City of Austin

Abiotic Differences between Canopy and Open Habitats Within Juniper-Oak Ecosystems

Balcones Canyonlands Preserve Annual Report

Datalogger stand in a closed-canopy site (© Cristina Campbell)

City of Austin, Austin Water
Wildland Conservation Division
Balcones Canyonlands Preserve
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Summary

We report summarized preliminary data on an observational field study identifying abiotic differences between two distinct habitats found in a juniper-oak woodland ecosystem on the City of Austin's Balcones Canyonlands Preserve (BCP). We looked at the difference between canopy habitat located just inside the edge of forested habitat dominated by juniper and oak and adjacent unshaded open habitat dominated by grass species at six different sites. Our study was implemented on five City of Austin BCP tracts – Cortaña, Double J & T North, Double J & T South, Sam Hamilton Memorial Reserve West, Reicher Ranch, and Whirlpool Cave. We collected atmospheric data which included ambient air temperature, relative humidity and dew point, soil temperature and soil moisture, and light data in the form of exposure value, a correlate of light intensity. We also collected auxiliary soil temperature and ambient air temperature from a seventh site, Vireo Preserve. Our dataset ranges from June 2021 to September 2022.

Based on our datasets, canopy habitat supported cooler and more moist conditions during hot summer months. Daily maximum air temperatures in the open habitats were on average 2.7°F warmer throughout the entire year (90.1°F) than under canopy (87.4°F), and 6°F warmer during summer months (107°F in the open and 101°F under canopy). When analyzed on a granular level, the hourly air temperatures in the open habitats were both hotter and cooler throughout the day both in the summer and the winter months. Average hourly air temperature throughout the year was generally hotter in the summer for the open habitats and less variable during the rest of the year. Average summer (June-August) relative humidity was 62.4% in the open habitat and 63.9% in canopy habitat. Summer (June-Aug) month air temperatures and relative humidity differed both by habitat and by site. There was a mild inverse correlation between soil temperature and soil moisture in both the open and canopy habitats. Maximum soil temperatures during summer were 87.7°F under canopy, 108.7°F in native bunchgrass, and 121.3°F in barren caliche. Soil temperatures under canopy were more stable. Temperatures varied by 20°F in caliche, 16.1°F in grass, and 5.4°F in canopy on average over the course of a day.

This was a pilot study comparing air temperature, relative humidity, soil temperature, and soil moisture in paired open and canopy habitats. The continued collection of data can help quantify the effects of native tree canopy on local climate and vegetation. We also hope to add vegetation water content data to this dataset in the future to better understand drought conditions that can lead to die-off events.

Introduction

Our studies were implemented on the City of Austin's BCP located in central Texas on the eastern edge of the Edwards Plateau. The region is characterized by juniper-oak woodlands (*Juniperus ashei–Quercus sp.*) interwoven with pockets of open grassland areas (Fernando et al. 2016). Average yearly precipitation for the last 22 years is 896 mm (calculated from NOAA's website https://www.weather.gov/). The endangered golden-cheeked warbler (*Setophaga chrysoparia*) primarily breeds in the mature, closed-canopy forests of the BCP. The City of

Austin and Travis County actively manage the BCP along with several other public and private entities, including the Lower Colorado River Authority, The Nature Conservancy, Travis Audubon Society, and St. Edwards University/Wild Basin.

Our unique juniper-oak woodlands are an understudied ecosystem. The eastern edge of the Edwards Plateau sits over rocky shallow soil and karst limestone and is an important location of aquifer recharge (Leite et al. 2020, Kukowshi et al. 2013). In this mesic region of juniper-oak woodlands the vegetation structure between the wooded areas and unshaded open areas creates two distinct habitats whose structure and function have different effects on wildfire risk, seed germination and plant growth, and water infiltration (Leite et al. 2020, O'Donnell et al. 2020). In our dynamic ecosystem there is ongoing juniper recolonization of open areas, and these vegetation shifts exert important climate-ecosystem feedbacks (Adams et al. 2009). Studies are expanding on the effects that vegetation cover has on climate (Hansen et al. 2013, Duveiller et al. 2018). A climate-simulated model based on the biophysical variables of albedo, leaf area index, vegetation cover and surface roughness found in the southern Great Plains in Texas showed that woody colonization led to higher rainfall and slightly increased air temperatures (although not significantly higher) (Ge and Zou, 2013). Using global satellite data, Prevedello et al. (2019) found that evapotranspiration and albedo mediated local land surface temperature, and that forestation led to a cooling effect (especially in tropical and temperate regions). Many of these studies focus on other regions and ecosystems, so it is important to add to these collective studies with data from the Balcones Canyonlands ecoregion.

Our study was implemented on the following BCP tracts – Cortaña (CT), Double J & T (JJT) North and South, Sam Hamilton Memorial Reserve West (HM), Reicher Ranch (RR), and Whirlpool Cave (WH) (Figure 1). A separate dataset of soil temperatures was collected from the Vireo Preserve (VP). Data were collected along the edge of wooded areas, hereafter referred to as canopy habitat. Canopy habitats were dominated by Ashe juniper (*Juniperus ashei*) and plateau live oak (*Quercus fusiformis*) and to a lesser extent Texas red oak (*Quercus buckleyi*) and shin oak (*Quercus sinuata* var *breviloba*). The most common co-occurring species were cedar elm (*Ulmus crassifolia*), Texas persimmon (*Diospyros texana*), agarita (*Mahonia trifoliata*), Texas mountain-laurel (*Dermatophyllum secundiflorum*), yaupon (*Ilex vomitoria*), twist-leaf yucca (*Yucca rupicola*), silk tassel (*Garrya ovata*), evergreen sumac (*Rhus virens*) and cedar sedge (*Carex planostachys*). The vegetation at the canopied WH site differed from the other sites. While there were juniper and oaks, WH was dominated by a stand of young cedar elm, with several persimmon. The WH site also contained invasive Japanese privet (*Ligustrum japonicum*) and nandina (*Nandina domestica*). The open habitats were dominated by grass species, including seep muhly (*Muhlenbergia reverchonii*), little bluestem (*Schizachyrium scoparium*), slim tridens (*Tridens muticus*), hairy grama (*Bouteloua hirsuta*) and big muhly (*Muhlenbergia lindheimeri*). The invasive species King Ranch bluestem (*Bothriochloa ischaemum*) was also present on several sites.

We have outlined the abiotic differences between two distinct habitats (canopy and open) found in our juniper-oak woodland ecosystems. At VP, we subdivided the open habitat into native bunchgrass (little bluestem) and barren caliche with no vegetation and collected soil temperature data from these and canopy habitat.

