots were nested within 8 independent sampling units	Unpublished data

Abundance of <i>Tomicus</i> based on shoots fallen to the ground due to maturation feeding	June, 2007 and March, 2008	4 years and 5 years	24 plots	12 control and 12 irrigated plots were nested within 8 independent sampling units	Unpublished data
Occurrence of <i>Tomicus</i> maturation shoot feeding in the tree canopy	2016	13 years	526 shoots	385 irrigated shoots of 43 branches of 18 trees were nested with 3 independent sampling units while 141 shoots of 18 branches of 6 trees were nested within 1 independent sampling units	Unpublished data

Section S1. Measurement protocols of different variables

Natural precipitation

The monthly precipitation data was obtained from a nearby climate station (Sion), which is located 4.8 km distance from the study site.

Soil volumetric water content

Soil volumetric water content (VWC) was measured hourly in one out of four control and in one out of four irrigated plots using the Time Domain Reflectometry (Tektronix 1502B cable tester, Beaverton, OR, USA) with three to four depth replicates per plot. The measurements were conducted at three different soil depths: 10, 40 and 60 cm. In the period from 2003 to 2014, the VWC sensors occasionally had measurement failures. In total missing VWC values amount to 28.1% of the time series. These gaps were filled by simulated VWC using the process-based soil-vegetation-atmosphere-transport model LWFBrook90 (Hammel & Kennel, 2001) recently implemented in an R environment (Schmidt-Walter *et al.*, 2020). LWFBrook90 is a modification of the well-known Brook90 model (Federer, 2002) which simulates daily transpiration, interception, soil and snow evaporation, streamflow and soil water fluxes through a soil profile covered with vegetation. The water movement in the ground results from the numerical solution of the Richards equation via the Mualem-van Genuchten parameters. These hydraulic parameters were predicted from measured soil texture, bulk density and organic matter content per soil horizon using the pedotransfer function of Puhlmann *et al.* (2009). The daily meteorological forcing data was derived from the adjacent MeteoSwiss Sion and measured irrigation amounts. The measured VWC from 2003 to 2014 was used to calibrate the sensitive model parameters (Schmidt-Walter *et al.*, 2020). Parameters with maximum Kling-Gupta efficiency (KGE) were selected for the simulation to gapfill missing values. For the control sites, KGEs of 0.65, 0.65, and 0.62 were achieved for 10, 40 and 60 cm soil depth, respectively. The irrigation plots model

performance was lower but can still be considered behavioural (Knoben *et al.*, 2019) with KGE values of 0.41, 0.55, and 0.32 for 10, 40 and 60 cm soil depth, respectively.

For quantifying the impact of irrigation on soil VWC, we quantified the VWC in irrigated plots relative to control plots in percentage using the following formula:

$$\frac{(VWC \text{ in irrigated plots} - VWC \text{ in control plots})}{VWC \text{ in control plots}} \times 100$$

We quantified this index separately for each measurement year starting from 2003 to 2014 based on the data availability across the three soil layers.

Needle and shoot length

In April 2006, six trees from control and six trees from irrigated plots were randomly selected. Five main shoot leaders were selected from the branches, and shoot lengths were measured to the millimetre going back to the year 2003. Within each annual shoot, 20 needles were selected close to the centre of each annual shoot for needle length measurement (see details in Dobbertin *et al.*, 2010). The second sampling for needle and shoot data was conducted in 2012. 16 trees from control and 16 trees from irrigated plots were selected randomly. From each tree, two branches were selected, and shoot lengths were measured to the millimetre going back to the year 2008. The needle length was measured following the same procedure described in Dobbertin *et al.* (2010). In 2017, 12 trees of irrigated and 10 trees of control were selected for needle and shoot length measurements. This third phase of measurement used the same procedure as before for needle and shoot length (Zweifel *et al.*, 2020).

Leaf Area Index (LAI)

From 2004 to 2018, we took hemispherical pictures at the three points along the main axis of each plot at the end of each vegetation period. These points were marked by stakes and used each measurement year. A digital camera (Coolpix 4500, Nikon, Tokyo) with a fish-eye lens (Nikon FC-E8) was fitted to self-levelling gimbals (SLM2, Delta-T, Cambridge,

UK) mounted on a tripod at 1 m above ground. The detail of the measurement protocol is provided in Dobbertin et al. (2010).

Tree ring width

In 2014 after the end of the growing season, 20 trees from non-irrigated and 21 trees from irrigated treatments were cored using a 5 mm increment borer (Haglöf, Långsele, Sweden) at 1 m height from the base (Timofeeva *et al.*, 2017). Tree-ring width (TRW) was measured using a Lintab system with a precision of 0.01 mm, using the TSAP-Win software V.3.5 (Rinntech, Heidelberg, Germany) (Eilmann *et al.*, 2010), and dated with existing TRW chronologies from the study site using the software COFECHA (Grissino-Mayer, 2001).

Carbon isotope ratios

Five trees from each non-irrigated and irrigated treatments were used for $\delta^{13}\text{C}$ measurements of individual tree rings (Timofeeva *et al.*, 2017). Individual rings were separated using a surgical scalpel under a Wild M8 stereomicroscope. The separated rings were then cut into small pieces and packed into teflon filter bags for subsequent chemical treatment (Ankom Technology, Macedon, NY, USA). Cellulose was extracted according to Boettger *et al.* (2007) with homogenization according to Laumer *et al.* (2009) using an ultrasonic treatment with a HD3100 sonotrode (Hielscher, Berlin, Germany). The cellulose samples were measured using a high-temperature pyrolysis method with subsequent analysis on an isotope-ratio mass-spectrometer (delta Plus XP, Thermo; instrument precision 0.2%). Carbon isotope ratios are reported against Vienna Pee Dee Belemnite (VPDB). Individual tree-ring $\delta^{13}\text{C}$ values were corrected back to preindustrial conditions to account for the Suess effect (McCarroll & Loader, 2004).

Percentage of ray parenchyma and Percentage of NSC

In March 2013, 20 adult Scots pine trees per irrigation and control treatment of similar age and size were randomly selected with an experimental design that consists of five trees from each replicated treatment plots ($5 \times 8 = 40$ trees) (von Arx *et al.*, 2017). Tissue for NSC measurement was extracted from all sampled trees by taking four 5-mm stem cores at breast height from the north, east, south and west side of the tree. The stem cores were then kept on dry ice in a cooler immediately after the extraction. Cores were then microwaved at 600 W for >90 s for eliminating enzymatic activity (Popp *et al.*, 1996) and subsequently air-dried in an oven at 65 °C for 3 days. In May 2013, one 10-mm increment core was extracted adjacent to the NSC samples for quantifying the ray abundance.

High-resolution images of anatomical samples were used for quantifying the percentage of ray parenchyma of 40 stem cores. For this purpose, cross-sections of <15 µm thickness perpendicular to the axially oriented tracheids were cut from the 10-mm cores with a microtome (Gärtner *et al.*, 2015), placed on a slide, and stained with Alcian blue (1% solution in acetic acid) and safranin (1% solution in ethanol). This staining procedure results in blue un lignified (parenchyma) and red lignified (tracheid) cells. The cross-sections were then dehydrated using a series of ethanol solutions of increasing concentrations, washed with xylol, and then preserved by embedding them into Eukitt glue (Gärtner & Schweingruber, 2013).

