Emerald Ash Borer related tree removal and implications for urban heat: a pilot field study

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Abstract: Urban tree canopies help mitigate urban heat through evaporative cooling and shading and are valued for providing numerous ecosystem services. In Boulder, Colorado, 25% of the urban forest is composed of ash trees (*Fraxinus americana* and *F. pennsylvanica*). Emerald ash borer (EAB, *Agrilus planipennis*) has migrated from the eastern United States to Boulder, posing a significant threat to canopy loss and reduction in ecosystem services such as reduced urban shade and cooling. In September 2018, we conducted an exploratory pilot study in Boulder, CO, to examine the immediate impact of ash removal on air temperature at one site along Boulder Creek. We measured air temperature (1 sample/min) over a 5-day period under two EAB-infected ash trees to be removed on day 3. Temperature was also logged at two other control sites, one in full sun and one under another EAB-infected ash tree that would not be removed for reference comparisons. Removal of the two EAB-infected trees showed an average increase of 0.88 F (SE = 0.035, N = 2 trees) in ambient air temperature at the site of ash tree removal compared to a control sensor in full sun, and 0.337 F (SE = 0.067, N = 2 trees). Since removal of two ash trees at this single site showed a measurable difference, With a larger study, we may be able to establish baseline values for EAB-mortality related tree restoration ecosystem service goals, provide predictions for local urban heat dynamics with tree canopy loss, and consider shade intervention structures to mitigate heat-related human health concerns and increased energy consumption for summer heat waves.

Introduction: With increasing global air temperatures and increased urbanization, cities adding urban heat mitigation into their strategic sustainability plans. Urban tree canopies help mitigate urban heat through evaporative cooling and shading and are valued for providing numerous ecosystem services (Moss et al. 2019) and many cities aim to increase their tree canopy especially in areas that disproportionately affect disadvantaged populations (Huang et al. 2011). Areas of less tree canopy and more impervious surface exposure have increased thermal infrared radiation of approximately 12 - 17 F (Napoli et al. 2016) and ambient air temperature variations averaging 6.3 F depending on tree canopy cover (Ziter et al. 2019). Surface radiation typically has a higher degree of contrast between sun and shade relative to air temperature, but air temperatures experienced by humans is more relevant for human thermal comfort and determinant of heat-related illness risks (Yoshida et al. 2015).

In Boulder, Colorado, ash trees (*Fraxinus sp.*) make up over 25% of Boulder's urban forest (City of Boulder Strategic Plan 2018). Emerald ash borer (EAB,*Agrilus planipennis*) was detected in Boulder in 2013, putting a large proportion of the urban canopy at risk of beetle infestation and subsequent mortality. Many trees missed the window for proactive chemical treatments before infestation, and the City of Boulder and other landowners are working to remove infected ash trees before they become structurally hazardous. The loss of these mature ash trees will significantly reduce urban shade, and we hypothesize there may be a detectable increase in local air temperature after ash tree removal. The immediate effects of ash removal on local microclimates have not been studied in Colorado. This 7-day study in September 2018 is expected to give insight to the immediate changes in local weather that residents and wildlife may experience with significant urban forest canopy loss.

Research question: How is ambient air temperature immediately impacted by green ash tree (*Fraxinus pennsylanica*) removal?

Hypothesis: Air temperature will increase at the location of the removed ash trees due to increased solar radiation and decreased shade and evapotranspiration.