We collected ambient air temperature, relative humidity and dew point using EZ-logger dataloggers (Lascar EL-USB-2). Dataloggers were mounted on a 1.5 m PVC pipe that was placed over and held up by a ~1 m metal rebar driven halfway into the ground. The PVC stand was covered with a 55 cm diameter plastic lid to protect the dataloggers from direct UV light and rain. They were raised 1.5 m off the ground according to the NOAA guidelines (https://www.nws.noaa.gov/directives/sym/pd01013002curr.pdf). Data were recorded hourly at the beginning of each hour. The data were downloaded in the field onto EasyLog software via a computer every three to six months. All dataloggers were set up between June 2021 to August 2021. Although dew point was collected, this variable is not being used here as it is correlated to relative humidity.

We placed 12 dataloggers at six different sites on City of Austin tracts (Cortaña, JJT-North, JJT-South, Reicher Ranch, Sam Hamilton, and Whirlpool) (Fig. 1). Locations were mapped using a handheld Garmin global positioning system (GPS) unit and the mapped locations were made in ArcGIS Pro 2.1.94 (ESRI). These sites were selected to provide a variety of spatial coverage across the BCP while providing replication. Dataloggers were paired at each site, with one datalogger in open habitat and one under canopy. Dataloggers in open and canopy habitats ranged 10-30 m apart except for the WH site where the pair of dataloggers were 55 m apart. Dataloggers in canopy habitats were inset 4-10 m under the canopy edge (or canopy drip line) of discontiguous patches of trees. Canopy habitats varied by patch size and stand age. Open habitats were centered in gaps between wooded patches. Light intensity was measured in exposure value (EV) using an International Light Technologies ILT350 Light Meter and ranged from 82,404 - 117,034 in the open habitat and 2,585 - 35,087 in the canopy habitat.

Some data were lost because of datalogger failure due to storm events and once because of vandalism. The two sites missing data are CT and WH. The CT site is missing open and canopy data from November 10, 2021 – August 8, 2022. The WH site is missing open data only from October 22, 2021– June 8, 2022. The full dataset is n = 100,342, n = 49,846 for open and n = 50,496 canopy.

Data from the dataloggers were filtered to exclude the 20:00 hour (we used a 24-hour system) during the summer analysis, 18:00 during the winter months and the hours of 18:00-20:00 were removed for the 12-month analysis due to sunlight potentially hitting the dataloggers directly while the sun was setting in the sky. The air temperature analysis uses average daily temperature, maximum daily temperature, or average hourly temperature.

Soil temperature and soil moisture were taken using handheld probes (Hanna Instruments Soil Thermometer and ExTech Soil Moisture Meter). Data were taken roughly every 2 weeks from mid-July to mid-October 2022. Light intensity was taken approximately 2x/month from August to October 2022. Soil temperature at VP was collected in canopy and two types of open habitat (native bunchgrass, barren caliche) using a Greenco stainless steel compost thermometer with a 50.8 cm stem that was inserted through a PVC pipe and 3 cm into the soil. Daily readings were taken by BCP staff and volunteers twice a day, in the morning and afternoon.

Datalogger Sites

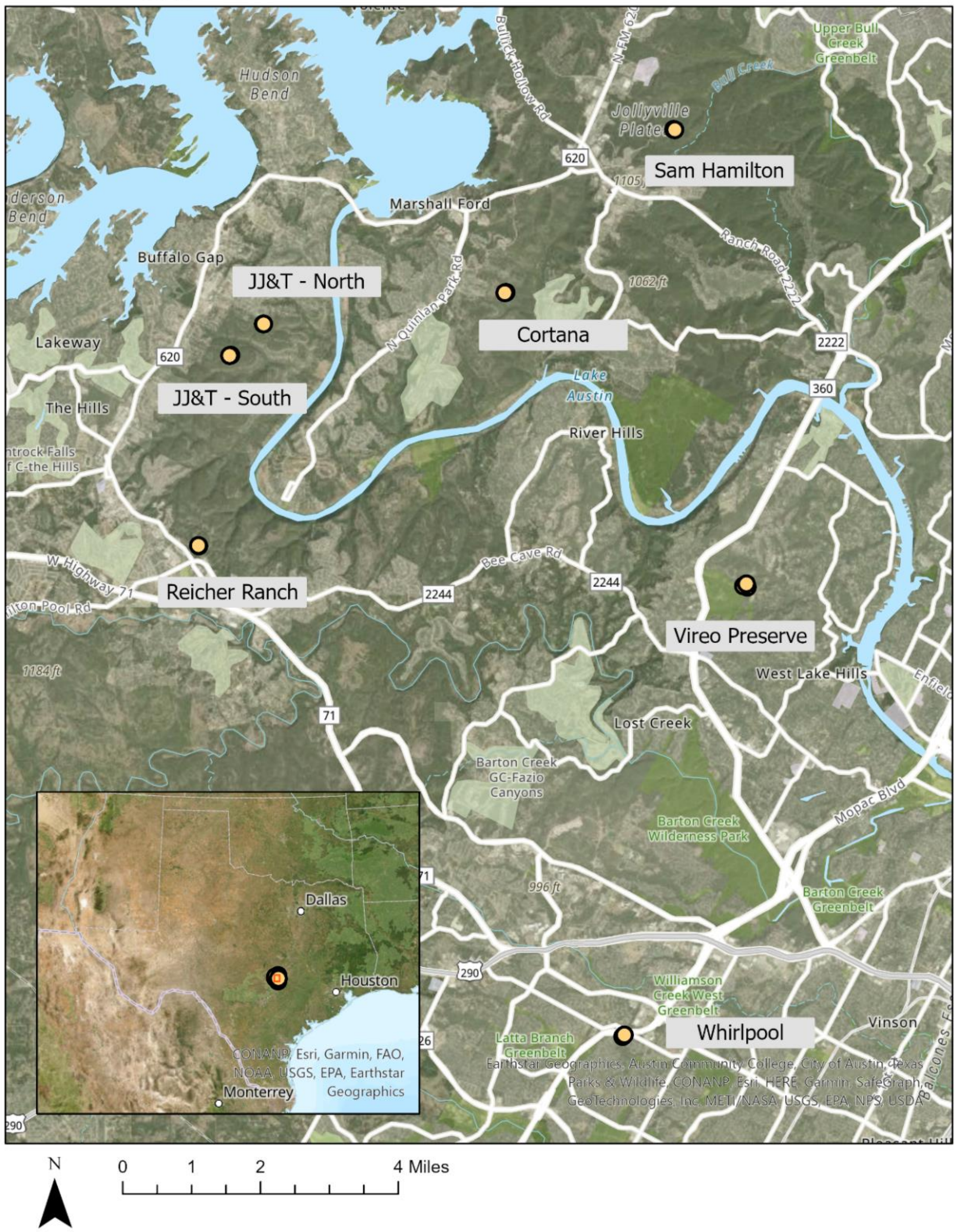

Figure 1. Location of all study sites. Paired dataloggers compared air temperature, relative humidity, soil temperature, and soil moisture in open and canopy habitats (CT, HM, JJT North and South, RR, and WH). Soil data from three habitats was collected from an additional site (VP). All sites are located on the Balcones Canyonlands Preserve, Texas.

