Live Fuel Moisture Monitoring

Balcones Canyonlands Preserve Investigative Report IP 2022

Darrell Hutchinson
City of Austin, Austin Water Wildland Conservation Division
Balcones Canyonlands Preserve
Austin, Texas

INTRODUCTION

Live Fuel Moisture monitoring is a technique used by foresters to assess how available vegetation is to prescribed burn or wildfire. Live and dead fuel moisture values are used for various management purposes, including determining drought trends, formulating fire danger ratings, gathering input for fire behavior modeling, determining prescription parameters for prescribed burns, and determining the effects of fire in an ecosystem (Zahn and Henson 2011).

For describing wildland fire behavior, all combustible vegetation is considered fuel. A fuel's moisture value helps predict whether the vegetation will combust when exposed to an ignition source. Live Fuel Moisture Content (LFMC) is the water content present in live foliar material, expressed as a percent of the oven-dry weight of the fuel. Since water content exerts direct control on fuel ignitability, fuel availability, and fire spread, LFMC is an essential parameter of wildfire risk assessment (Sharma and Dhakal 2021).

Wildland Conservation Division began sampling LFMC in 2007 to better understand wildfire risk. By 2013, four sites were established, two of which were in north Austin on the Balcones Canyonlands Preserve (BCP) and two in south Austin. All four sites are characterized as open woodland dominated by Ashe juniper (*Juniperus ashei*). Vegetation samples are collected from Ashe juniper exclusively because it is ubiquitous and abundant.

In 2021, the BCP program expanded the LFMC monitoring effort to different habitat types to inform our understanding of potential wildfire behavior across the landscape. By summer 2022, we established three sites with three plots each roughly aligned along a transect to compare forest interior to open woodland/forest edge to open scrubland. To determine how LFMC was distributed within the forest interior, we compared growing tips from saplings, the lower branches of trees, and the upper branches of the tree canopy separately.

We predicted that forest interior plots would have higher LFMC values than forest edge, and open scrubland would have the lowest LFMC values of all three plots. Within the forest, we predicted LFMC would be highest among leaves collected near the forest floor, due to higher evapotranspiration and lower albedo occurring in the treetops.

METHODS

Wildland Conservation Division's live fuel moisture monitoring is a volunteer driven program. Volunteers collect vegetation samples by removing the growing tips of Ashe juniper trees and placing them into three separate cans. "Wet" weight of each can is calculated within 3 hours of collection using an electronic scale. All cans are placed uncovered in a drying oven for 24 hours at 100˚C, and then weighed again to calculate "dry" weight. Fuel moisture is the ratio of weight of water in the sample to the dry weight in the sample. For a full description of the methodology, see McCaw et al. (2018).

Two long term plots are located on the BCP at Cortaña and Reicher Ranch. Both plots experienced mechanical clearing and grazing during the mid-20th century, are dominated by Ashe juniper, and presently contain 40% - 70% canopy cover (McCaw et al. 2018). Although Cortaña and Reicher Ranch were originally described as 'open woodland', we categorize them as Ashe juniper-oak forest edge because fine scale vegetation sampling occurs along a forest edge bordered by open scrubby grassland at both sites.

In fall 2021, we established two new closed canopy, forest interior plots near the original forest edge plots at Cortaña and Reicher Ranch. The interior forest plots are dominated by Ashe juniper with 10% - 20% live oak (*Quercus fusiformis*), an average canopy height of 30 - 35 ft, and average canopy cover of 90% - 95%. We also established a new site with two plots at Kent Butler. The two plots are forest edge and forest interior. The forest edge plot runs along a boundary between closed-canopy, juniper-oak forest and a cleared power line corridor. The forest interior plot ranges from 25 - 100 yards from the forest edge and comprises 70% Ashe juniper, 10% live oak (*Q. fusiformis*), 10% shin oak (*Quercus sinuata* var. *breviloba*), and 10% Texas red oak (*Quercus buckleyi*) with an average canopy height of 35 - 40 ft, and average canopy cover of 96%.

In August 2022, we added an open plot to each of the three sites at Reicher Ranch, Cortaña, and Kent Butler. Open plots are defined as scrubland containing isolated Ashe juniper shrubs and small mottes of Ashe juniper and live oak trees between 10 - 20 ft. high surrounded by grasses. At Reicher Ranch, the dominant grasses are little bluestem (*Schizachyrium scoparium*), seep muhly (*Muhlenbergia reverchonii*), and tall grama (*Chondrosum hirsutum*); at Cortaña, the dominant grasses are little bluestem (*S. scoparium*), seep muhly (*M.* reverchonii), tall grama (C. *hirsutum*), and slim tridens (*Tridens mutius*); and at Kent Butler, the dominant grasses are King Ranch bluestem (*Bothriochloa ischaemium*) and green sprangletop (*Leptochloa dubia*).