Overlapping images covering the entire samples were captured with a Nikon D90 digital camera mounted on a Nikon Eclipse 50i optical microscope with 1009 magnification and merged to a single image using PTGUI v8.3.10 Pro (New House Internet Services B.V., Rotterdam, the Netherlands). All rays of the outermost 20 years (comprising 10 years before and 10 after the onset of irrigation) were then quantified in the merged images as described previously (von Arx *et al.*, 2015). In short, rays and the annual ring borders were manually

outlined using a tailored clone of ROXAS v1.6 (von Arx & Carrer, 2014). The final sample width ranged from 7 to 9 mm, resulting in mean PERPAR (percentage of ray volume) values being within $\pm 5\text{--}6\%$ (rel. 95% confidence interval) of the true values (von Arx et al., 2015).

Increment cores for NSC measurements were cut in 5-year segments starting from the bark for the outer 20 years (resulting in two pre- and two post-treatment segments), and a fifth segment including all remaining sapwood rings (between 7 and 57 rings). Five-year segments were chosen to provide sufficient wood material for reliable NSC measurements, because of the generally small growth rates in Scots pine trees. Corresponding segments from different cores of the same tree were then pooled and milled. Extraction of NSC followed the anthrone technique (Olano *et al.*, 2006). This technique provides an estimate of NSC content per wood dry weight (%NSC), distinguishing between the contribution of soluble mono and oligosaccharides and non-soluble carbohydrates (starch). % NSC was calculated for each tree and radial segment by adding soluble and insoluble carbohydrate contribution.

Crown transparency and tree mortality

Crown transparency and tree mortality (i.e., live or dead) was measured once a year from 2003. Crown transparency inventory was conducted by visual rating of the crown transparency (also termed percentage of defoliation) using reference photographs ranging from 0% (i.e., a fully foliated tree) to 100% (i.e., a dead tree) (Dobbertin et al., 2010; Schönbeck et al., 2018). We created four crown transparency classes for this analysis such as <34%, 34-66%, >66-99%, and 100% transparency.

Probability of tree survival

Tree survival was quantified as a binary variable (1 if alive, 0 otherwise). Each tree was monitored and recorded as live or dead once a year from 2003. We quantified probability of survival or death between successive measurements from 2003 to 2017.

Fine roots biomass from soil cores

For fine root sampling, three trees were selected from each plot (n=8; four irrigated and four control). Overall, twelve trees from the control and nine trees from the irrigation-treatment were considered in the analysis. Two soil cores per tree were taken in April/May in 2003, 2004, 2005, 2012, 2014, and 2016 (Brunner *et al.*, 2019; Brunner *et al.*, 2009; Herzog *et al.*, 2014). After sampling, the soil cores were packed in plastic bags and stored at a 4 °C temperature until they were analysed. The soil cores were then washed in a sieve for separating roots from the soil. The sorted fine roots were then dried at 60 °C temperature for 3 days, and then weighed for the biomass. Fine roots were calculated per cm³ of soil for making a comparison across the measurement years (Brunner *et al.*, 2019).

Ingrowth of fine roots

The first phase of ingrowth core sampling was established in April 2003. Glass-fiber-netting cylinders (11 cm in height, 5 cm in diameter, with a 5 mm mesh size) were installed with the ingrowth cores inserted into the holes of the cylinders where soil core samples had been taken previously for the fine-root biomass (Brunner *et al.*, 2009). The ingrowth cores were refilled with sieved topsoil from outside the plots. The ingrowth cores were harvested with a large soil corer 8.5 cm in diameter in May 2005 (i.e., 2 years after the core installation). After harvest, the ingrowth cores were packed undisturbed in plastic bags and stored in the laboratory at 4 °C temperature until they were analysed. The fine roots were then separated from the cores and stored in tap water in a refrigerator until fine-root morphology and architecture was analysed (Brunner *et al.*, 2009). The second phase of ingrowth core sampling was established in April 2014 using the identical ingrowth cores as before. The ingrowth cores were then harvested in spring 2016. However, trees other than those from the first series were used, and three ingrowth cores per tree instead of two were

installed. In total, six trees were selected from control plots treatment and six trees from irrigated plots.

The ingrowth of fine roots from 2005 and 2016 sampling were scanned for morphological characteristics before drying and weighing. The scanned pictures were then analysed using the WinRHIZO software package (version 4.1c, Regent Instruments Inc., Quebec, Canada) for morphological and architectural traits such as length, diameter, root volume, tips, and forks. The measured fine-root traits were root biomass density (g m^{-2}), root length density (m m^{-2}), mean diameter (mm), tip frequency (n cm^{-1}), and root tissue density (mg cm^{-3}). Biomass and length were calculated per soil area and to a soil depth of 10 cm (topsoil), tips to the root length, and root tissue density to the fine-root volume (Brunner et al., 2019; Brunner et al., 2009).

Natural regeneration

Field measurement was conducted in September 2019 (i.e., 16 years after irrigation treatment application). Two circular regeneration inventory plots of 50 m^2 each was established, both under canopy gaps as well as under canopy shelters in each replicated irrigation treatment plots. This makes 4 regeneration inventory plots (i.e., 2 under canopy gaps and 2 under canopy shelters) \times 8 irrigation treatment plots (i.e., 2 treatments \times 4 replications) = 32 plots. Regeneration inventory plots (i.e., total four plots within each irrigation treatment plot) were nested within irrigation treatment plots (i.e., total eight plots) which were incorporated as random effects in the mixed-effect models. The regeneration inventory measures every individual by their species and size (i.e., height). The regeneration height was characterized by three categories 0-19 cm, 20-119 cm, and 120-400 cm.

Species richness and abundance of ground beetles and spiders

Three pitfall funnel traps ($\varnothing 15$ cm) were installed in each of the eight plots in the 4th (2007) and 5th (2008) seasons after the onset of the irrigation experiment. They were

arranged in the form of an isosceles triangle with each trap being 6 m away from the plot borders. The distances between the traps within each plot were 19 m (2x) and 28 m. Traps were active from April to September and emptied monthly. Subsequently, the catches were sorted to higher taxonomic level and ground beetles (Carabidae) and spiders (Araneae) were identified to species level by taxonomic specialists.

Abundance of oak galls

In each plot, 20 randomly distributed oak trees with >1 cm stem diameter and <4 m height were assessed for the presence of galls from gall wasps (Hym., Cynipidae). The most frequent galls were *Neuroterus quercusbaccarum* (L.), *Cynips quercusfolii* L., and *Andricus foecundatrix* (Hartig). The surveys were done at the end of September in the years 2007 and 2008, respectively.

Shoot feeding of pine shoot beetles (Tomicus spp.)

Along a 66 m long and 2 m wide transect between the three pitfall traps in each plot (see section “*Species richness and abundance of ground beetles and spiders*” above) all shoots fallen to the ground due to maturation feeding (shoot feeding) by the two pine shoot beetles *T. minor* and *T. piniperda* were counted. The first survey was made in 2007 and all collected shoots were removed. Therefore, this survey summed up the shoot feeding of the last 1-2 years. The second survey from 2008 included only the shoot feeding of one year.

This ground-based study was complemented by a study in pine crowns carried out in 2016 using scaffolds. We analysed 71 canopy shoots from 24 trees which were accessible from the five scaffolds.

Litterfall

Litterfall was sampled by placing litter traps of 0.5 m x 0.5 m continuously on the soil surface. In each of the eight replicated plots (4 control and 4 irrigated), seven litter traps were randomly distributed. Litter samples were collected in November 2014.