Figure 2. Datalogger stands in open (left) and canopy (right) habitats.

Statistical Analysis

We determined that our dataset was non-Gaussian and variances were non-heterogenous using the Shapiro-Wilks test and the Levene's test. To compare our site temperature data, we used Wilcoxon sign-ranked T-tests. To find differences in site and treatment we ran a Scheirer-Ray-Hare test, the non-parametric equivalent of a two-factor ANOVA using the package "scheirerRayHare" followed by a Pairwise Bonferroi-adjusted comparison test, in place of Tukey's HSD for our multiple comparison procedure. Our soil correlations used the Spearman method. We fit afternoon soil temperature to afternoon ambient air temperature using a Rank-based estimation regression using the "rcompanion" and "Rfit" package. All statistical analyses and graphs were made in R studio version 2022.02.1.

Results and Discussion

Annual maximum air temperatures were higher in the open habitat. A histogram of daily maximum air temperatures displays the ranges and frequency of daily highs over a 12-month period (Fig. 3). The annual average high for the open habitat was 90.1°F (range 33-120°F) and for the canopy 87.4°F (range 33-112°F). Both habitats have similar air temperature distributions at the lower end of the histogram, representing similar spans of cooler temperatures. However, the two habitats differ as the temperature gets warmer, in the open habitat there are more days with hotter temperatures.

The summertime (June-August) maximum daily air temperature highs for the open habitat was 107°F (range 81-120°F) and for the canopy was 101°F (range 85-112°F). A divergence in summer (June-August) air temperature frequency between the two habitats starts around 98°F, where the open habitat temperatures skew hotter. The highest frequency of days in the open habitat cluster around 106-108°F (156 days total), the highest frequency of days in the canopy habitat cluster around 99-101°F (202 days). A Wilcoxon sign-ranked T-test confirms that the daily maximum air temperatures are significantly different between the two habitats ($t = 18.49$, $df = 842.11$, $p = <0.001$). The summer (June-August) average relative humidity for the open habitat was 62.4% (range 18-100%) and for the canopy was 63.9% (range 21-100%).

Looking at the data on a more granular level shows that during summer months (June-August) the air temperature is hotter during the daylight hours of 9:00 – 19:00, with hourly averages ranging in a difference from 3.3-5.7°F between the two sites. Air temperature was cooler between the hours of 21:00 – 8:00, with hourly averages ranging in a difference from 0.2-1.4°F (Fig. 5). This trend follows for the winter months (December - February) (Fig. 6), where higher air temperatures are seen from 10:00 – 17:00, with hourly average ranging in a difference from 0.2 – 4.1°F. Cooler air temperatures were observed from 20:00 – 9:00, with hourly average ranging in a difference from 0.8 – 1.9°F.

A heatmap displays the average hourly air temperature by the hour for each month by habitat type (Fig. 7). The most obvious difference is the temporal variation in air temperatures between the months of June and September, where the open habitat stays hotter (above 100°F) for longer throughout the day. There was a difference in the summer (June-August) air temperature and precipitation between 2021 and 2022, with 2022 being warmer and drier.

A Scheirer-Ray-Hare test of habitat and site on summertime (June-August) air temperature shows that there is a significant difference among site and habitat type (Table 1). This indicates a true difference in air temperature between habitat type and that at least one site is different from the others. A Pairwise Bonferroi-adjusted comparison test revealed that one site pair (RR – HM) was not statistically different ($p = 0.50$). The site pair HM – JJT North fell just under the significance level ($p = 0.04$). Although there is a difference in air temperatures among sites, a boxplot of the air temperature shows a consistent pattern, with the canopy habitat showing a lower average temperature and more stable temperature distributions. This pattern holds for all sites except WH (Fig. 8). A Scheirer-Ray-Hare test shows an interaction effect, but when the WH site is removed from the analysis the interaction effect is not significant ($p = 0.39$). Like the air temperature analysis, a Scheirer-Ray-Hare test looking at habitat and site of summertime (June-August), relative humidity shows a significant difference among site and habitat (Table 2). A Pairwise Bonferroi-adjusted comparison test shows that one paired site (JJT North – HM) was not statistically different ($p = 0.41$). The site pair RR – HM were just under the significance level ($p = 0.04$). A consistent pattern in relative humidity among sites is demonstrated in the boxplot (Fig. 9), with the canopy showing a higher RH average and more stable air temperature distributions. This pattern holds for all sites except WH (Fig. 9). As with air temperature, running the Scheirer-Ray-Hare test on relative humidity shows an interaction effect, but when the WH site is removed from the analysis the interaction effect is not significant ($p = 0.44$). We were not expecting this divergent pattern in air temperature and relative humidity at the WH site. However, there are several factors that might explain the difference from the other five sites. WH is the southernmost site, the open datalogger sits in a shallow ravine with lower elevation which is located near a cave (~22 m), and this area tends to pool cool air. As stated above, the woody species composition in the canopy habitat at WH differs from the other sites.

A mild inverse correlation between soil temperature and soil moisture was found in both habitats using a Spearman's rank correlation, ($r = -0.41$, $p < 0.001$) in the open habitat and ($r = -0.25$, $p = 0.01$) in the canopy habitat (Fig. 10). Soil temperature averaged 84.8°F (range 58.3 – 113°F) in the open habitat and averaged 77.7°F (range 58.1 - 92.8°F) in the canopy, the soil moisture averaged 4.9 % (range 0 – 47.6 %) in the open and averaged 3.9 % (range 0 – 23.2 %) in the canopy. This may be explained by the difference in soil composition and compaction between the two habitats. O'Donnell et al. (2020) showed canopied sites have higher organic matter, ectomycorrhizal colonization and soil K and have a different soil composition than does the open area.

Soil temperature from our seventh site (VP) was taken from three different habitats. The caliche habitat averaged 96.2°F (range 60 – 121.3°F), the grass habitat averaged 88.9 °F (range 54.7 – 108.7°F) and the canopy averaged 77.5°F (range 54.7 – 87.7°F). A linear Rank-based estimation regression looking at afternoon data shows that ambient air temperature had a strong positive relationship with soil temperature in all habitats; caliche ($R^2 = 0.77$, $t = 15.69$, $p < 0.0001$), grass ($R^2 = 0.82$, $t = 19.33$, $p < 0.0001$) and canopy ($R^2 = 0.86$, $t = 25.95$, $p < 0.0001$) (Fig. 11). A boxplot shows the magnitude of daily soil temperature change between afternoon and morning soil temperatures, under canopy soil temperatures are more stable and less influenced by air temp than the other two habitats. (Fig. 12). The soil temperature warmed on average 20°F (range 0 – 49.7°F) in the caliche, 16.1°F (range 0 – 33.7°F) in the grass, and 5.4°F (range 0 – 10.3°F) in the canopy. On one occasion the soil temperature in the canopy habitat grew cooler by 2.7°F from the morning to the afternoon, and on three occasions the caliche grew cooler by 2, 3, and 6.7°F from the morning to the afternoon.