We reduced the sampling area of the original edge plots at Reicher Ranch and Cortaña to focus on areas where relatively large patches of forest bordered open scrubland (Figures 1 - 3). The modified edge plots are contained entirely within the original edge plots. In our results, we separated LFMC data collected by staff and volunteers in the original edge plot from data collected by staff in the newer edge plots.

Also, beginning in August 2022, we investigated how LFMC was distributed vertically across strata within the closed canopy forest plots by collecting vegetation samples from Ashe juniper saplings, lower tree branches, and upper tree canopy branches separately. We defined saplings as 3 - 8 ft. tall. We collected from lower branches on trees 10 ft. or taller. We collected from the upper branches using a 14 ft. extendable pruning shear to trim the top branches in the lower crown on trees 25 - 30 ft. tall.

Rainfall data were collected using a precision rain gauge with mounting bracket set up in an open area near the edge plots. Each measure is the accumulation of rainfall since the previous collection date. The rain gauge at Kent Butler was mounted one sampling increment after LFMC data collection began in October 2021.

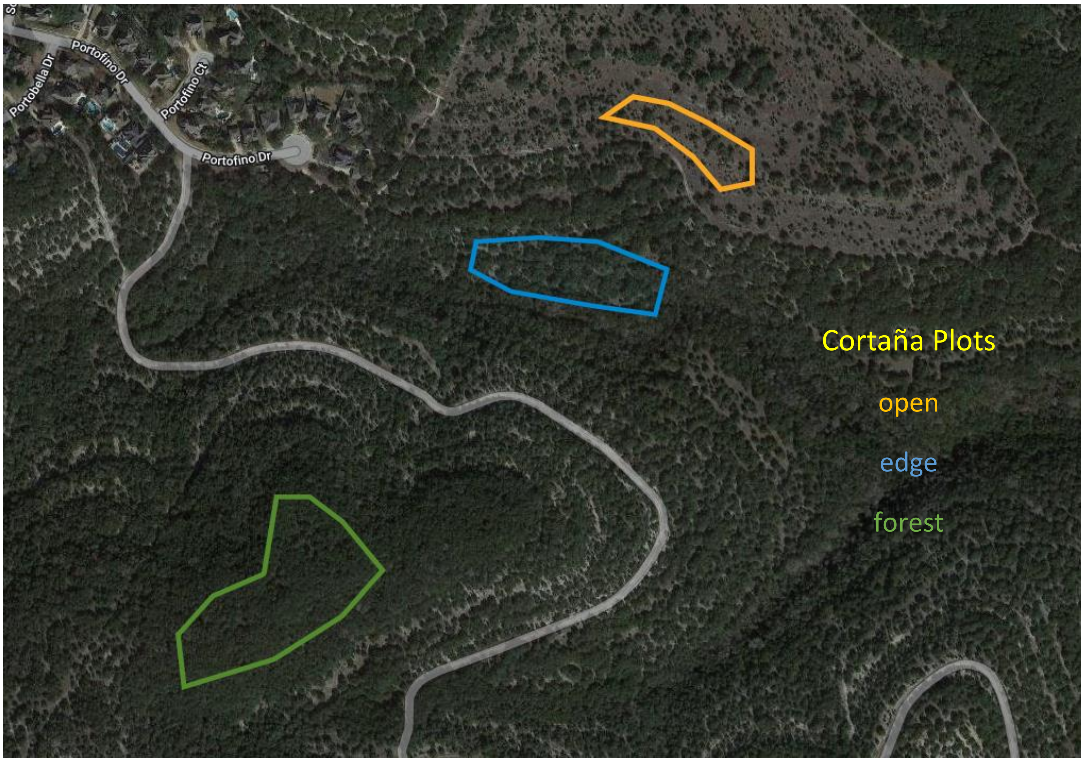

Figure 1. **Cortaña Live Fuel Moisture Content Plots** containing open, edge, and forest plots.

