

Soil respiration response to decade-long warming modulated by soil moisture in a boreal forest

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Supplementary information

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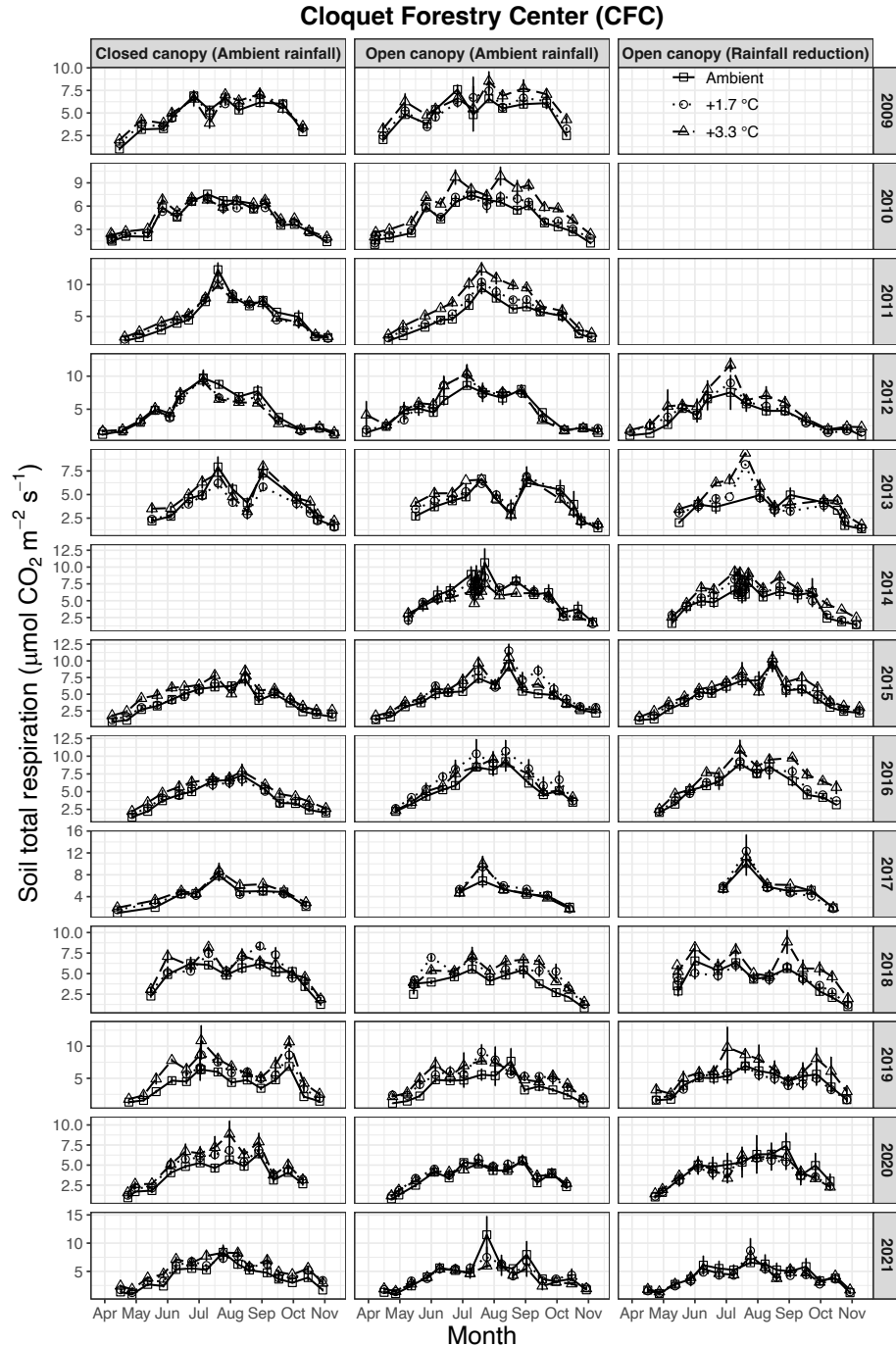
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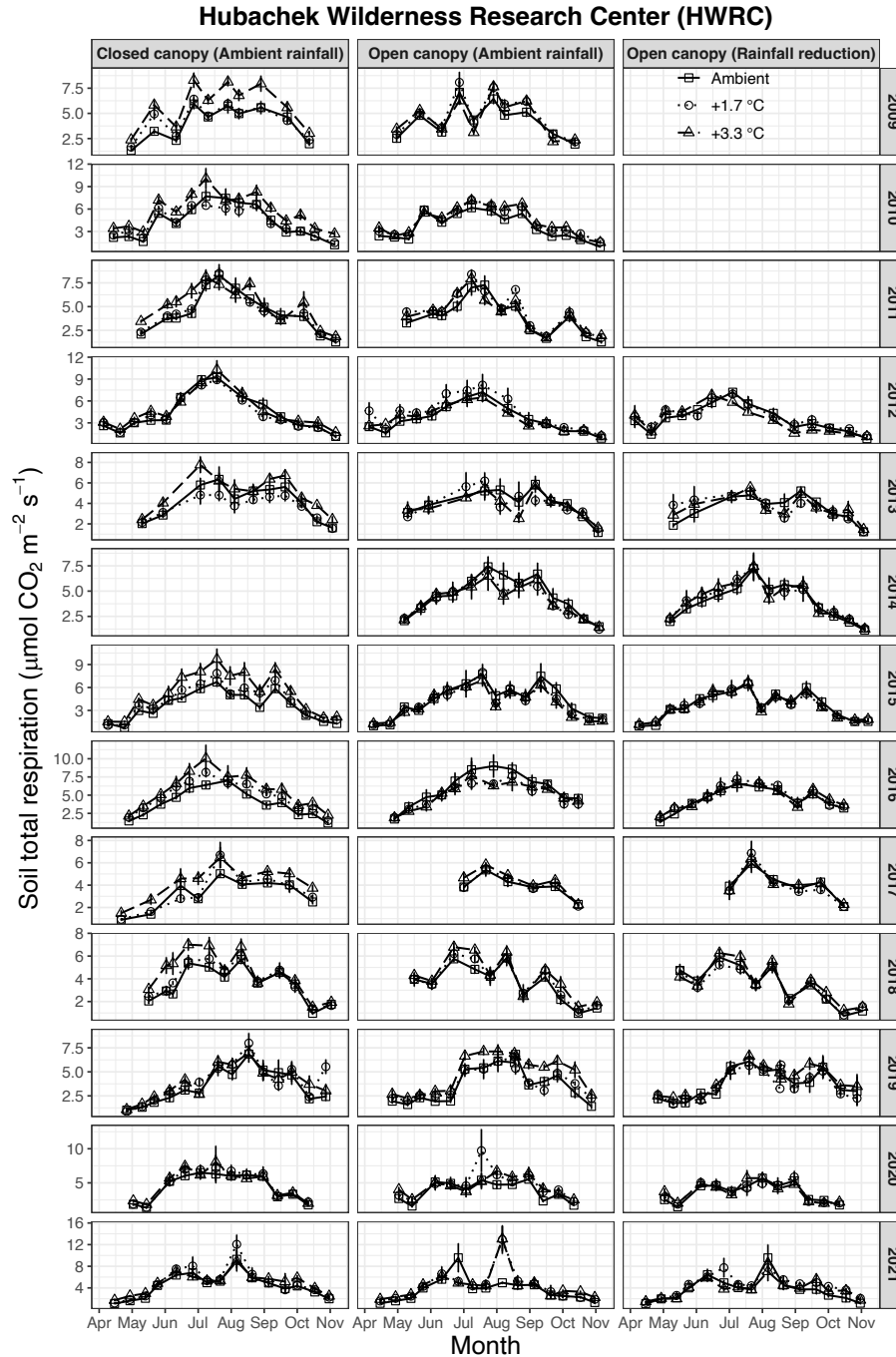
Supplementary Table 1. Climatic and soil characteristics of the two sites.