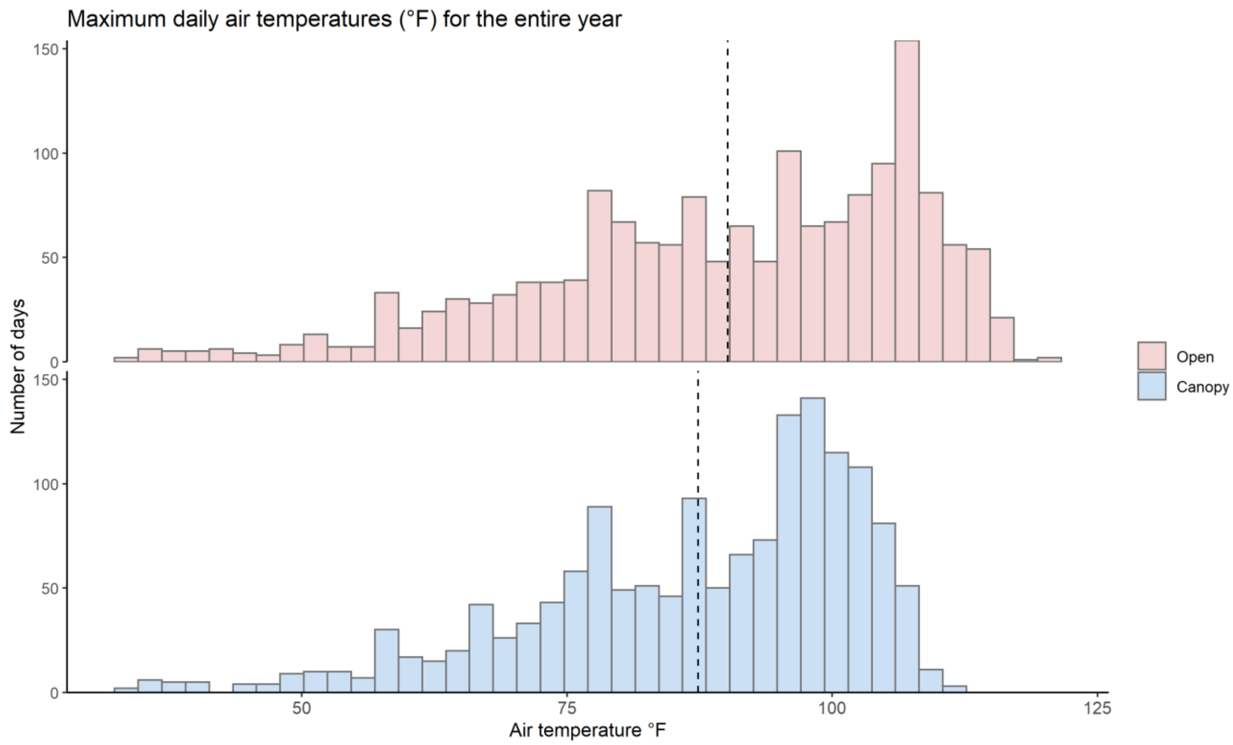

Figure 3. Histogram comparing the maximum air temperature of open and canopy habitat throughout the year for 2021 and 2022. The open histogram shows a slight shift to hotter daily maximum highs. The average maximum daily high in the open is 90.1°F and 87.4°F in the canopy.

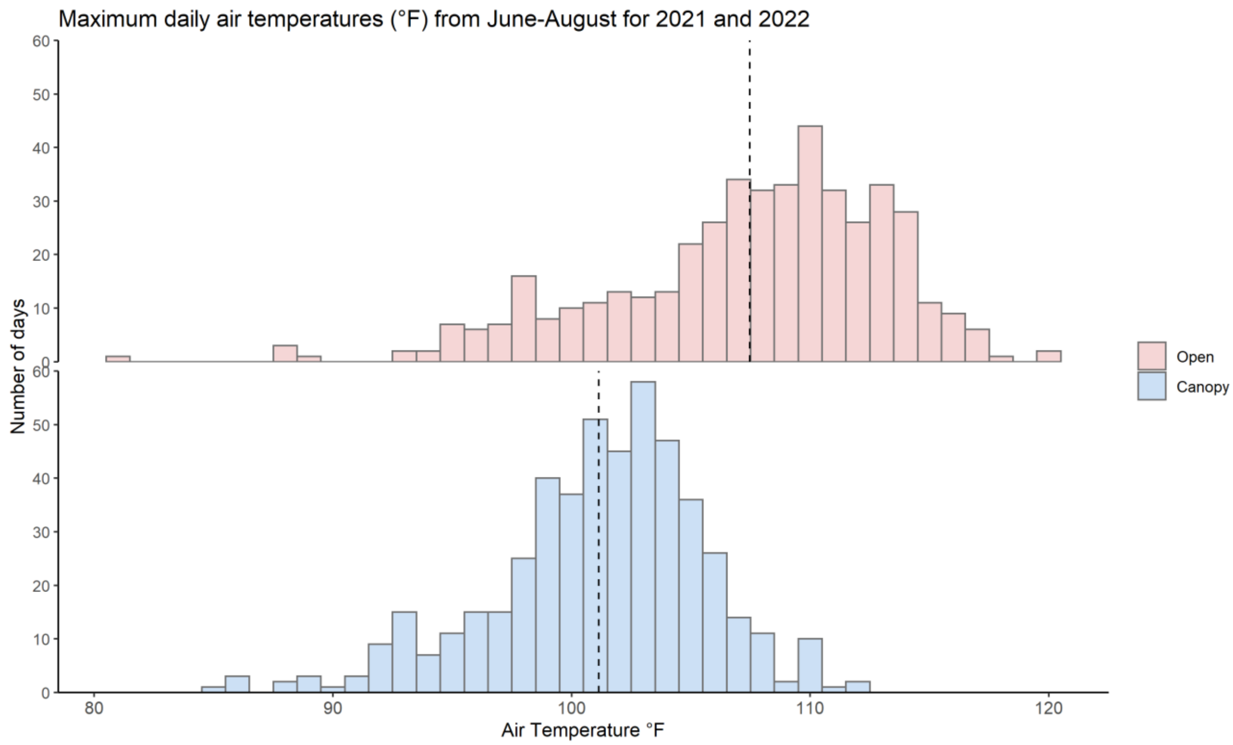

Figure 4. Histogram comparing the maximum air temperature of open and canopy habitat from June-August for 2021 and 2022. The temperature distribution of open canopy during the summer months shows a marked shift to hotter daily maximum highs. The average maximum daily high in the open is 107°F and 101°F in the canopy.