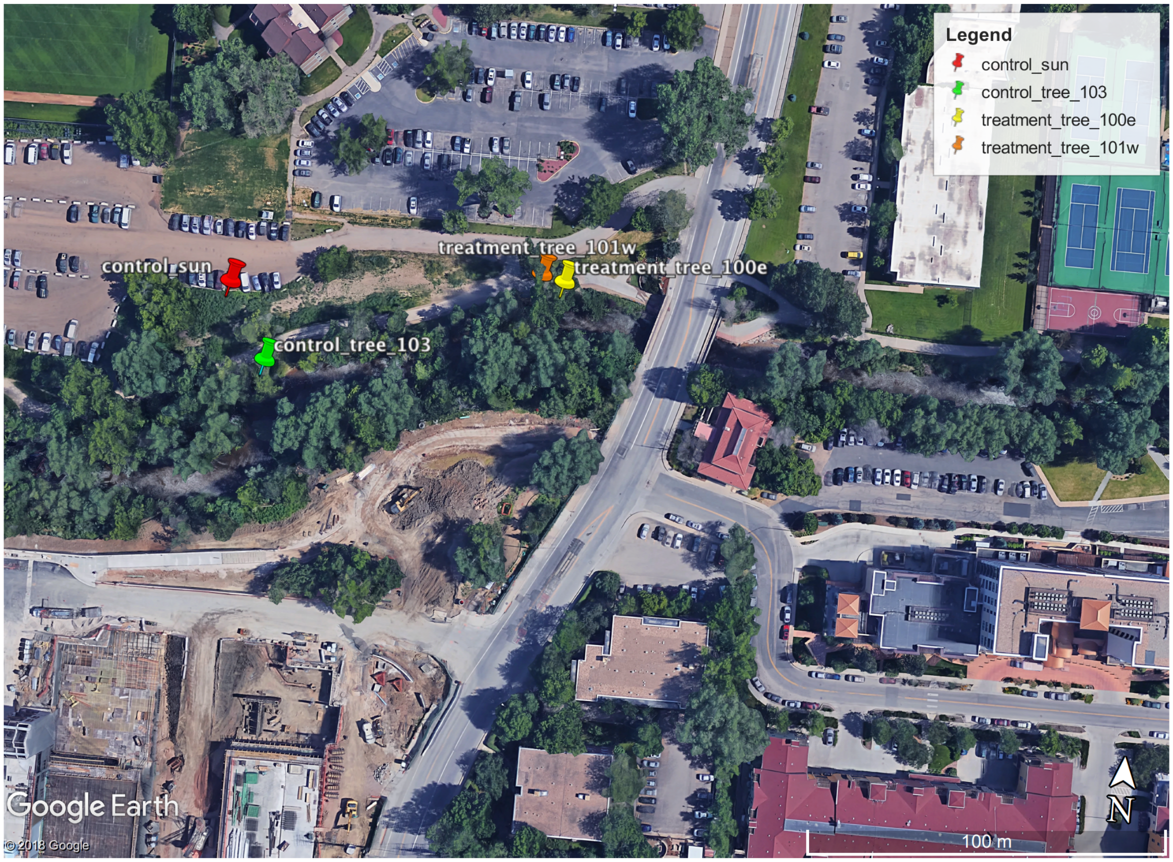

Figure 1. Aerial view of the study area, North of Boulder Creek, Boulder, Colorado.

Methods: Air temperature was measured at three sites along Boulder creek (Figure 1) from September 17-23. The first site had two air temperature sensors each under two adjacent green ash trees (2.5 m distance, *Fraxinus pennsylvanica*). Treatment trees #100e, (40.011491, -105.263795, DBH = 16 inches, dripline width = 41 ft, Figure 2a,b) and #101w (40.01148, -105.263828, DBH = 13.1 inches, dripline width = 24 ft, Figure 2b,c) were lopped at the trunk base on September 20th between 8am - 11am (Figure 2). Two additional sensor sites served as controls for reference comparison: one site under a EAB-infected green ash tree (*F. pennsylvanica*) that was not removed (#103, 40.011222,-105.26472, DBH = 9.06 inches, dripline width = 28 ft, Figure 3a) and second control site in full sun (40.011496, -105.263789, Figure 3b). The two treatment and one control trees had between 65-75% leaf foliage loss from the original full canopy. The treatment and control sites were approximately 80 meters apart. Air temperature was logged (1 sample/minute) using HOBO MX2201 sensors enclosed in Onset solar radiation shields at a height of 1.29 m (4 ft) from the ground. Data was analyzed in R software V 1.1.456 using ANOVA and Tukey's HSD tests.

Results:

We detected air temperature increases with comparisons of the treatment sensors to the two controls. Analysis of variance (ANOVA) of mean air temperature values among the two treatment ash trees that were removed (101w, 100e) and two controls trees (103, sun) showed significant differences after removal [$F(11, 58920) = 2375$, $p < 0.001$] (Figure 4). The smallest differences in mean air temperatures were between the two treatment trees, and the greatest differences were between the sun and ash tree controls. Differences between treatment and control pairs were observed post-ash tree removal (Figure 5) to account for overall weather differences in the raw data before and after removal (Figure 6).

The air temperature under the treatment trees increased by an average of 0.88 F(SE = 0.036, N = 2 trees) relative to the sun control sensor. A Tukey post-hoc test showed the mean air temperature difference between

Figure 2. Photo of treatment site where two green ash trees (*Fraxinus pennsylvanica*) infected with Emerald Ash Borer beetles were removed Sept 20, 2018 from Boulder Creek, Boulder, Colorado. a) shows treatment tree 100e and b) shows treatment tree 101w.