Foliar decomposition rates

The decomposition rate of organic matter was measured through the mass loss of *Pinus sylvestris* needles and *Quercus pubescens* and *Viburnum lantana* leaves over 140 days. The needles/leaves were filled in two types of litter bags with different mesh sizes, allowing the access of only microfauna in a fine mesh and meso as well as macrofauna in a coarse mesh. The fine mesh bags consist of mesh size 0.1 x 0.1 mm, while the coarse mesh bags consist mesh size of 10 x 10 mm. The fine mesh bags were made of nylon cloth material from Frank Eckerd GmbH, while the coarse mesh bags were made of a polyester net from Eckert Waldkirch, Germany. All mesh bags were approximately 10 x 10 cm in size. For litter materials, the needles were collected from litter traps, while the leaves were picked from the soil surface. The litter (leaves and needles) was dried at 40 °C for 72 hours and kept dry in desiccators. All leaves were cut into pieces of approximately uniform size (~2 x 2 cm). The needles were left untreated. All litter was well mixed within its litter type and 1 g ± 0.02 g was put in each numbered litter bag. Each litter type was separated into the two origins (control and irrigation) and into the two-mesh sizes (fine and coarse) which means four treatments per litter type and thus overall 12 (4 × 3 species) treatments.

The experimental design consists 2 types of mesh bags (fine and coarse) × 2 irrigation treatments (control and irrigation) × 8 replication treatment plots × 6 dates of measurements (0, 10, 40, 80, 110, and 140) = 192 litter bags for each species (*P. sylvestris*, *Q. pubescens*, and *V. lantana*). The bags were arranged in groups in a subplot, 8 bags × 3 species = 24 bags in a subplot. We used a total of 24 subplots. The litter bags were directly placed on the surface soil (A-horizon). A distance of 20 to 30 cm was kept between two bags. The bags were placed between 3rd - 6th of May 2015. The litter samples were collected at six different dates over the 140 days. The litter of the collected samples were removed and were again dried at 40 °C for 72 hours and the residual litter material was cleaned from mineral soil and

deposits from irrigation with a brush before weighing. The dry and clean litter was weighed again to determine the mass loss.

Root decomposition rate

Root samples were extracted using a spade in autumn 2013 and stored in plastic bags. In laboratory, the roots were then washed on a sieve under running water. Roots < 2 mm in diameter were considered for the decomposition experiment. The root samples were then air dried and kept at room temperature. In February 2014, 1 mm mesh sized litterbags of size 10 × 10 cm were filled with 1 g of airdried root materials. The litterbags were made of a nylon mesh (Sefar Petex, Sefar AG, Heiden, Switzerland). The 1 mm mesh size generally allows the mesofauna (e.g., mites, springtails) to enter in the litterbags, but not the macrofauna such as earthworms. At the end of March 2014, each root-filled litterbag was buried in the same plot from where root materials were collected. In order to destructively sample the litterbags at five different time points (i.e., 3, 6, 12, 18, and 24 months), five litterbags per time-point and plot were tied together with a nylon cord and buried horizontally between the O and A layers at 5 cm depth measured from the surface (O layer). In total, 240 litterbags were buried. Litterbags of each time point were excavated carefully and stored in plastic bags and cool boxes during transportation to the laboratory. In the laboratory, the roots were carefully cleaned with a fine brush to remove adhesive soil, frozen in liquid nitrogen, and freeze-dried. Subsequently, roots from the same plot and time point were pooled, dry weights were measured, and samples were then stored at -20 °C until further processing. From the remaining root litter mass, the decomposition rate was quantified (see details in Herzog *et al.*, 2019).

Fungal abundance and biomass

Above-ground fungal abundance and biomass was assessed by recording fungal fruit body production of macromycetes (visible to the naked eye) weekly during the mushroom

season (May – November) from 2003 to 2007. Within each treatment plot, 12 trees were selected and all epigeous soil-inhabiting macromycetes within a radius of 2 m around the trunks were counted, weighted, macro- and microscopically identified to species or genus level and assigned to two ecological guilds based on their lifestyle as saprotrophs or ectomycorrhizal symbionts.

Table S3. Comparing model outputs (estimate and *p*-value) with and without temporal autocorrelation. For each response variable (radial growth, $\delta^{13}\text{C}$, and shoot length), a linear mixed-effect model was performed, measurement year, treatments (control and irrigated), and the interaction between measurement year and treatments were considered as fixed effects while trees nested within plots were considered as random effects. The temporal autocorrelation across measurement years was included by using the *corARI* function of *nlme* package in R.

Treatment effect comparison across measurement years. (Control vs irrigated in 2003 was considered as the reference)	Tree-ring width (mm)				Tree-ring $\delta^{13}\text{C}$ (%)				Log-transformed shoot length (mm)				Crown transparency (%)			
	With temporal autocorrelation		Without temporal autocorrelation		With temporal autocorrelation		Without temporal autocorrelation		With temporal autocorrelation		Without temporal autocorrelation		With temporal autocorrelation		Without temporal autocorrelation	
	Estimate	<i>p</i> -value	Estimate	<i>p</i> -value	Estimate	<i>p</i> -value	Estimate	<i>p</i> -value	Estimate	<i>p</i> -value	Estimate	<i>p</i> -value	Estimate	<i>p</i> -value	Estimate	<i>p</i> -value
Control vs irrigated in 2004	0.381	0.000	0.381	0.000	-1.92	0.000	-1.92	0.000	0.36	0.002	0.37	0.000	1.177	0.192	1.174	0.335
Control vs irrigated in 2005	0.492	0.000	0.492	0.000	-1.82	0.001	-1.82	0.000	0.74	0.000	0.74	0.000	4.218	0.000	4.209	0.000
Control vs irrigated in 2006	0.706	0.000	0.706	0.000	-1.43	0.006	-1.43	0.005	0.56	0.000	0.57	0.000	13.659	0.000	13.664	0.000
Control vs irrigated in 2007	0.644	0.000	0.644	0.000	-0.40	0.434	-0.40	0.426	0.82	0.000	0.86	0.000	15.077	0.000	15.070	0.000
Control vs irrigated in 2008	0.445	0.000	0.445	0.000	-1.07	0.044	-1.07	0.035	0.60	0.000	0.64	0.000	15.117	0.000	15.117	0.000
Control vs irrigated in 2009	0.429	0.000	0.429	0.000	-0.57	0.267	-0.57	0.259	0.62	0.000	0.66	0.000	14.066	0.000	14.072	0.000
Control vs irrigated in 2010	0.167	0.188	0.167	0.119	-1.15	0.026	-1.15	0.023	0.93	0.000	0.96	0.000	15.371	0.000	15.383	0.000
Control vs irrigated in 2011	0.298	0.021	0.298	0.006	-0.65	0.202	-0.65	0.194	0.69	0.000	0.72	0.000	12.001	0.000	12.022	0.000
Control vs irrigated in 2012	0.319	0.015	0.319	0.003	-1.19	0.022	-1.19	0.019	0.80	0.000	0.83	0.000	17.642	0.000	17.704	0.000
Control vs irrigated in 2013	0.342	0.009	0.342	0.001	-1.43	0.006	-1.43	0.005	-	-	-	-	18.610	0.000	18.787	0.000

Control vs irrigated in 2014	0.157	0.236	0.157	0.142	-1.22	0.018	-1.22	0.016	-	-	-	-	15.458	0.000	15.277	0.000
Control vs irrigated in 2015	-	-	-	-	-	-	-	-	-	-	-	-	16.651	0.000	16.811	0.000
Control vs irrigated in 2016	-	-	-	-	-	-	-	-	-	-	-	-	15.743	0.000	15.828	0.000
Control vs irrigated in 2017	-	-	-	-	-	-	-	-	-	-	-	-	13.486	0.000	13.431	0.000