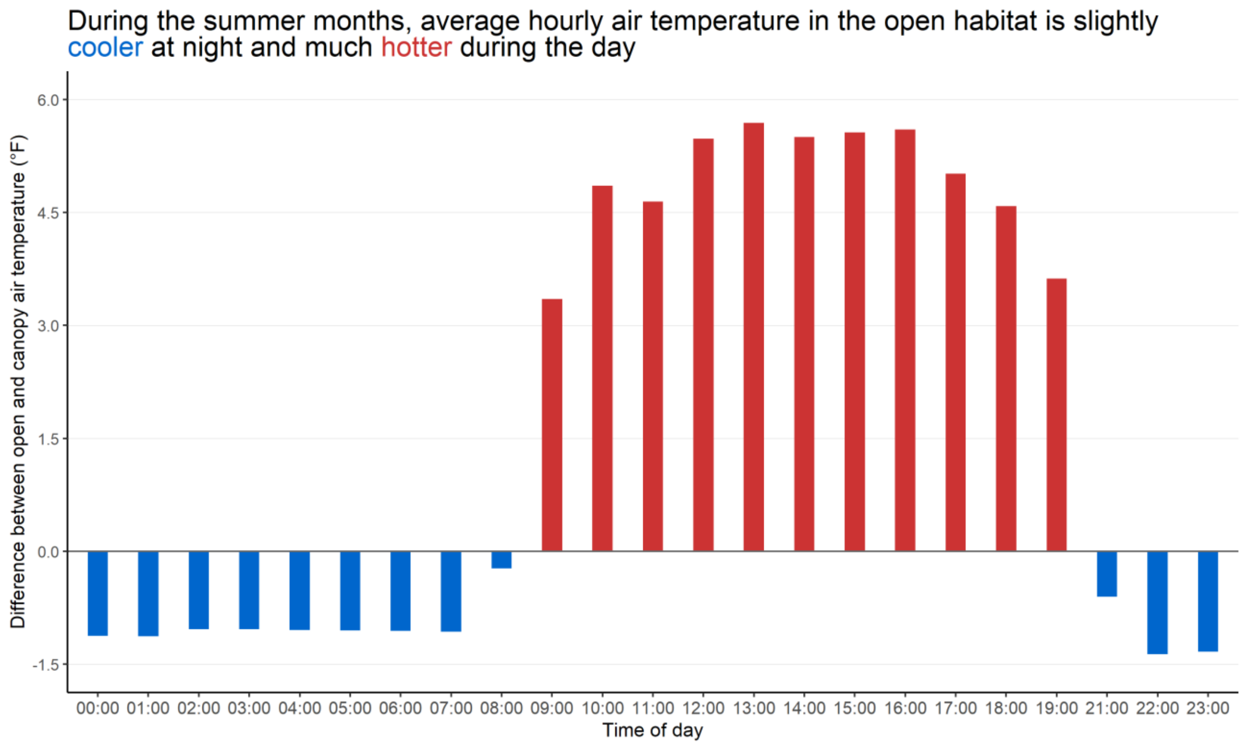

Fig. 5. Difference in hourly air temperatures between open and canopy habitat for the months of June-August for 2021-2022. The 20:00 hour has been removed to ensure sunlight that might have affected the datalogger is not influencing the air temperature readings.

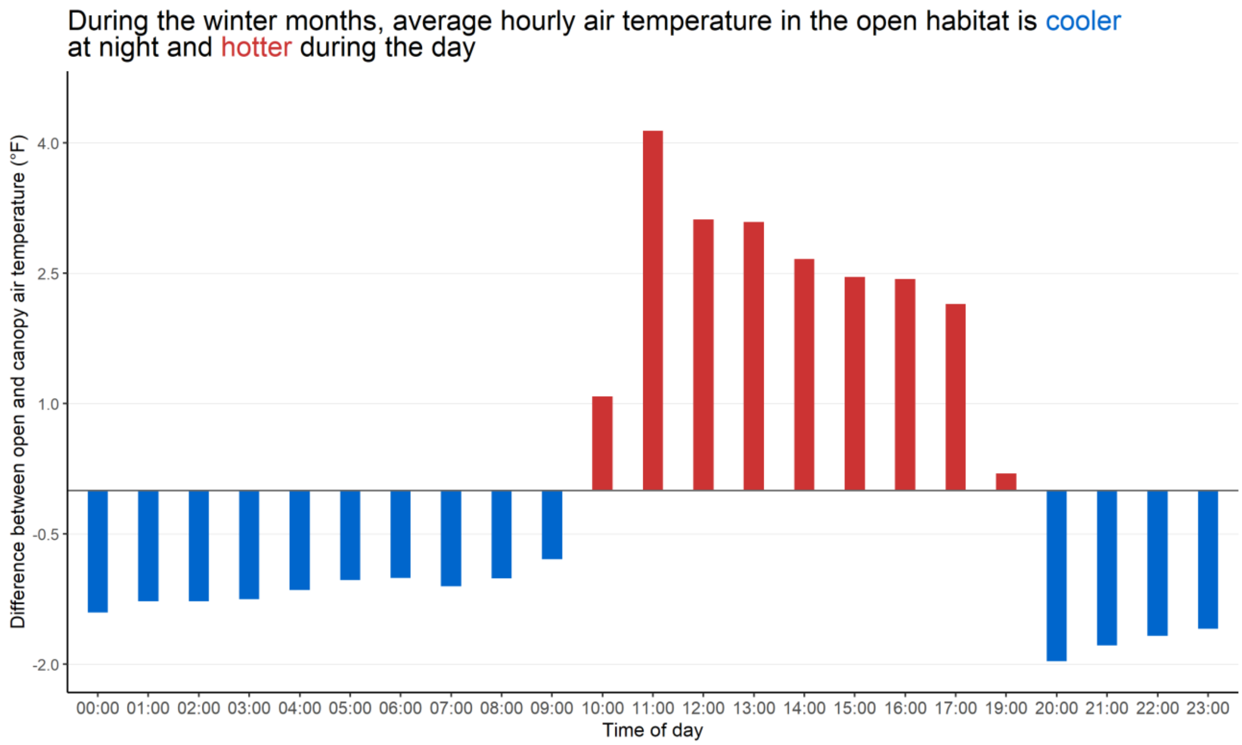

Figure 6. Difference in hourly air temperatures between open and canopy habitat for the months of December-February for 2021-2022. The 18:00 hour has been removed to ensure sunlight that might have affected the datalogger is not influencing the air temperature readings.