Figure 3. Study site where a) shows the control tree (*Fraxinus pennsylvanica*) that was not removed during the study and b) shows the control site without tree canopy in full sun along Boulder Creek, Boulder, Colorado.

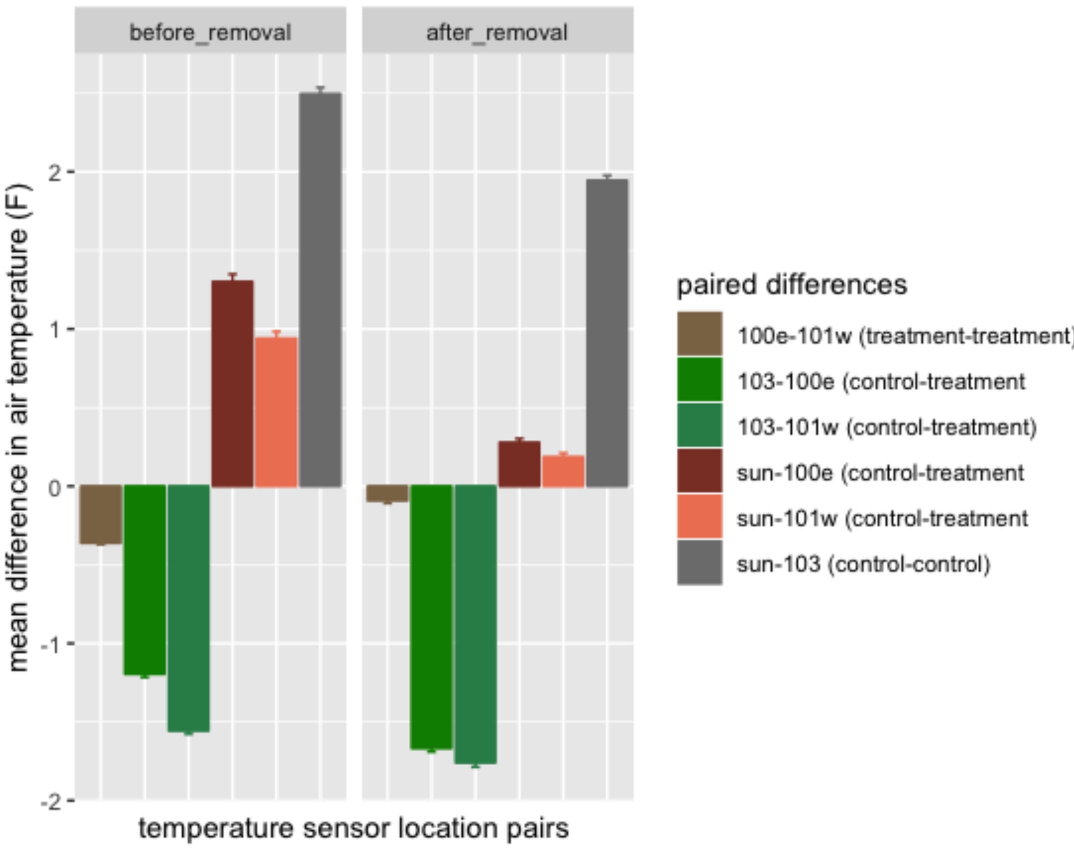

Figure 4. Mean difference in hourly air temperature among sensors pairs for before ash removal (Sep 17-19, 2018) and after (Sep 21-23, 2018) ash removal.

the 100e treatment tree and the sun control decreased by 1.023 F (SE = 0.036) after tree removal (before: mean difference = 1.300 F, SE = 0.048, after: mean difference = 0.277 F, SE = 0.025; $p < 0.001$). Similarly, the mean air temperature difference between the 101w treatment tree and the sun control decreased by 0.753 F (SE = 0.34) after tree removal (before: mean difference = 0.939 F, SE = 0.044, after: mean difference = 0.186 F, SE = 0.024; $p < 0.001$).

The air temperature under the treatment trees increased by an average of 0.337 F (SE = 0.067, N = 2 trees) relative to the green ash control sensor. A Tukey post-hoc test showed the mean air temperature difference between the 100e treatment tree and the 103 ash control increased by 0.472 F (SE = 0.111) after tree removal (before: mean difference = -1.194 F, SE = 0.020, after: mean difference = -1.667 F, SE = 0.022; $p < 0.001$). The mean air temperature difference between the 101w treatment tree and the sun control increased by 0.202 F (SE = 0.023) after tree removal (before: mean difference = -1.555 F, SE = 0.020, after: mean difference = -1.758 F, SE = 0.027; $p < 0.001$).