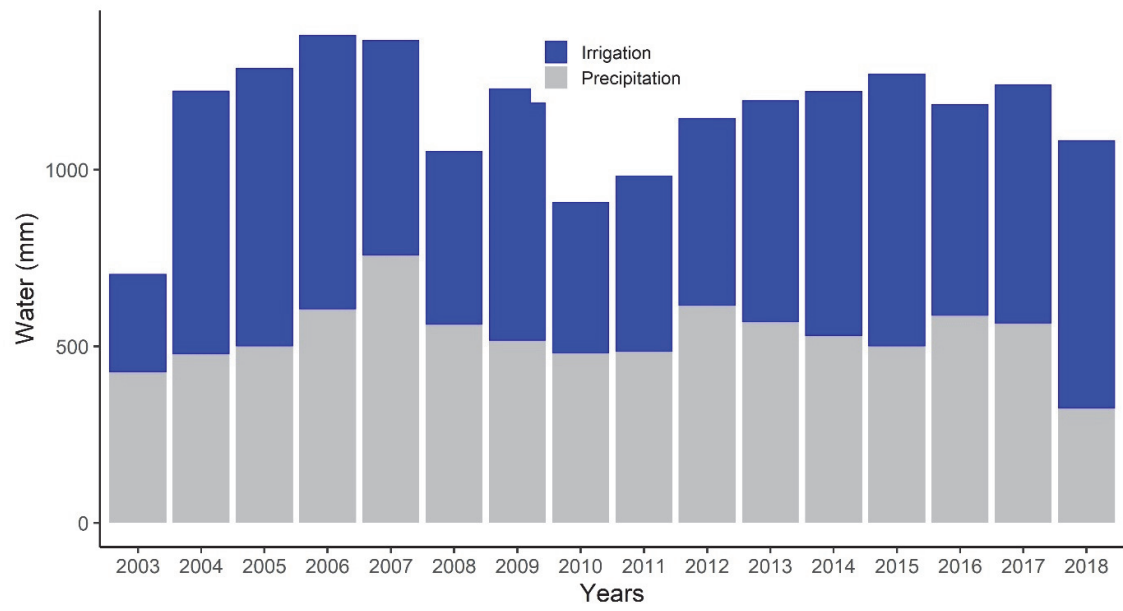


Figure S1. Total amount of precipitation in the control plots and the additional water in the irrigated plots.

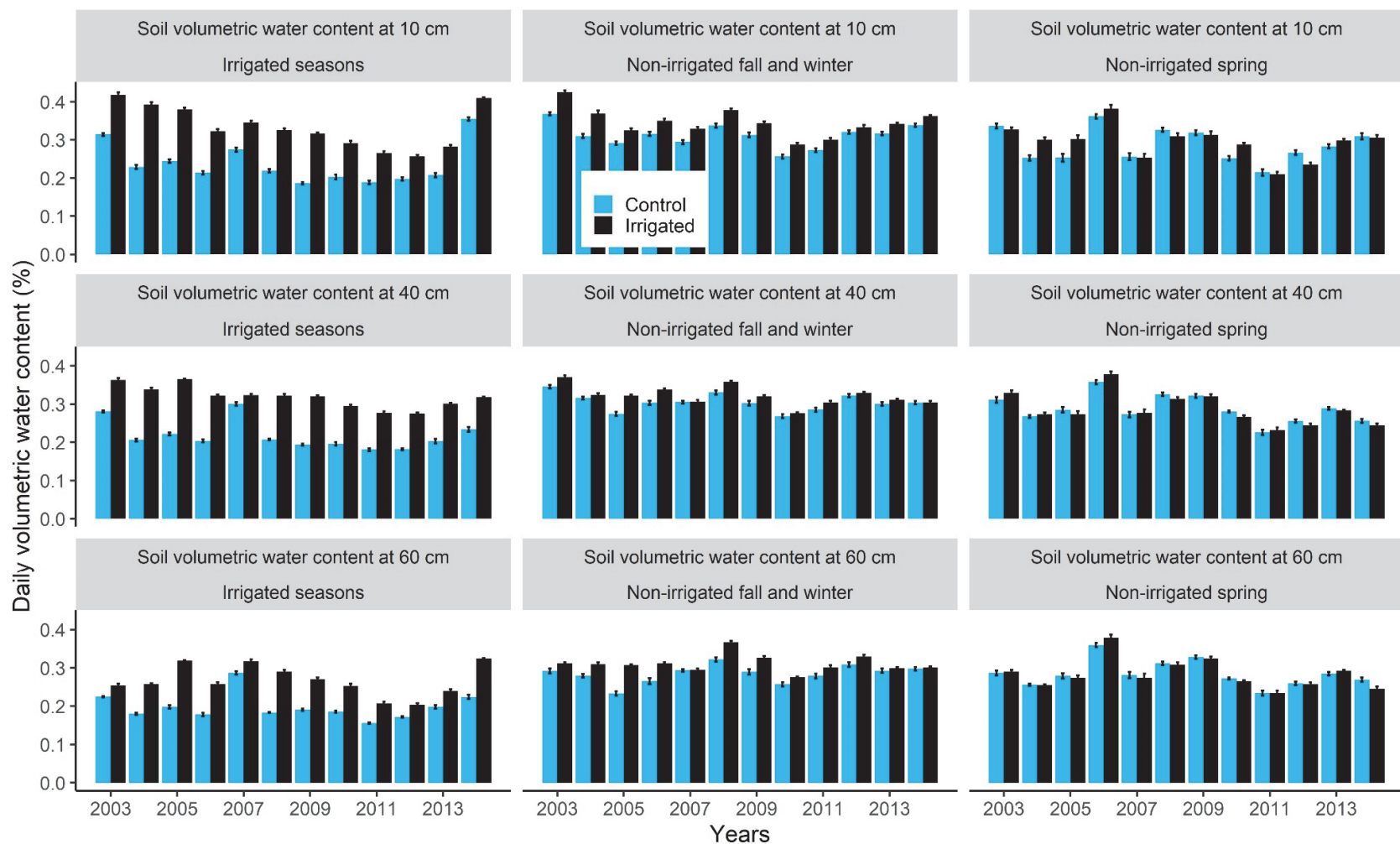


Figure S2. Soil volumetric water content (%) in irrigated and control plots across three different soil layers for the irrigation periods (see Table S1), non-irrigated fall-winter periods (September-February) and non-irrigated spring period (March-May). The VWC values represent the average of 1-4 measurements conducted within a single treatment plot (irrigation or control). Thus, no statistical test was performed. The standard errors were calculated from daily VWC data. Total amounts of annual precipitation and irrigation are provided in Figure S1 of the supplementary materials.