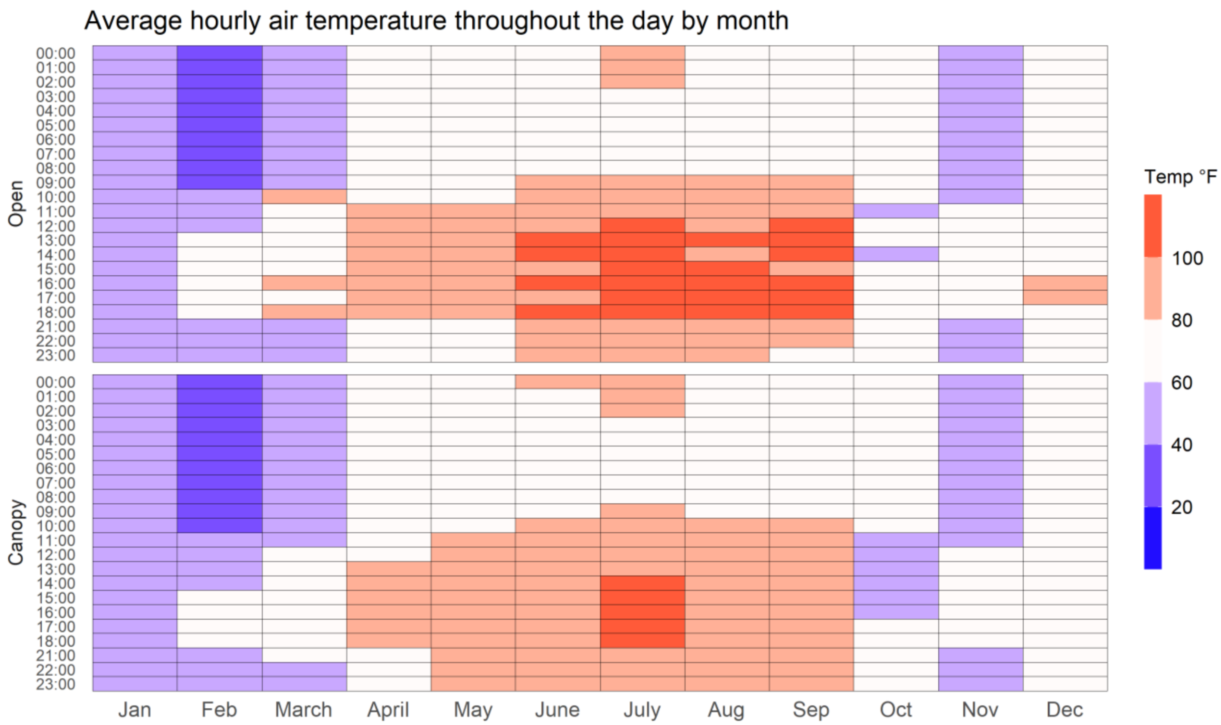

Figure 7. Monthly variation in air temperatures in open and canopy habitats. The heatmap presents the average hourly air temperature by month. Two hours (19:00 and 20:00) were removed due to the datalogger position relative to the setting sun. Open habitat (n = 13,281) and canopy habitat (n = 15,096).

Table 1. Scheirer-Ray-Hare test effect of habitat and site on summer (June-August) air temperature. When the WH site is removed the interaction effect is not significant (p = 0.39).

Source of Variation	**SS**	**df**	**H**	**p-value**
Habitat	2.35e+09	1	38.25	0.0001
Site	1.69e+10	5	276.15	0.0001
Interaction	6.14e+09	5	99.73	0.0001
Error	1.65e+12	27,178		

Table 2. Scheirer-Ray-Hare test effect of habitat and site on summer (June-August) relative humidity. When the WH site is removed the interaction effect is not significant (p = 0.41).

Source of Variation	**SS**	**df**	**H**	**p-value**
Habitat	4.21e+08	1	6.83	0.0008
Site	6.32e+10	5	1026.84	0.0001
Interaction	1.35e+10	5	219.38	0.0001
Error	1.59e+12	27,178		

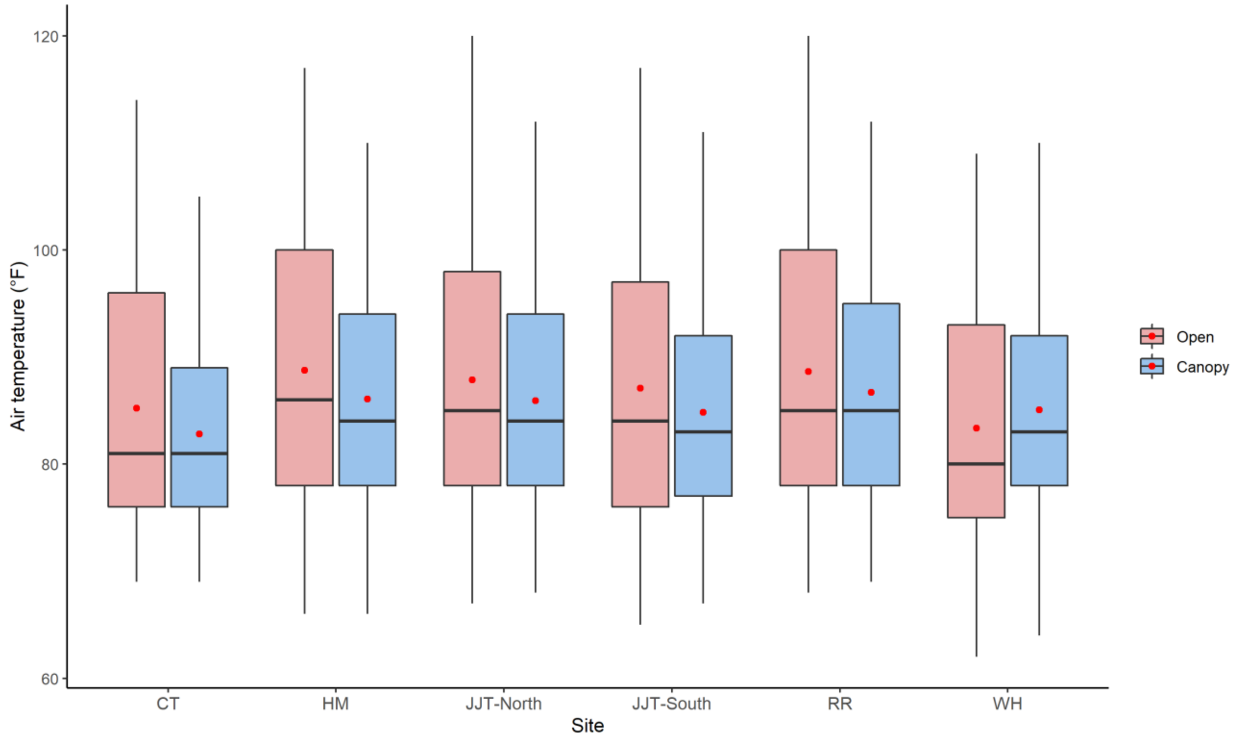

Figure 8. Boxplot of air temperature distributions showing the spread of summer (June-August) air temperatures over the period of 2021-2022. The horizontal line of the boxplot is the median, the box contains the 50th percentile, with whiskers no more than 1.5 times the interquartile range. Red points show the average air temperature for each habitat type.