The air temperature between the sun and shaded ash tree control sensor locations was on average 2.219 F higher at the sun sensor throughout the 7 day study. Tukey's post-hoc test showed the mean air temperature difference between the sun control and the 103 ash control was 2.492 F (SE = 0.020, $p < 0.001$) before tree removal. The mean air temperature difference between the sun control and the 103 ash control was 1.944 F (SE = 0.032, $p < 0.001$), which was a 0.55 F decrease in the overall weather differences after tree removal.

Discussion:

Overall, we found that the removal of the two ash trees had a measurable and significant effect on ambient air temperature. We found at least a 0.33 - 0.88 F average increase of mean air temperature with ash tree

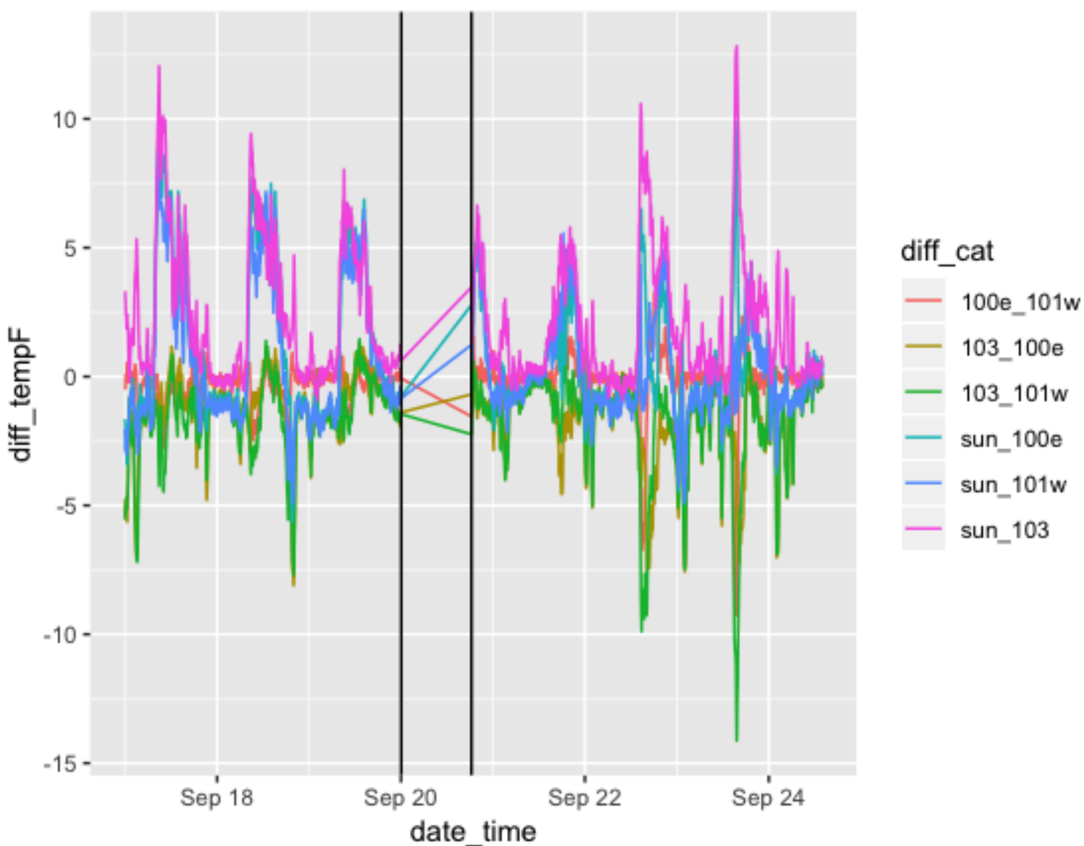

Figure 5. Time series of the differences in temperature among sensor pairs for before tree removal (Sep 17-19, 2018) and after removal (Sep 21-23, 2018). Time between the two black vertical lines represents treatment tree removal and data was not recorded.