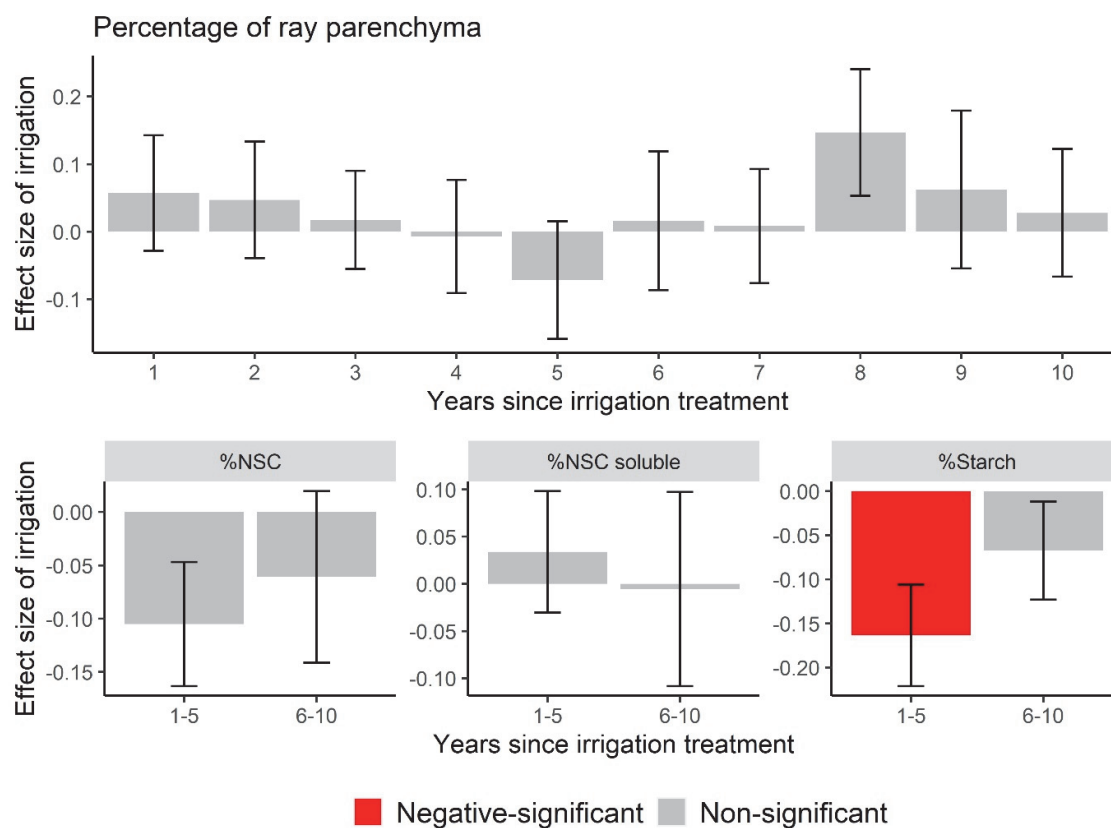


Figure S3. Effect size (i.e., coefficient of the mixed-effect model) of irrigation treatment on percentage of ray parenchyma and NSC (non-structural carbohydrates) in the trunks of Scots pine. The grey bar indicates non-significant effect of irrigation treatment (>0.05). The error bars represent mean \pm standard errors. The number of observations used for each analysis is provided in Table S2. The analysis was performed separately for each time period.

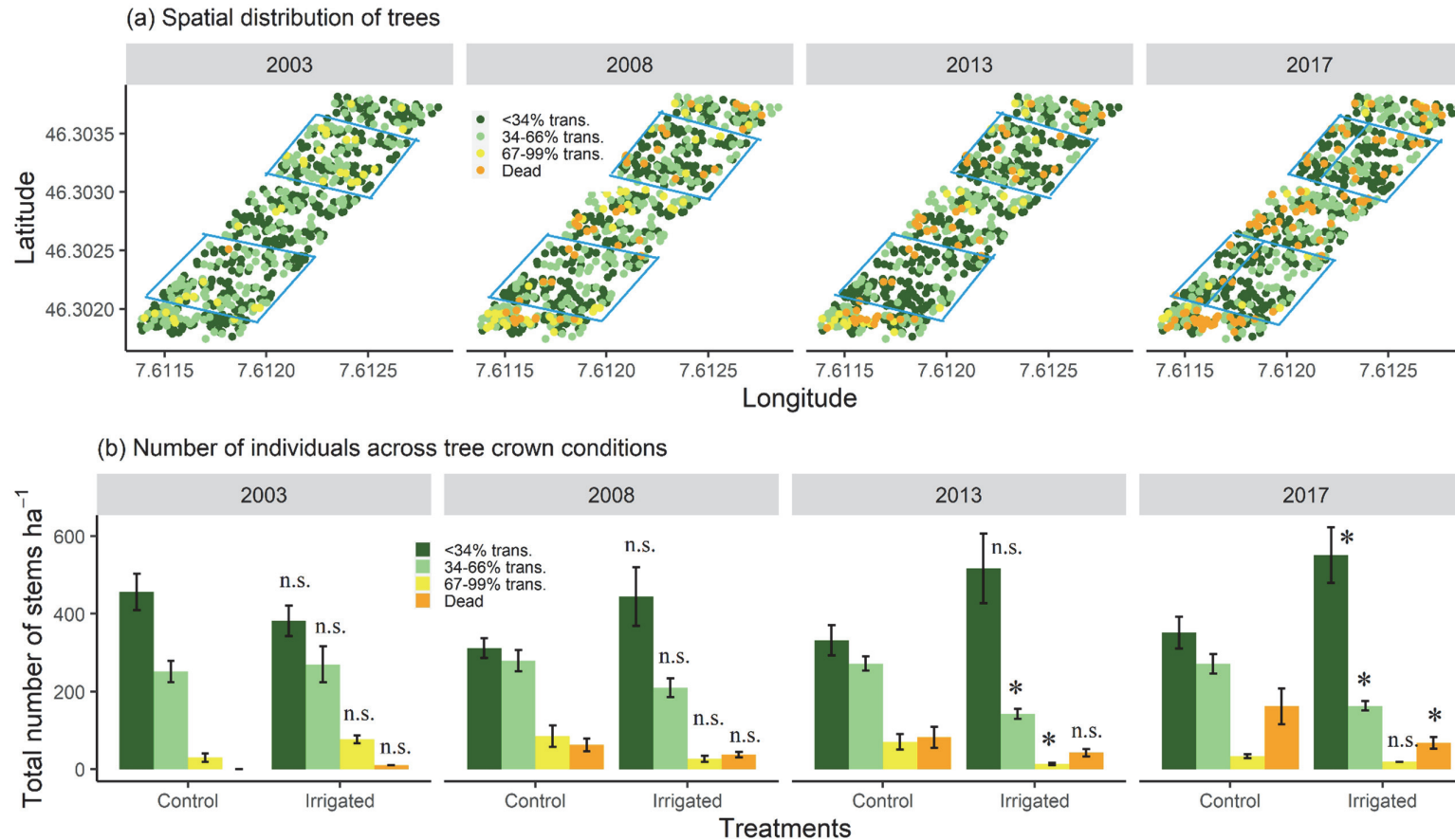


Figure S4. (a) The changes in crown transparency (trans) in irrigated (squares) and non-irrigated plots over time since irrigation treatment application; (b) The changes in number of tree individuals across four crown transparency classes over time since irrigation treatment application. 0% trans indicates full foliage while 100% trans indicates full defoliation or dead. In Fig. a, the entire blue squared areas are irrigated plots (two plots within each of those two squares). The remain areas are control plots ($n=4$). In 2017, the total number of stems ha^{-1} in irrigated plots is lower than that of previous measurement years, this is due to change in plot size starting after the growing season 2013 when approx. one-third of the area of each irrigated plot was converted to an irrigation-stop treatment. This reduced plot size, i.e., changes in individual tree-level expansion factor affected the quantification of stems ha^{-1} in irrigated plots. In Fig b, * and n.s. indicate statistically significant and non-significant difference between irrigated and control treatments, respectively.