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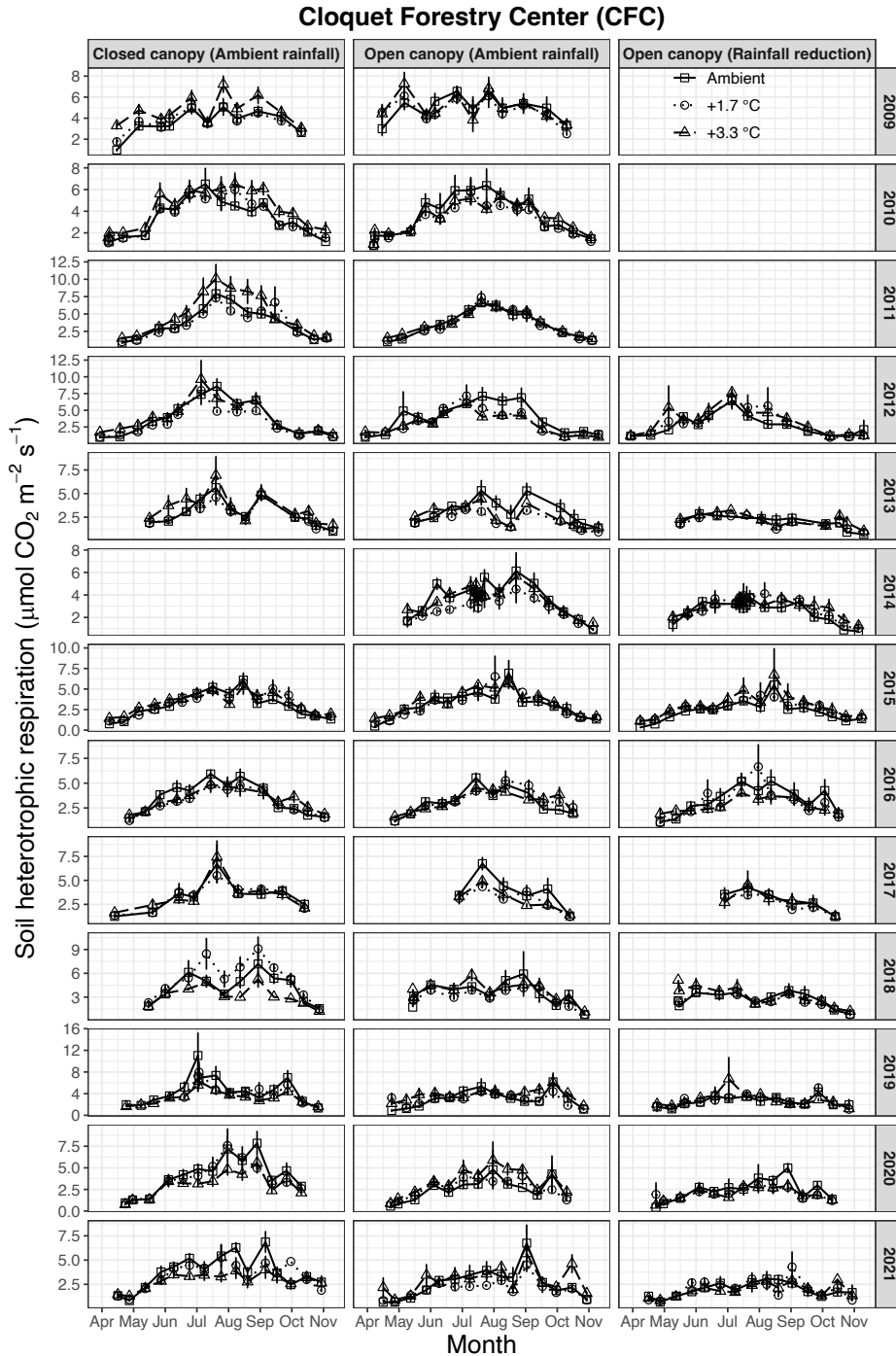
Supplementary Table 3. The values of constants in the equations that were used to estimate stem biomass of 16 out of 21 species that we planted in the study.