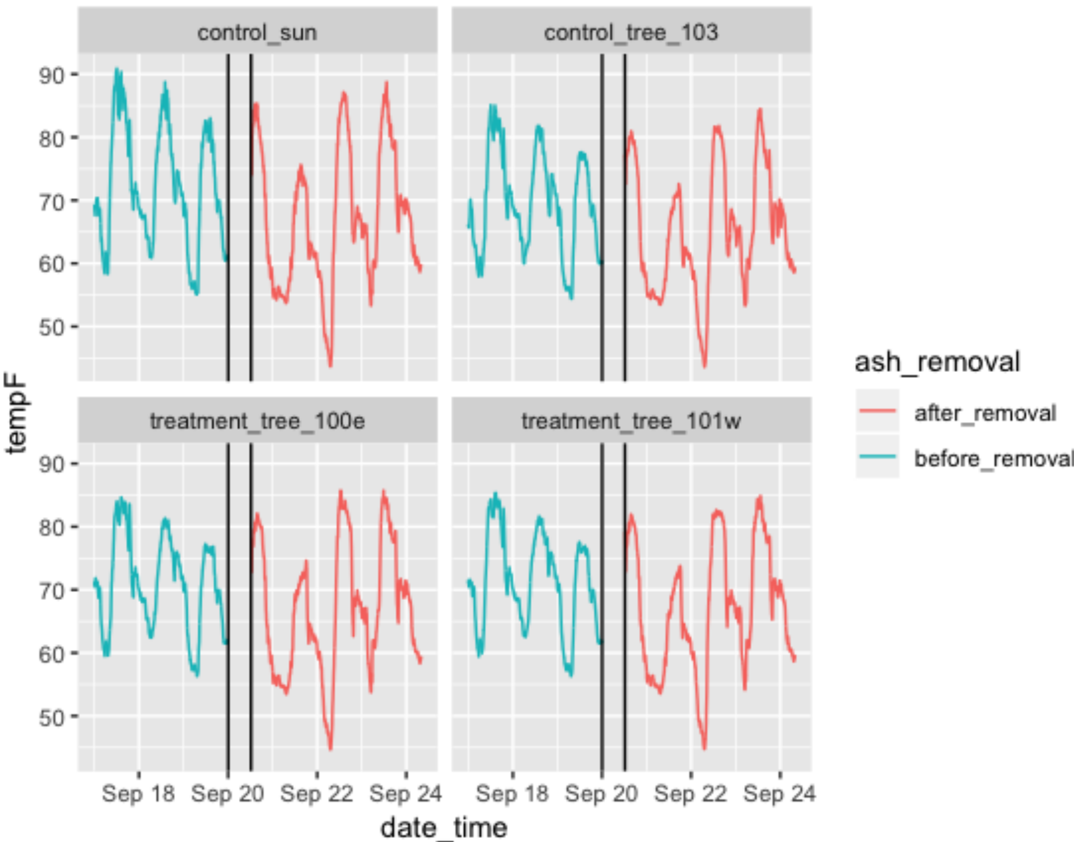

Figure 6. Temperature values from the four sensors under the two treatment ash trees that were removed (101w, 100e), the control ash tree (103), and the sun control before tree removal (Sep 17-19, 2018) and after removal (Sep 21-23, 2018).

removal relative to the green ash trees and sun control sensors, respectively. The average difference between the sun and shade control trees was 2.219 F, suggesting that the remaining tree canopy surrounding the removal site likely provides substantial cooling benefits to a patch of missing canopy. The sun and shade control sensor differential of 2.2219 F is an expected value given past study of air temperature under 10 tree species in Taiwan parks demonstrated that unshaded open space is 1.152-4.05 F higher compared to shaded similar areas with tree canopies (Lin and Yin 2010). In the case of our study location at Boulder Creek, the air temperature differences after ash tree removal have been partially obscured by a "creek effect" (Hathway and Sharples 2012). All sensors were within an 80 m buffer area in which water and relatively dense vegetation may have affected the results. The variation in average pre/post temperatures differences between the treatment and control trees confirms a need for larger replicated study of the immediate effects of ash removal.

Other metrics could be used to further explore the effect of tree canopy and associated removal on air temperature. The analysis presented in this study focused on overall mean differences before and after the tree removal. Daily aggregates of air temperature or minimum and maximum air temperature values (see Figure S1 and S2) could also be analyzed to further tease out before and after ash removal differences. We found air temperatures under the treatment trees that were 2.5 meters apart to be slightly different before and after ash removal with the 101w tree logged higher maximum temperatures than the 100e treatment tree (Figure S1). There was also a difference in mean temperature between the two treatment trees and the control tree before removal. The effect of the Boulder Creek microclimate or the position of the sensor relative to remaining vegetation may partially explain the difference in average temperatures between the two treatment sensors and between the treatment and green ash control sensor. Further analysis of this data pertaining to diurnal/nocturnal trends could illuminate more about these differences.