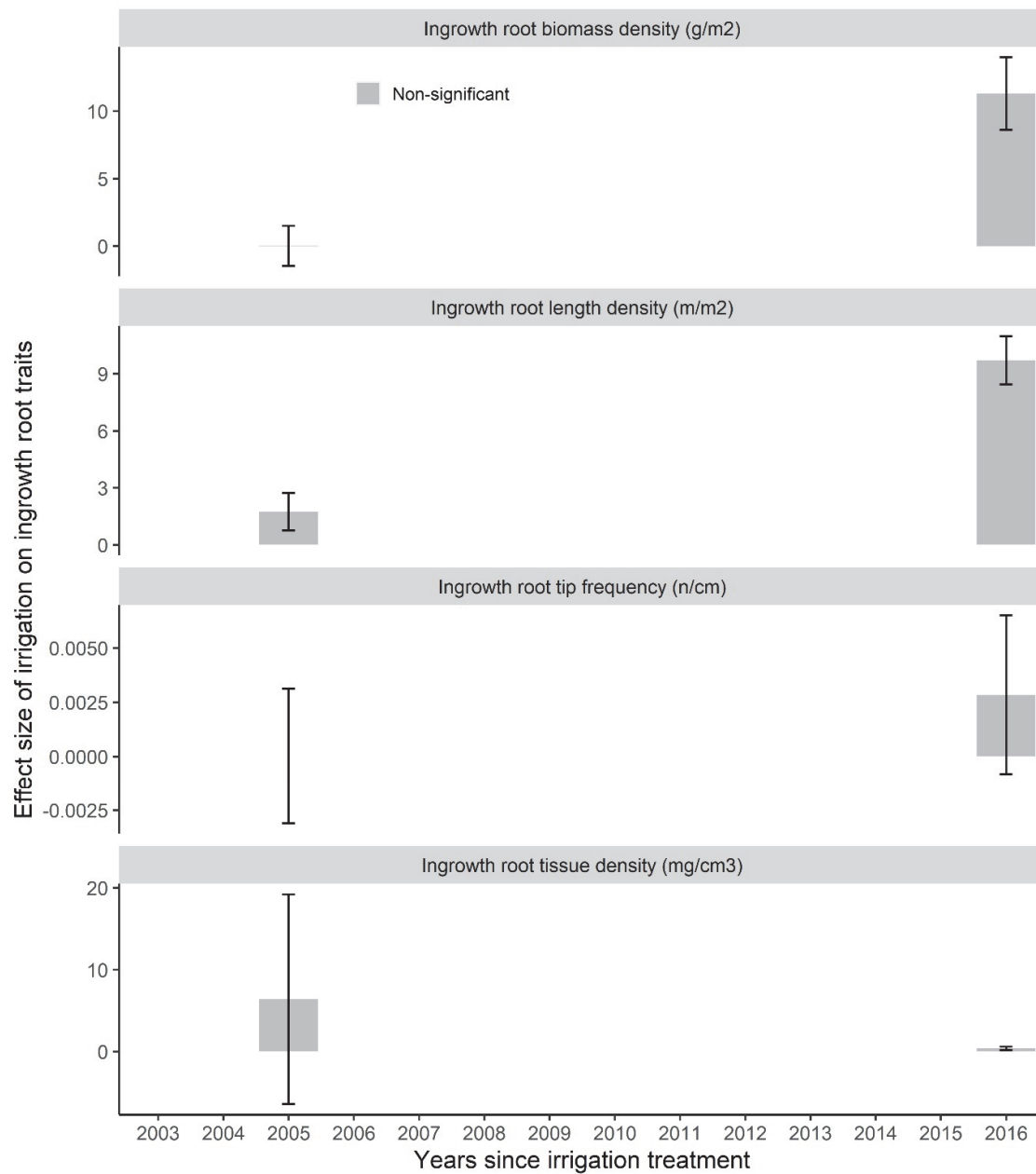


Figure S5. Effect size (i.e., coefficient of the mixed-effect model) of the irrigation treatment on ingrowth (newly formed) root traits. The grey bar indicates non-significant effect of irrigation treatment (>0.05). The error bars represent mean±standard errors. The number of observations used for each analysis is provided in Table S2. The analysis was performed separately for each time period.

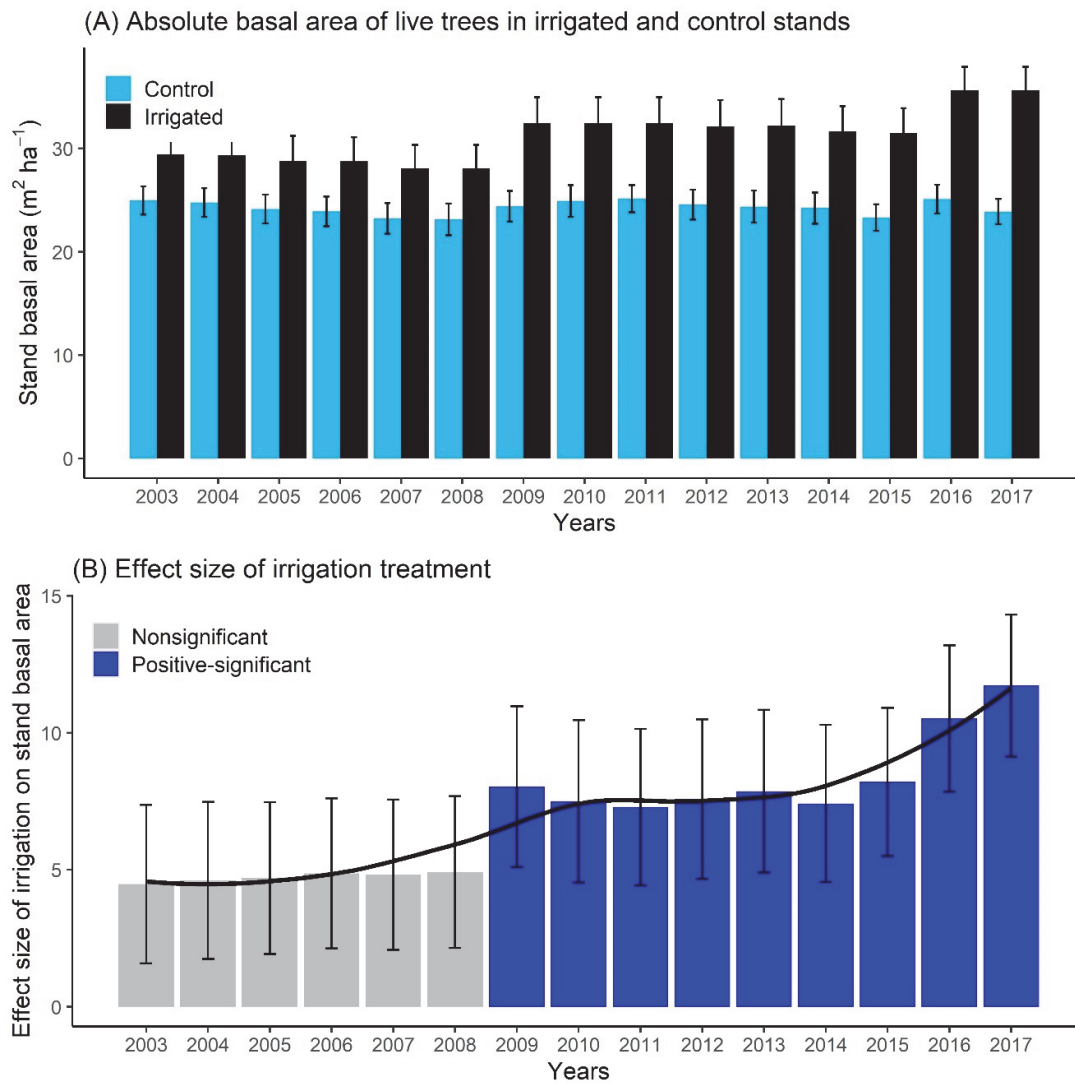


Figure S6. Irrigation effect on stand-level basal area of live trees. (A) Absolute stand-level basal area of live trees in irrigated and control plots from 2003 to 2017, and (B) Effect size (i.e., coefficient of the mixed-effect model) of the irrigation on stand-level basal area of live trees from 2003 to 2017. The error bars represent the mean \pm standard errors and the fitted line shows the locally estimated *smoothing* (i.e., *loess*). The number of observations used for each analysis is provided in Table S2. The analysis was performed separately for each year. Irrigation started in 2003.