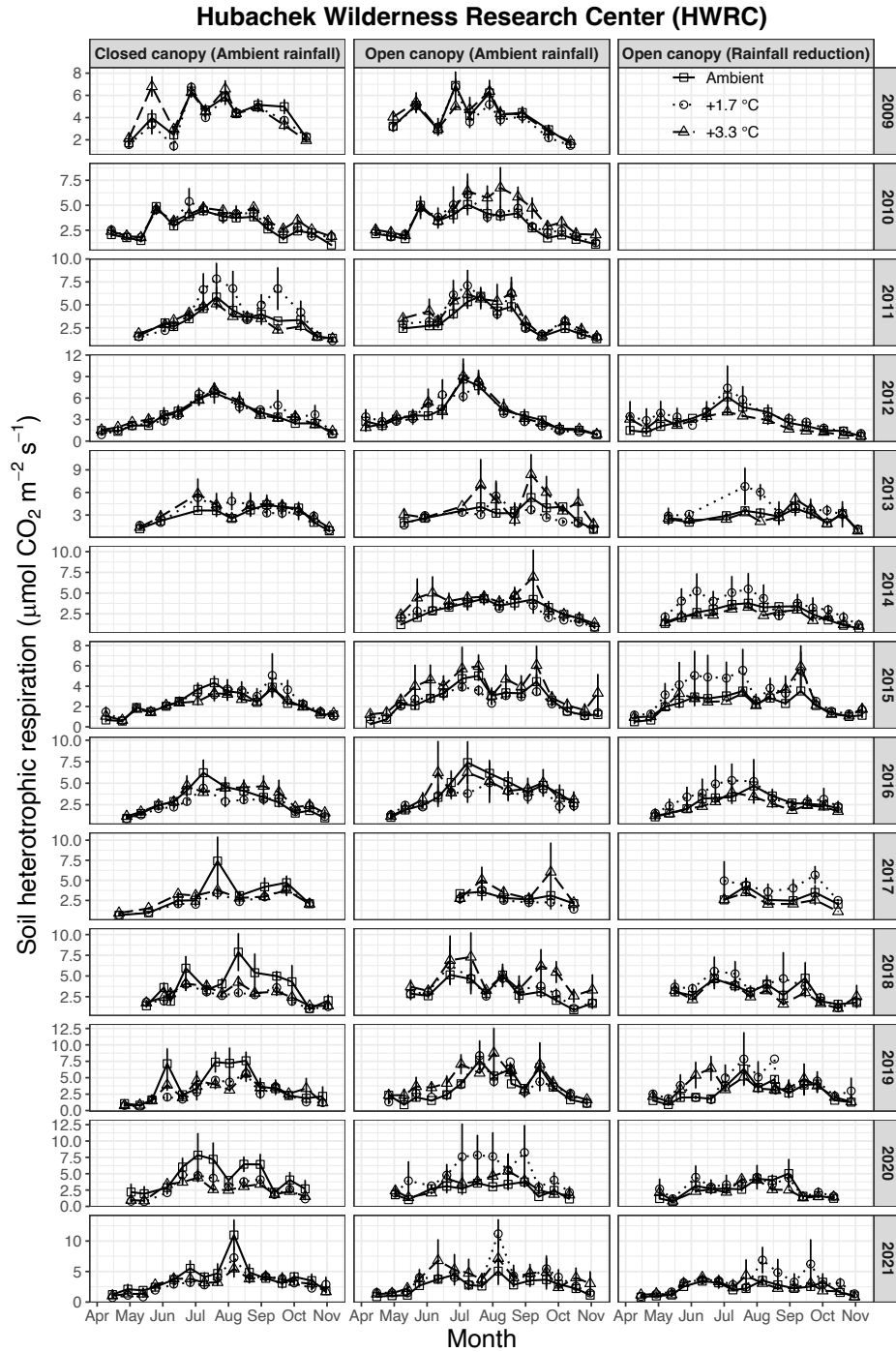
Supplementary Fig. 1. Soil total respiration under different treatments at the CFC site from all campaigns (2009-2021). Panels under “Closed canopy (Ambient rainfall)” and “Open canopy (Ambient rainfall)” show results under different overstory canopy openness; panels under “Open canopy (Ambient rainfall)” and “Open canopy (Rainfall reduction)” show results under different rainfall amounts. Error bars are standard errors of the mean for each treatment combination. The sample size was 6 for all treatments before 2012 and for all treatments under closed canopy across all years, and was 3 for all treatments under open canopy during 2012 and beyond.