Future studies could extend this experimental design to encompass a greater number of replicates and environmental site diversity to gain more information about the spatial and temporal dynamics of tree shading. With the loss of such a high percentage of *Fraxinus sp.* canopy in Boulder, other existing air temperature sensor networks could be leveraged to calculate the temperature differences with ash tree removal and compared with a centrally located reference sensor. Future research could also investigate the impact of varied degrees of foliage loss on air temperature. Trees that have the majority of their canopy foliage lost compared to trees displaying less advanced symptoms of the EAB to understand more about temporal ecosystem service benefits. Furthermore, larger-scale studies could provide comprehensive baseline values for EAB-mortality related tree restoration goals. Larger geographic coverage of air temperature may yield predictions for urban heat dynamics with tree shade loss to aid in decision-making for future tree removal planning. Finally, if air temperature increases are found to be close to 1 degree or more due to canopy loss, then municipalities and homeowners may consider intermediate intervention plans for shade while new trees mature. Man-made structures may be necessary for mitigating human health concerns such as heat stroke, and summertime energy demand increases from air conditioning.

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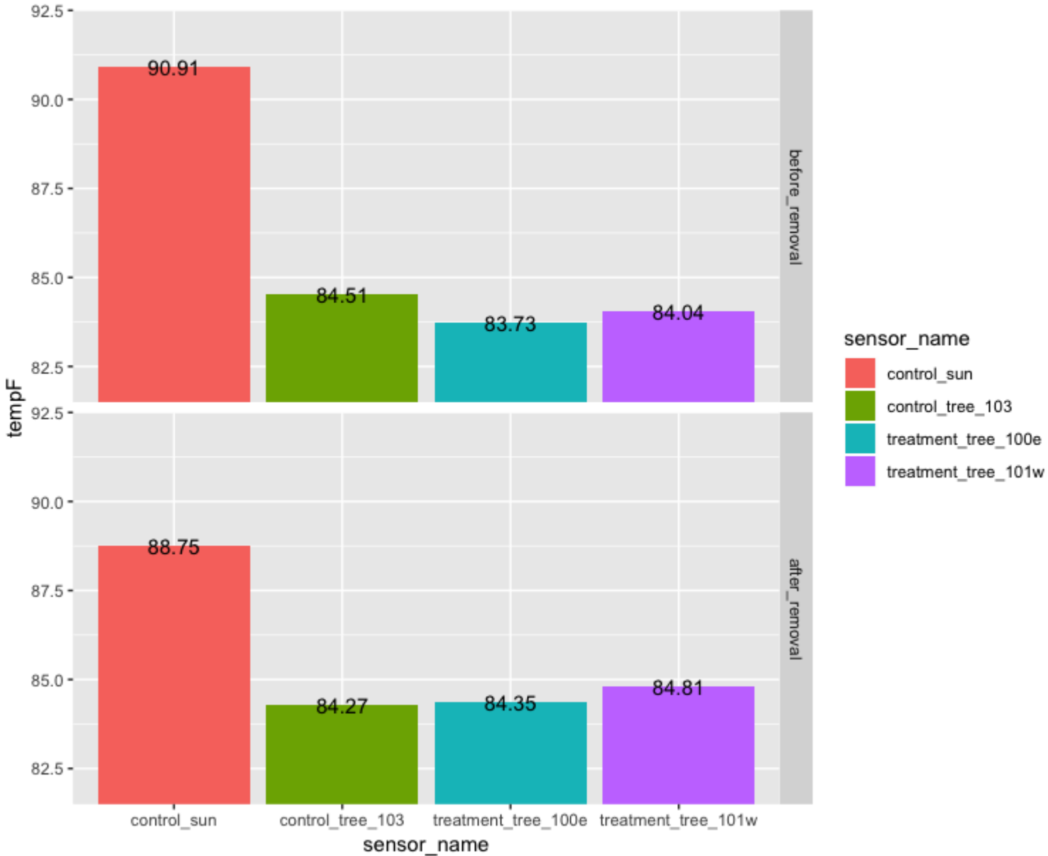

Figure S1. Maximum temperature values for the two treatment ash trees that were removed (101w, 100e), the control ash tree (103), and the sun control with no tree canopy before treatment tree removal on September 17 at 1:22pm and after removal on September 22, 7:12am.