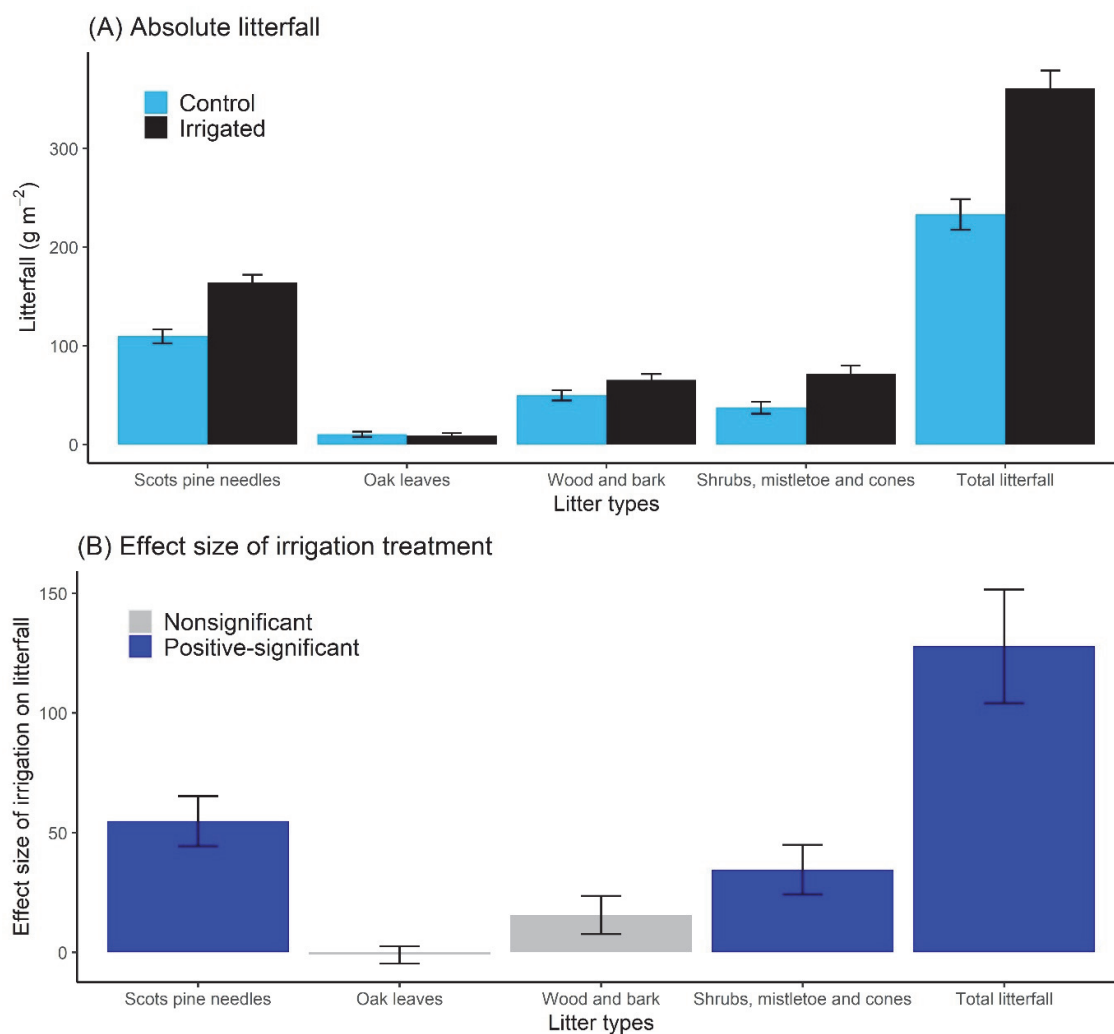


Figure S7. Irrigation effect on litterfall. The litterfall samples were collected in November 2014. (A) Absolute litterfall in control and irrigated plots, and (B) Effect size (i.e., coefficient of the mixed-effect model) of the irrigation treatment on litterfall. The error bars represent the mean \pm standard errors.

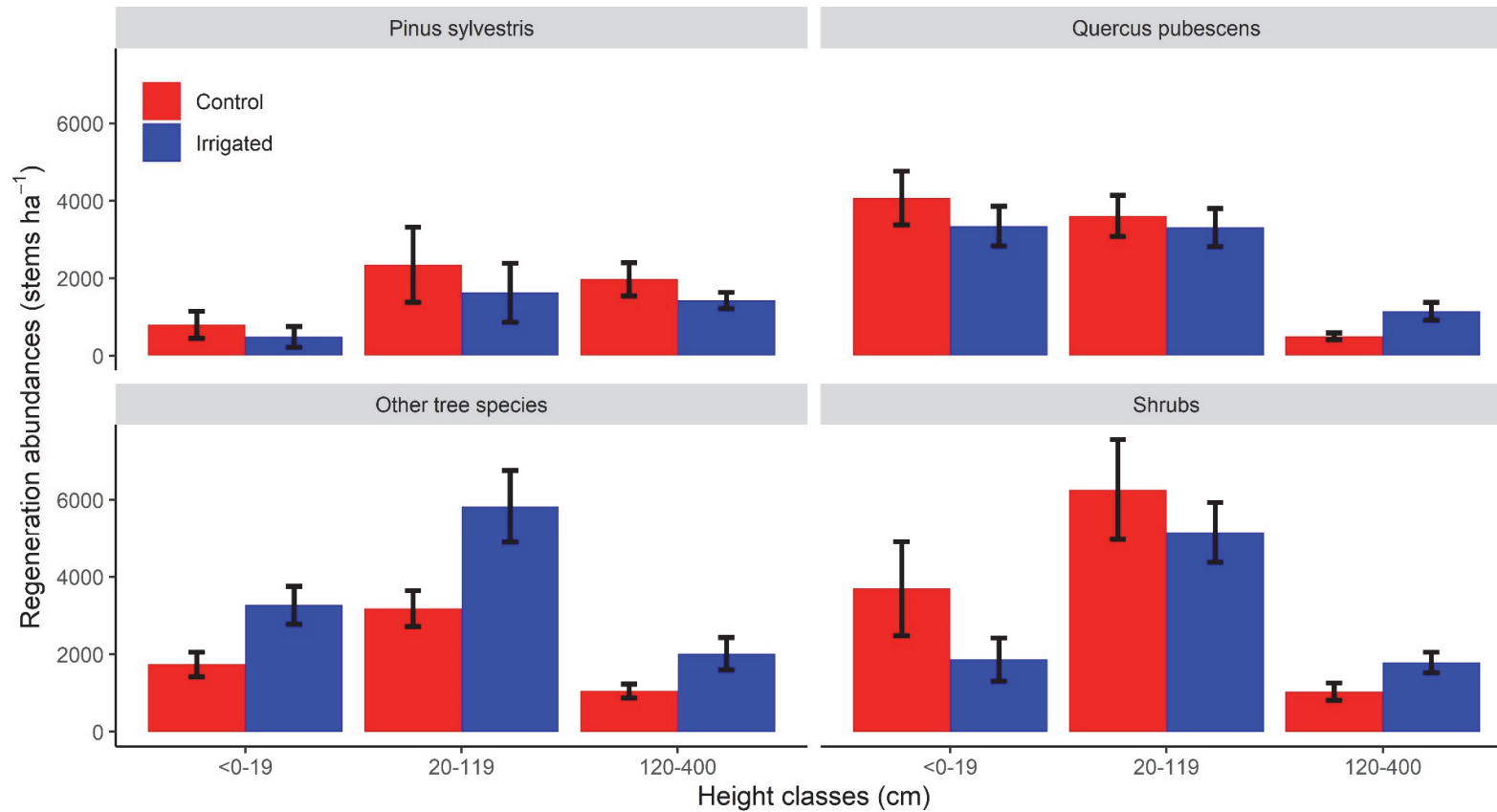


Figure S8. Descriptive statistics of absolute regeneration abundances (stems ha^{-1}) across height classes of four different species types located in irrigated and control plots. The measurement was performed after 16 years since the onset of the irrigation treatment. The error bars represent mean \pm standard errors.