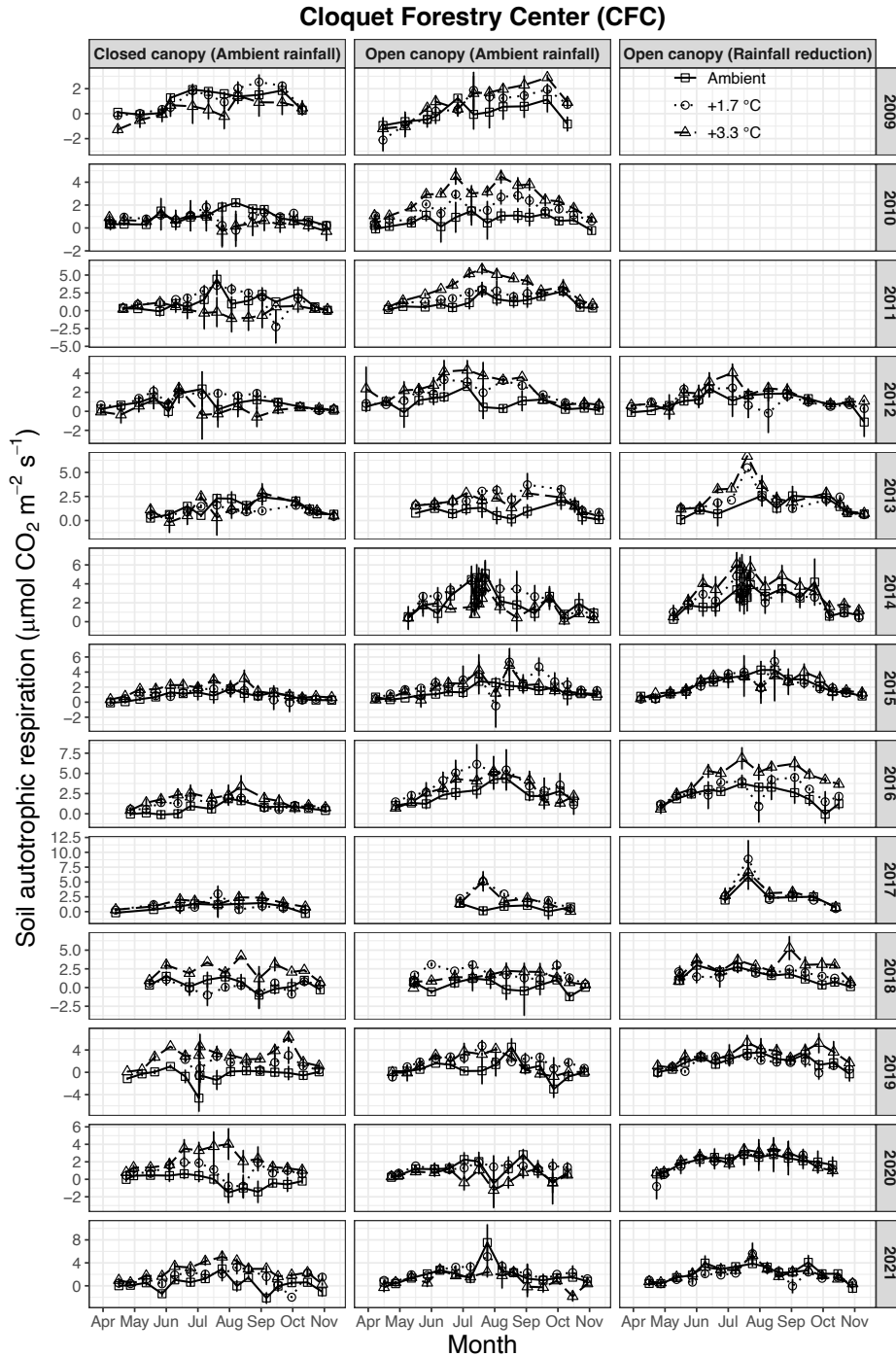
Supplementary Fig. 2. Soil total respiration under different treatments at the HWRC site from all campaigns (2009-2021). Panels under “Closed canopy (Ambient rainfall)” and “Open canopy (Ambient rainfall)” show results under different overstory canopy openness; panels under “Open canopy (Ambient rainfall)” and “Open canopy (Rainfall reduction)” show results under different rainfall amounts. Error bars are standard errors of the mean for each treatment combination. The sample size was 6 for all treatments before 2012 and for all treatments under closed canopy across all years, and was 3 for all treatments under open canopy during 2012 and beyond.