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Supplementary Figures

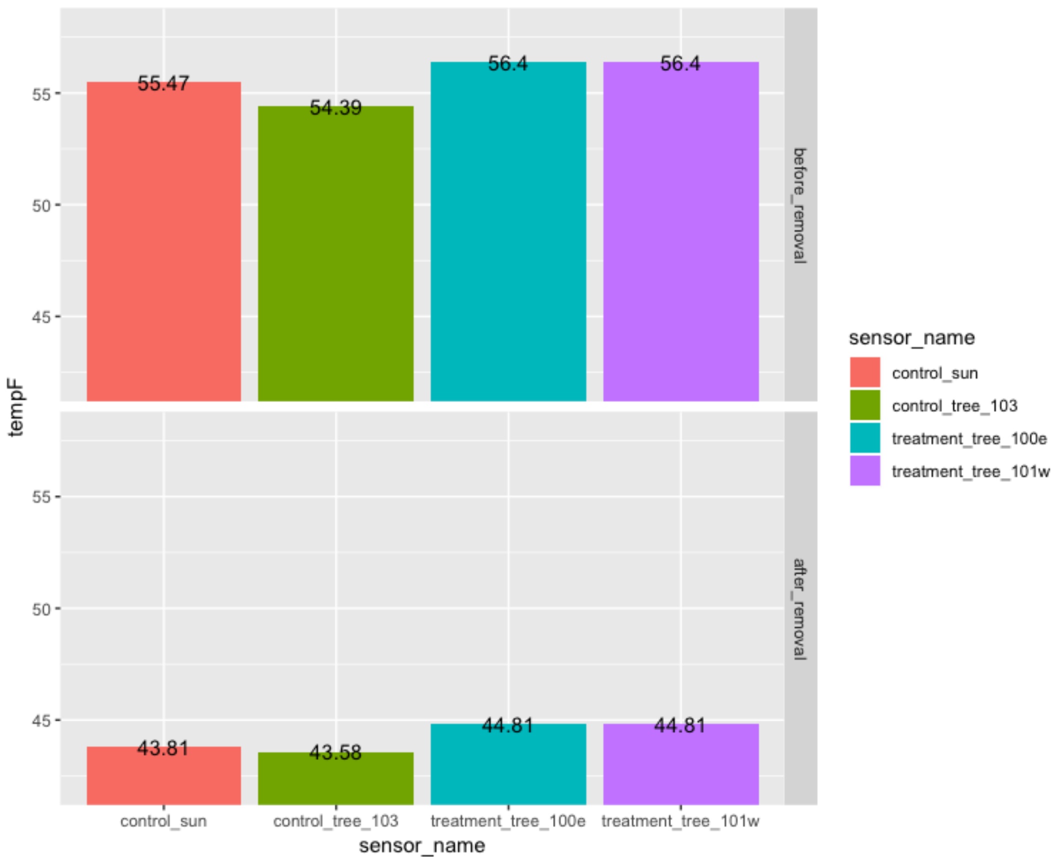

Figure S2. Minimum temperature values for the two treatment ash trees (101w, 100e), the control ash tree (103), and the sun control before removal on Sept 19 at 7:25am and after removal on on September 22 at 7:12am