References

- Boettger, T., Haupt, M., Knöller, K., Weise, S., Waterhouse, J., Rinne, K., Loader, N., Sonninen, E., Jungner, H., Masson Delmotte, V., et al. (2007). Wood cellulose preparation methods and mass spectrometric analyses of $\delta^{13}\text{C}$, $\delta^{18}\text{O}$, and nonexchangeable $\delta^2\text{H}$ values in cellulose, sugar, and starch: an interlaboratory comparison. *Analytical Chemistry*, 79(12), 4603-4612.
- Brunner, I., Herzog, C., Galiano, L., & Gessler, A. (2019). Plasticity of fine-root traits under long-term irrigation of a water-limited Scots pine forest. *Frontiers in Plant Science*, 10, 701.
- Brunner, I., Pannatier, E. G., Frey, B., Rigling, A., Landolt, W., Zimmermann, S., & Dobbertin, M. (2009). Morphological and physiological responses of Scots pine fine roots to water supply in a dry climatic region in Switzerland. *Tree Physiology*, 29(4), 541-550.
- Dobbertin, M., Eilmann, B., Bleuler, P., Giuggiola, A., Graf Pannatier, E., Landolt, W., Schleppi, P., & Rigling, A. (2010). Effect of irrigation on needle morphology, shoot and stem growth in a drought-exposed *Pinus sylvestris* forest. *Tree Physiology*, 30(3), 346-360.
- Eilmann, B., Buchmann, N., Siegwolf, R., Saurer, M., Cherubini, P., & Rigling, A. (2010). Fast response of Scots pine to improved water availability reflected in tree-ring width and $\delta^{13}\text{C}$. *Plant, Cell & Environment*, 33(8), 1351-1360.
- Federer, C. A. (2002). BROOK 90: A simulation model for evaporation, soil water, and streamflow. <http://www.ecoshift.net/brook/brook90.htm>.
- Gärtner, Gärtner, H., Lucchinetti, S., & Schweingruber, F. H. (2015). A new sledge microtome to combine wood anatomy and tree-ring ecology. *IAWA journal*, 36(4), 452-459.

- Gärtner, H., & Schweingruber, F. H. (2013). Microscopic Preparation Techniques for Plant Stem Analysis. *Kessel Publishing House, Remagenm, Germany*.
- Grissino-Mayer, H. D. (2001). Evaluating crossdating accuracy: a manual and tutorial for the computer program COFECHA. *Tree-Ring Res*, 57, 205–221.
- Hammel, K., & Kennel, M. (2001). Charakterisierung und analyse der wasserverfügbarkeit und des wasserhaushalts von waldstandorten in bayern mit dem simulationsmodell BROOK90. Frank.
- Herzog, C., Hartmann, M., Frey, B., Stierli, B., Rumpel, C., Buchmann, N., & Brunner, I. (2019). Microbial succession on decomposing root litter in a drought-prone Scots pine forest. *The ISME Journal*, 13(9), 2346-2362.
- Herzog, C., Steffen, J., Pannatier, E. G., Hajdas, I., & Brunner, I. (2014). Nine years of irrigation cause vegetation and fine root shifts in a water-limited pine forest. *PloS one*, 9(5), e96321.
- Knoben, W. J. M., Freer, J. E., & Woods, R. A. (2019). Technical note: Inherent benchmark or not? Comparing Nash–Sutcliffe and Kling–Gupta efficiency scores. *Hydrology and Earth System Science*, 23(10), 4323-4331.
- Laumer, W., Andreu, L., Helle, G., Schleser, G. H., Wieloch, T., & Wissel, H. (2009). A novel approach for the homogenization of cellulose to use micro-amounts for stable isotope analyses. *Rapid Communications in Mass Spectrometry*, 23(13), 1934-1940.
- McCarroll, D., & Loader, N. J. (2004). Stable isotopes in tree rings. *Quaternary Science Reviews*, 23(7), 771-801.
- Olano, J. M., Menges, E. S., & Martínez, E. (2006). Carbohydrate storage in five resprouting Florida scrub plants across a fire chronosequence. *New Phytologist*, 170(1), 99-106.

- Popp, M., Lied, W., Meyer, A. J., Richter, A., Schiller, P., & Schwitte, H. (1996). Sample preservation for determination of organic compounds: microwave versus freeze-drying. *Journal of Experimental Botany*, 47(10), 1469-1473.
- Puhlmann, H., Von Wilpert, K., Lukes, M., & Dröge, W. (2009). Multistep outflow experiments to derive a soil hydraulic database for forest soils. *European Journal of Soil Science*, 60(5), 792-806.
- Schmidt-Walter, P., Trotsiuk, V., Meusburger, K., Zacios, M., & Meesenburg, H. (2020). Advancing simulations of water fluxes, soil moisture and drought stress by using the LWF-Brook90 hydrological model in R. *Agricultural and Forest Meteorology*, 291, 108023.
- Schönbeck, L., Gessler, A., Hoch, G., McDowell, N. G., Rigling, A., Schaub, M., & Li, M.-H. (2018). Homeostatic levels of nonstructural carbohydrates after 13 yr of drought and irrigation in *Pinus sylvestris*. *New Phytologist*, 219(4), 1314-1324.
- Timofeeva, G., Treydte, K., Bugmann, H., Rigling, A., Schaub, M., Siegwolf, R., & Saurer, M. (2017). Long-term effects of drought on tree-ring growth and carbon isotope variability in Scots pine in a dry environment. *Tree Physiology*, 37(8), 1028-1041.
- von Arx, G., Arzac, A., Fonti, P., Frank, D., Zweifel, R., Rigling, A., Galiano, L., Gessler, A., & Olano, J. M. (2017). Responses of sapwood ray parenchyma and non-structural carbohydrates of *Pinus sylvestris* to drought and long-term irrigation. *Functional Ecology*, 31(7), 1371-1382.
- von Arx, G., Arzac, A., Olano, J. M., & Fonti, P. (2015). Assessing conifer ray parenchyma for ecological studies: Pitfalls and guidelines. *Frontiers in Plant Science*, 6, 1016.
- von Arx, G., & Carrer, M. (2014). ROXAS – A new tool to build centuries-long tracheid-lumen chronologies in conifers. *Dendrochronologia*, 32(3), 290-293.

Zweifel, R., Etzold, E., Sterck, F., Gessler, A., Anfodillo, T., Mencuccini, M., von Arx, G., Lazzarin, M., Haeni, M., Feichtinger, L., et al. (2020). Determinants of legacy effects in pine trees - implications from an irrigation-stop experiment. *New Phytologist*, 227, 1081-1096.