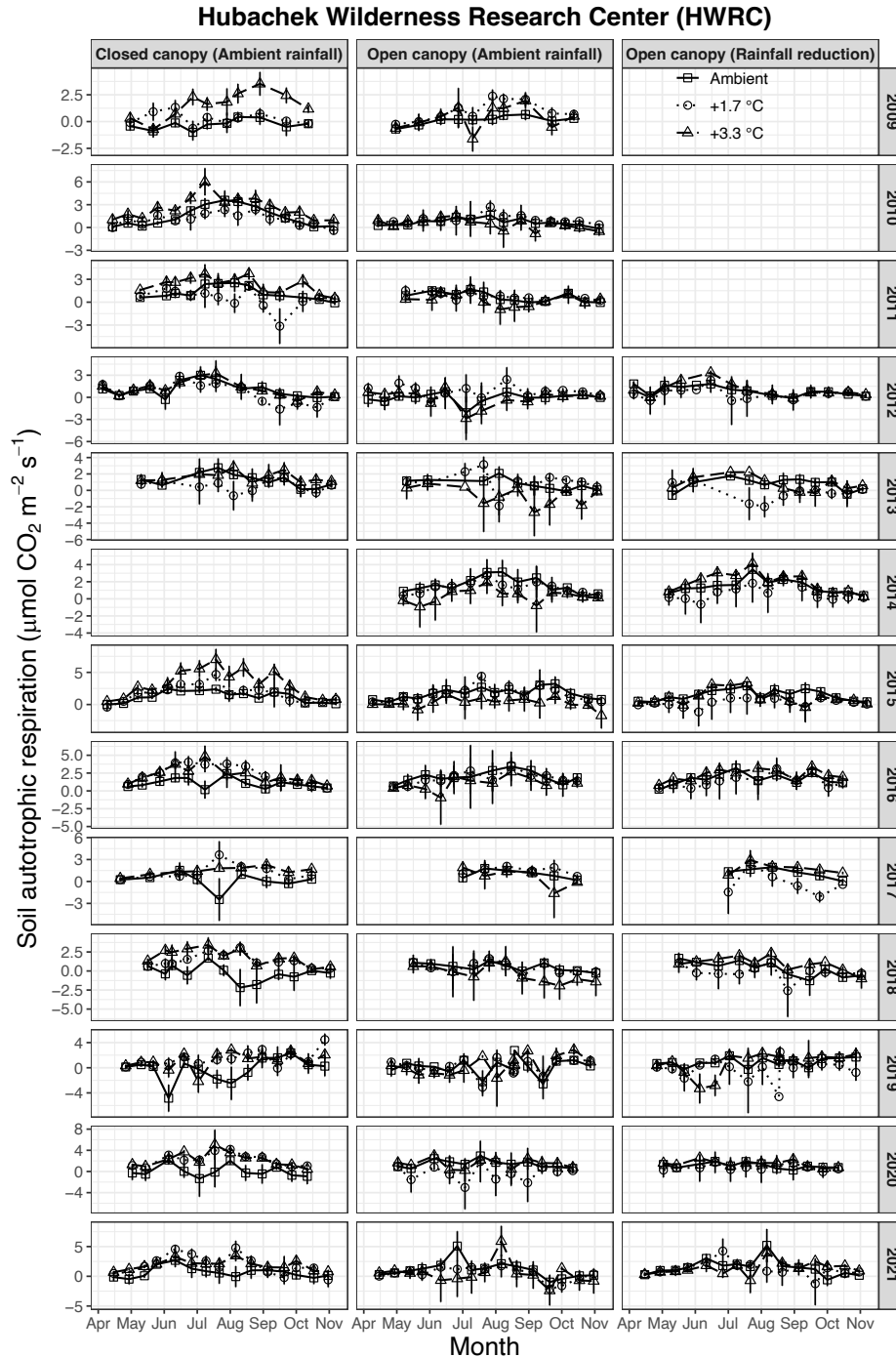
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Supplementary Fig. 4. Soil heterotrophic respiration under different treatments at the HWRC site from all campaigns (2009-2021). Panels under “Closed canopy (Ambient rainfall)” and “Open canopy (Ambient rainfall)” show results under different overstory canopy openness; panels under “Open canopy (Ambient rainfall)” and “Open canopy (Rainfall reduction)” show results under different rainfall amounts. Error bars are standard errors of the mean for each treatment combination. The sample size was 6 for all treatments before 2012 and for all treatments under closed canopy across all years, and was 3 for all treatments under open canopy during 2012 and beyond.