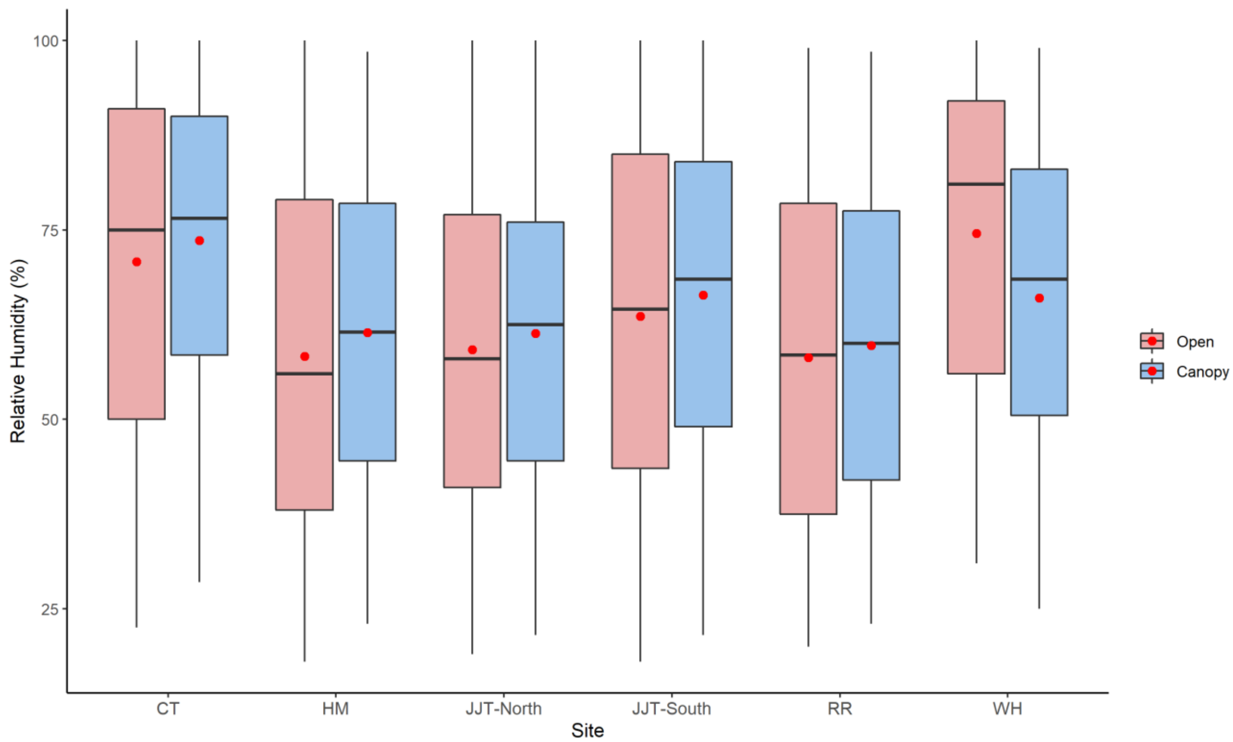

Figure 9. Boxplot of distributions showing the spread of summer (June-August) relative humidity over the period of 2021-2022. The horizontal line of the boxplot is the median, the box contains the 50th percentile, with whiskers no more than 1.5 times the interquartile range. Red points show the average air temperature for each habitat type.

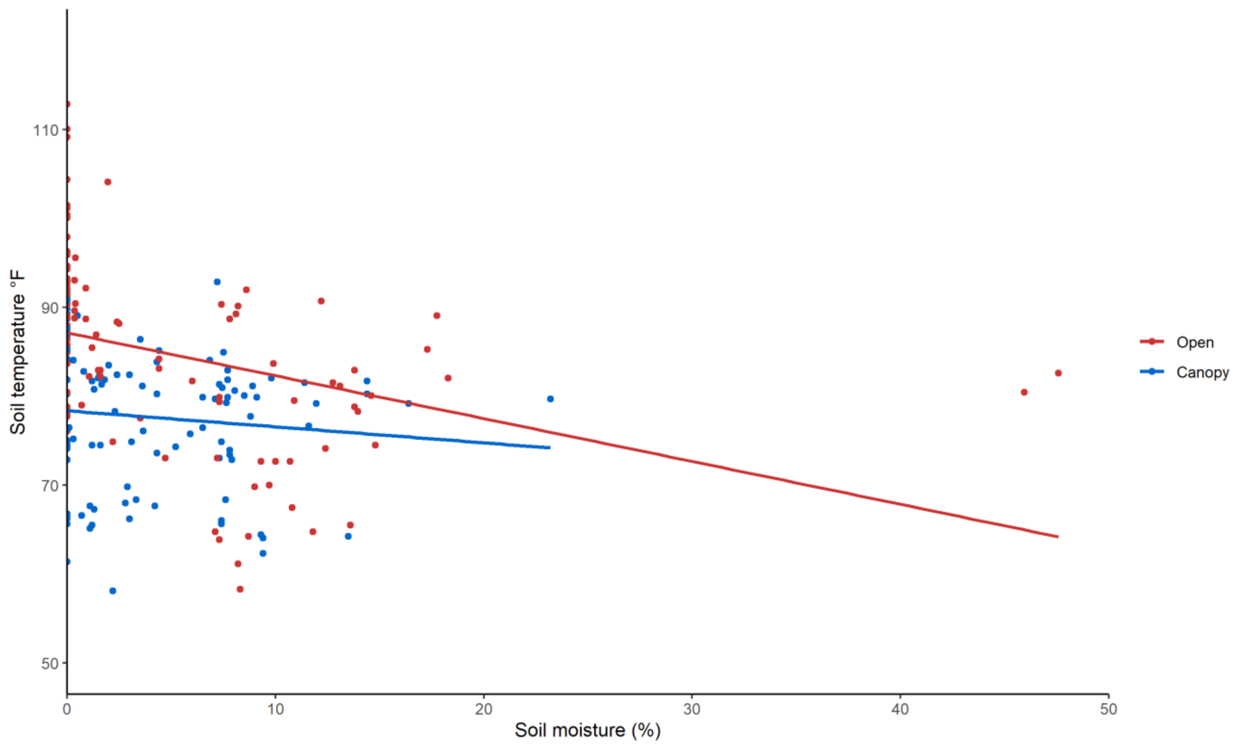

Figure 10. Correlation between soil moisture and soil temperature. A mild inverse relationship is shown in both habitats, open ($r = -0.41$, $p < 0.001$) and canopy habitat ($r = -0.25$, $p = 0.01$).