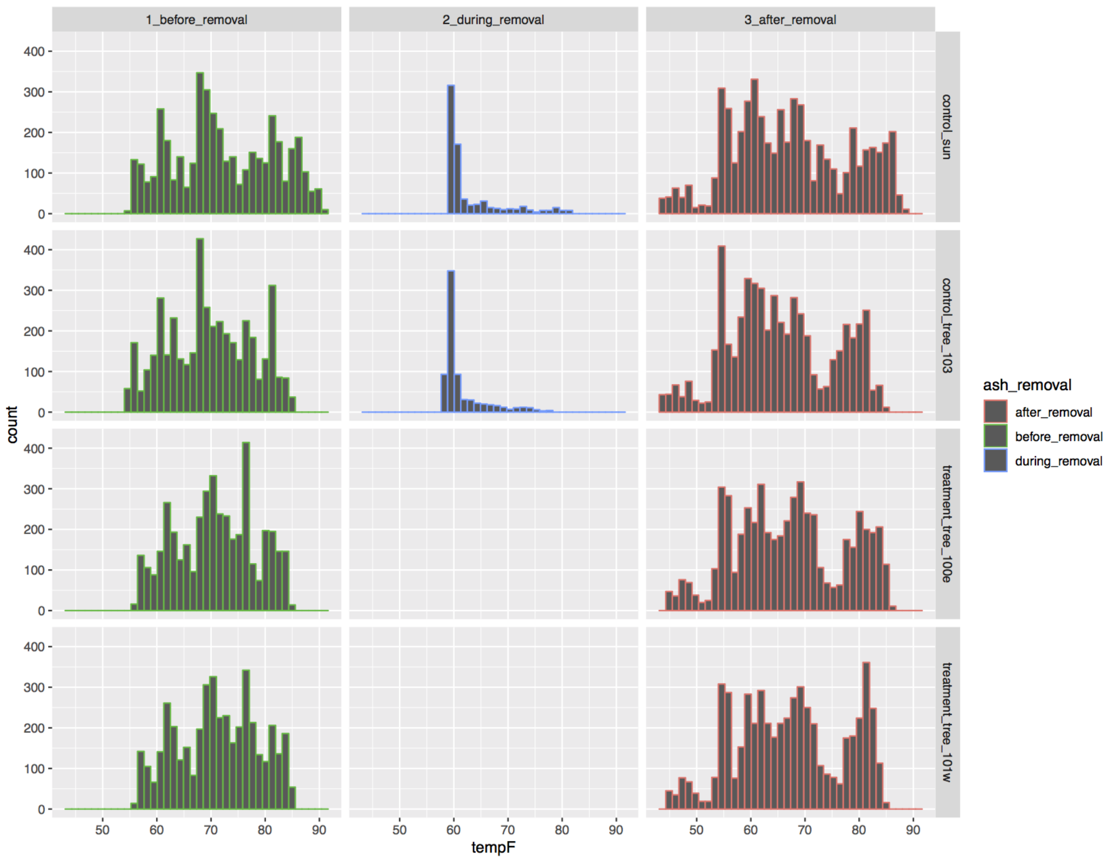

Figure S3. Temperature data from the four sensors under the two treatment ash trees that were removed (101w, 100e), the control ash tree (103), and the sun control with no tree canopy showing before tree removal, during removal, and after removal.

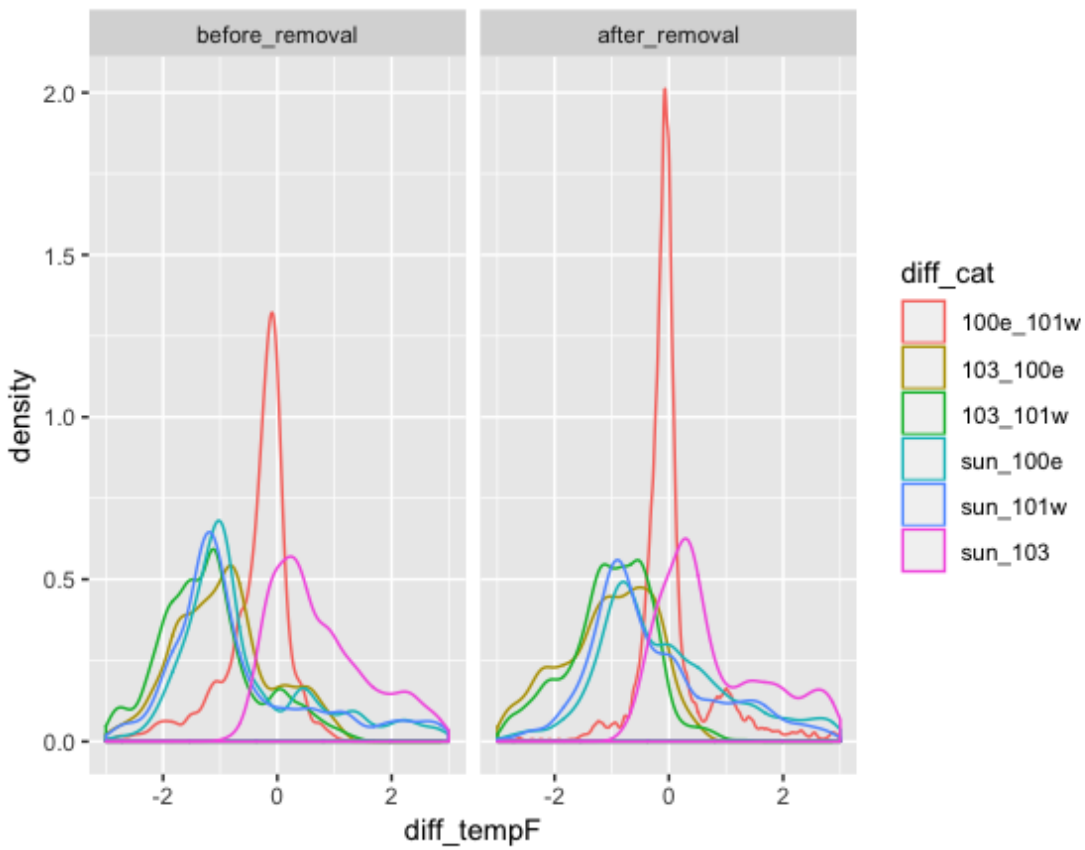

Figure S4. Densities of the difference in temperature among sensor pairs.