Supplementary Fig. 5. Soil autotrophic respiration under different treatments at the CFC site from all campaigns (2009-2021). Panels under “Closed canopy (Ambient rainfall)” and “Open canopy (Ambient rainfall)” show results under different overstory canopy openness; panels under “Open canopy (Ambient rainfall)” and “Open canopy (Rainfall reduction)” show results under different rainfall amounts. Error bars are standard errors of the mean for each treatment combination. The sample size was 6 for all treatments before 2012 and for all treatments under closed canopy across all years, and was 3 for all treatments under open canopy during 2012 and beyond.



Supplementary Fig. 6. Soil autotrophic respiration under different treatments at the HWRC site from all campaigns (2009-2021). Panels under “Closed canopy (Ambient rainfall)” and “Open canopy (Ambient rainfall)” show results under different overstory canopy openness; panels under “Open canopy (Ambient rainfall)” and “Open canopy (Rainfall reduction)” show results under different rainfall amounts. Error bars are standard errors of the mean for each treatment combination. The sample size was 6 for all treatments before 2012 and for all treatments under closed canopy across all years, and was 3 for all treatments under open canopy during 2012 and beyond.



Supplementary Fig. 7. The pictures of plots from the B4WarmED project. (a): the plot of + 3.3 °C under the open canopy; (b): the plot of + 3.3 °C under the closed canopy; (c): the rainout shelter that was installed to remove rainfall under the open canopy; (d): the PVC collar that was used to measure soil respiration. The height of the infrared lamp heater was approximately 1.6 m. All photos were taken by Guopeng Liang in June of 2023.

Supplementary Table 1. Climatic and soil characteristics of the two sites.

Characteristics	Cloquet Forestry Center	Hubacheck Wilderness Research Center
Mean annual precipitation (mm)	807	722
Mean annual temperature (°C)	4.5	3.0
Soil Taxonomy		
Order	Inceptisols	Entisols
Suborder	Udepts	Orthents
Subgroup	Typic Dystrudepts	Lithic Udorthents
Series	Cloquet Series	Conic Series
Parent material	Outwash plain	Glacial Till
O horizon (g m ⁻²)	694	925
Soil properties (0-10 cm mineral soil)		
pH	5.3	5.4
Soil organic carbon content (g kg ⁻¹ soil)	26.2	24.6
Soil total nitrogen content (g kg ⁻¹ soil)	1.6	1.3
Soil C:N	16.5	18.2
Soil clay content (%)	9.3	11.0
Soil sand content (%)	60.2	66.2
Live fine-root density (g m ⁻² at 0-20 cm soil depth)	4.3	11.8

Supplementary Table 2. The species of juveniles that were planted during the experiment.