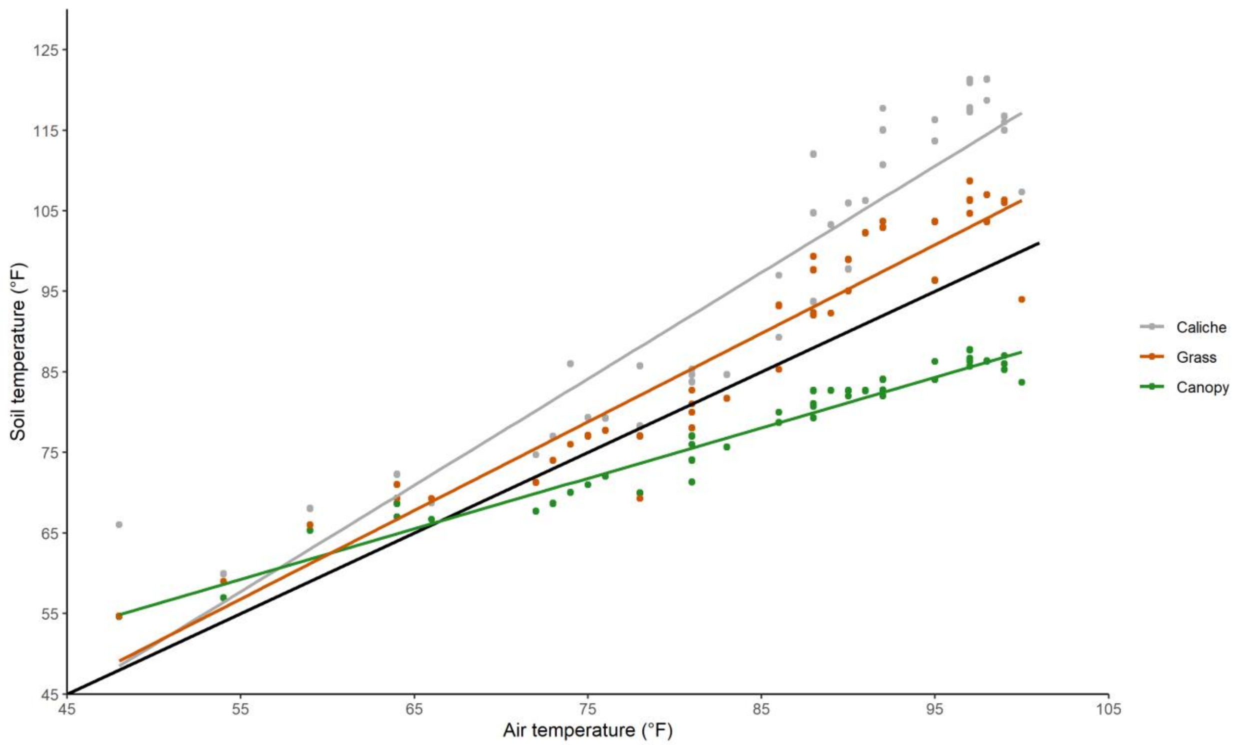

Figure 11. Model of air temperature and soil temperature. A significant positive relationship for all habitat types is shown; caliche ($R^2 = 0.77$), grass ($R^2 = 0.82$) and canopy ($R^2 = 0.86$). The black line is a 1:1 baseline.

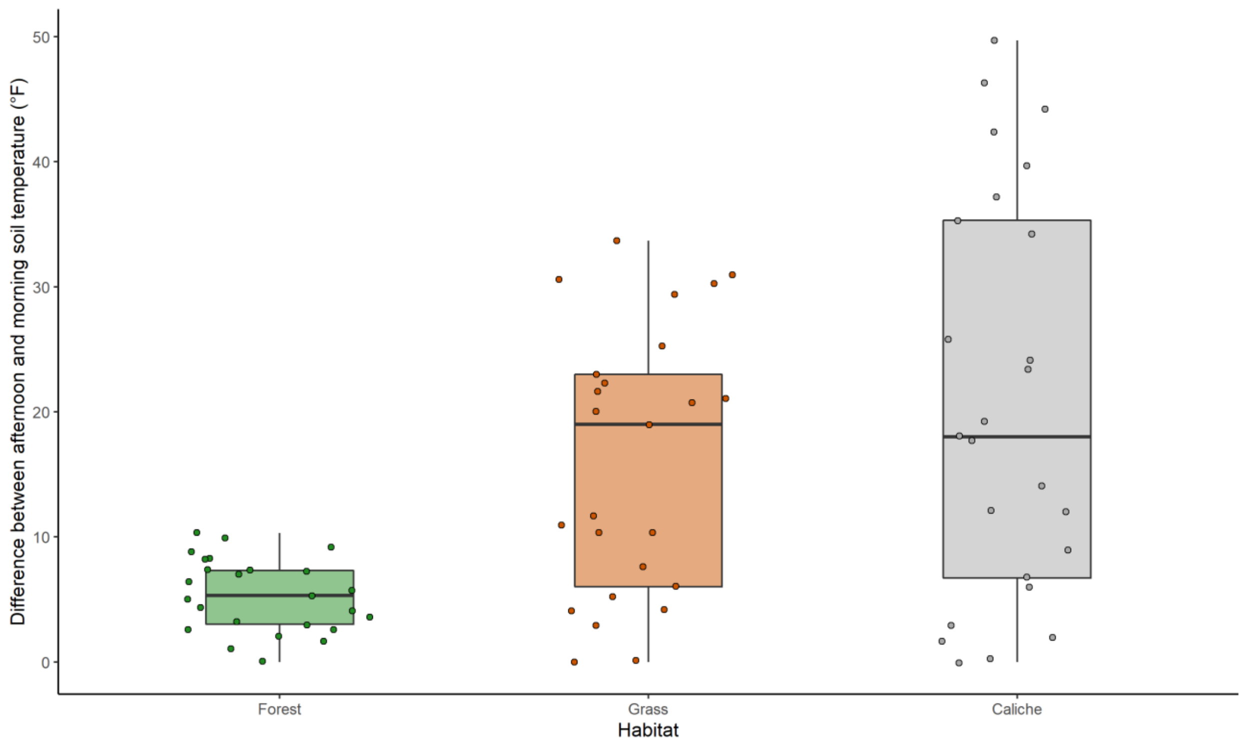

Figure 12. Boxplot of the difference between afternoon and morning soil temperatures between habitats. The horizontal line of the boxplot is the median, the box contains the 50th percentile, with whiskers no more than 1.5 times the interquartile range.

Conclusion

This study has demonstrated that air temperature, relative humidity, soil temperature, and soil moisture in two habitat types (canopy and open) located in the juniper-oak woodlands of the BCP differ from one another. These variables tend to be more stable in canopy habitat, which support cooler and more moist conditions during hot summer months. With our continued data collection and analysis, we can quantify the extent to which canopy can help ameliorate the effects of climate change, as well as effects on seed germination, plant growth and plant survival. As our light intensity data accumulate, we will analyze whether correlation in light intensity and air temperature among habitat types exists. We plan to pair this analysis to a study examining water content in juniper leaves (live fuel moisture) to help predict the likelihood of tree mortality.

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