Species	Time of cohorts for open canopy (year)	Time of cohorts for closed canopy (year)	Age of seedlings at the time of planting	Age range of the juvenile during the experiment
Abies balsamea L.*	2009-2012, 2012-2016, 2017-2019	2009-2013, 2014-2019	3	5-15
Acer rubrum L.	2009-2012, 2012-2016, 2017-2019	2009-2013, 2014-2019	2	4-14
Acer saccharum Marshall.	2009-2012, 2012-2016, 2017-2021	2009-2013, 2014-2019	2	2-14
Betula papyrifera Marshall.	2009-2012, 2012-2016, 2017-2019	2009-2013, 2014-2019	1	3-13
Picea glauca (Moench) Voss.	2009-2012, 2012-2016, 2017-2019	2009-2013, 2014-2019	3	5-15
Pinus banksiana Lamb.	2009-2012, 2012-2016, 2017-2019	2009-2013, 2014-2019	2	4-14
Pinus strobus L.	2009-2012, 2012-2016, 2017-2019	2009-2013, 2014-2019	2	4-14
Populus tremuloides Michx.	2009-2012, 2012-2016, 2017-2019	2009-2013, 2014-2019	1	3-13
Quercus macrocarpa Michx.	2009-2012, 2012-2016, 2017-2021	2009-2013, 2014-2019	2	2-14
Quercus rubra L.	2009-2012, 2012-2016, 2017-2019	2009-2013, 2014-2019	2	4-14
Rhamnus cathartica L.	2009-2012, 2017-2019		resprouts	2-12
Acer negundo L.		2014-2019	2	4-9
Betula alleghaniensis Britt.		2014-2019	1	3-8
Thuja occidentalis L.		2014-2019	3	5-10
Tsuga canadensis (L.) Carriere		2014-2019	3	5-10
Tilia Americana L.		2014-2019	2	4-9
Pinus resinosa Sol. ex Aiton		2014-2019	2	4-9
Picea mariana (Mill.) Britton		2014-2019	3	5-10
Frangula alnus Mill.	2017-2020		resprouts	1-4
Lonicera morrowii A. Gray	2017-2020		resprouts	1-4
Lonicera tatarica L.	2017-2020		resprouts	1-4

*: base species that are always added to each cohort were highlighted in bold, and the rest of the species (e.g. not highlighted in bold) were only added in some cohorts to test some specific hypotheses.

The number of planted juveniles was the same in each plot and in each new cohort. Given that the additional species with their corresponding replication represent a small fraction of all replication and species used in the experiment, we do not expect that they would have a significant effect on the main results presented in this study.

Supplementary Table 3. The values of constants in the equations that were used to estimate stem biomass of 16 out of 21 species that we planted in the study.

Species	a	b	c	d
<i>Abies balsamea</i> L.	0.01	0.14	-0.16	0.11
<i>Acer negundo</i> L.	0.05	0.94	-1.04	-2.73
<i>Acer rubrum</i> L.	-0.18	0.23	-0.29	0.30
<i>Acer saccharum</i> Marshall.	-0.08	-0.14	-0.14	0.83
<i>Betula alleghaniensis</i> Britt.	0.14	0.35	0.13	0.43
<i>Betula papyrifera</i> Marshall.	-0.19	0.25	-0.13	0.15
<i>Frangula alnus</i> Mill.	-0.15	-0.11	-0.14	0.48
<i>Lonicera morrowii</i> A. Gray	-0.20	-1.00	-0.10	0.05
<i>Lonicera tatarica</i> L.	-0.28	-1.28	0.07	-2.02
<i>Picea glauca</i> (Moench) Voss.	0.11	-0.27	0.71	-1.26
<i>Picea mariana</i> (Mill.) Britton	0.26	0.28	-0.08	1.81
<i>Pinus banksiana</i> Lamb.	-0.12	0.16	0.57	-0.89
<i>Pinus resinosa</i> Sol. ex Aiton	0.39	0.65	-0.60	-0.17
<i>Pinus strobus</i> L.	0.04	-0.39	0.67	-0.81
<i>Populus tremuloides</i> Michx.	-0.32	0.37	-0.06	1.30
<i>Quercus macrocarpa</i> Michx.	-0.09	-0.11	0.10	0.32
<i>Quercus rubra</i> L.	-0.02	-0.23	-0.04	0.94
<i>Rhamnus cathartica</i> L.	-0.11	-0.07	-0.07	0.76
<i>Thuja occidentalis</i> L.	0.27	-0.11	0.58	0.22
<i>Tilia Americana</i> L.	0.02	-0.05	0.04	0.17
<i>Tsuga canadensis</i> (L.) Carriere	0.45	0.40	-0.02	0.01