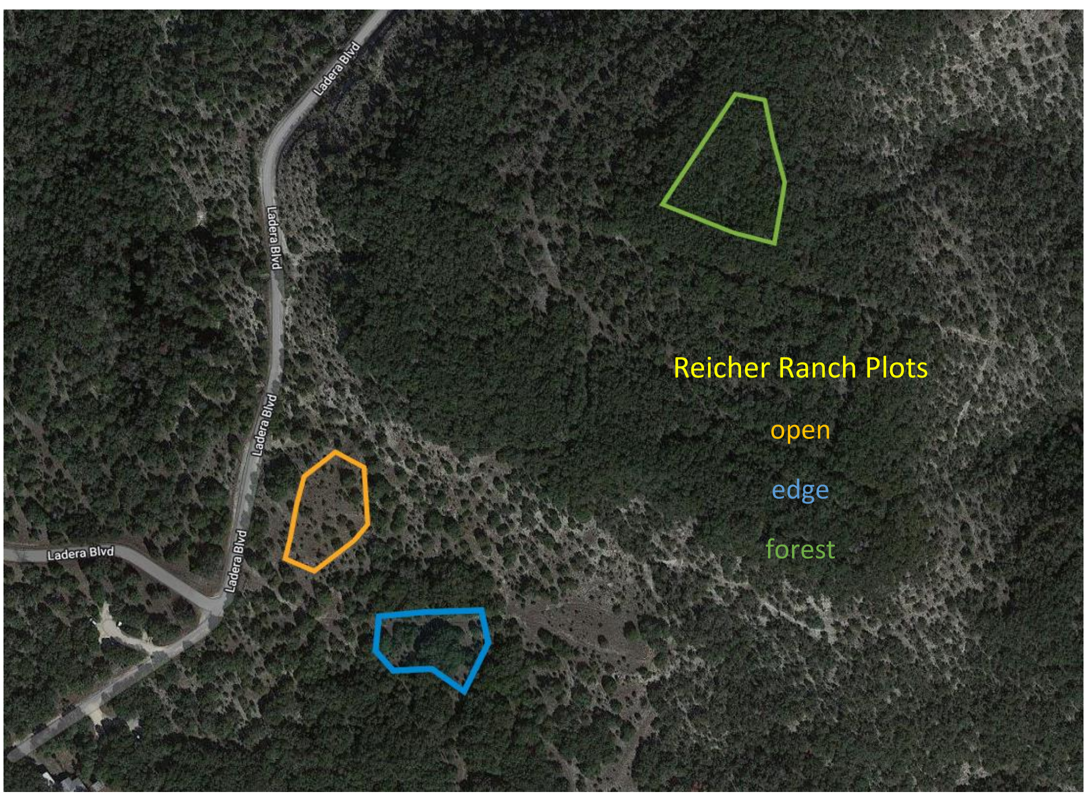

Figure 2. **Reicher Ranch Live Fuel Moisture Control Plots** containing open, edge, and forest plots.

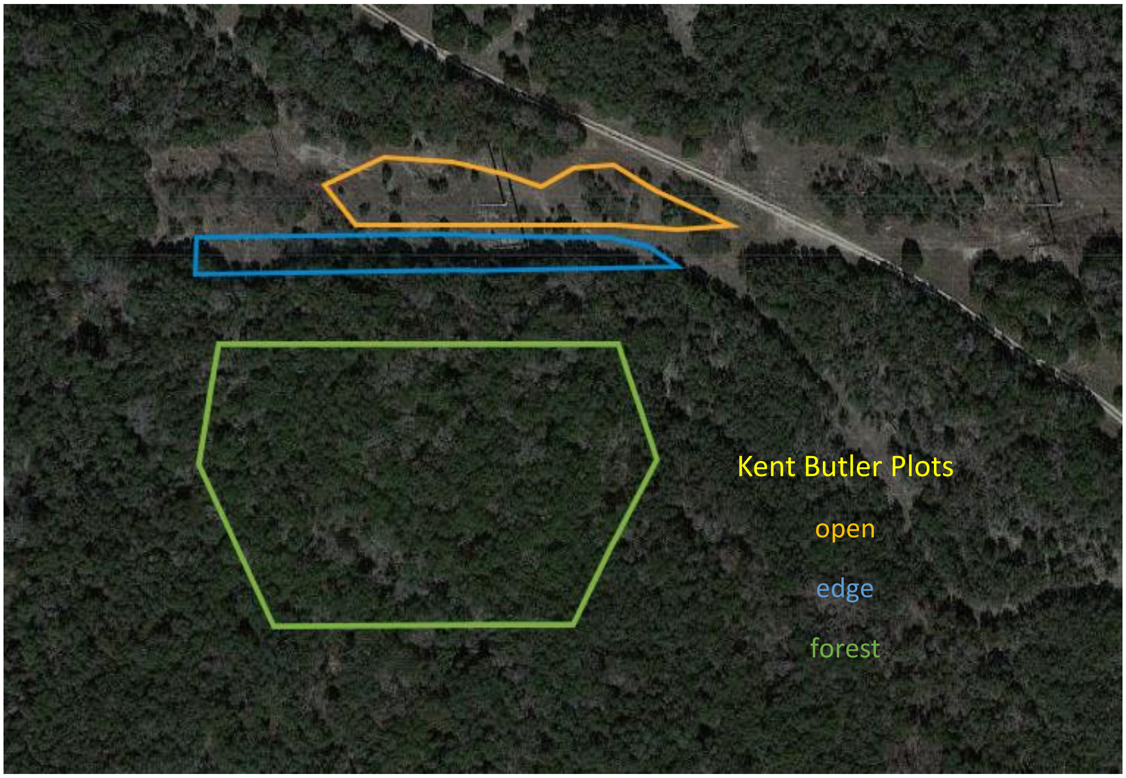

Figure 3. **Kent Butler Live Fuel Moisture Plots** containing open, edge, and forest plots.

RESULTS

From August 2021 to November 2022, LFMC was highly variable ranging from approximately 55% - 150% across all sites, plots, and forest vertical strata (Figure 4).

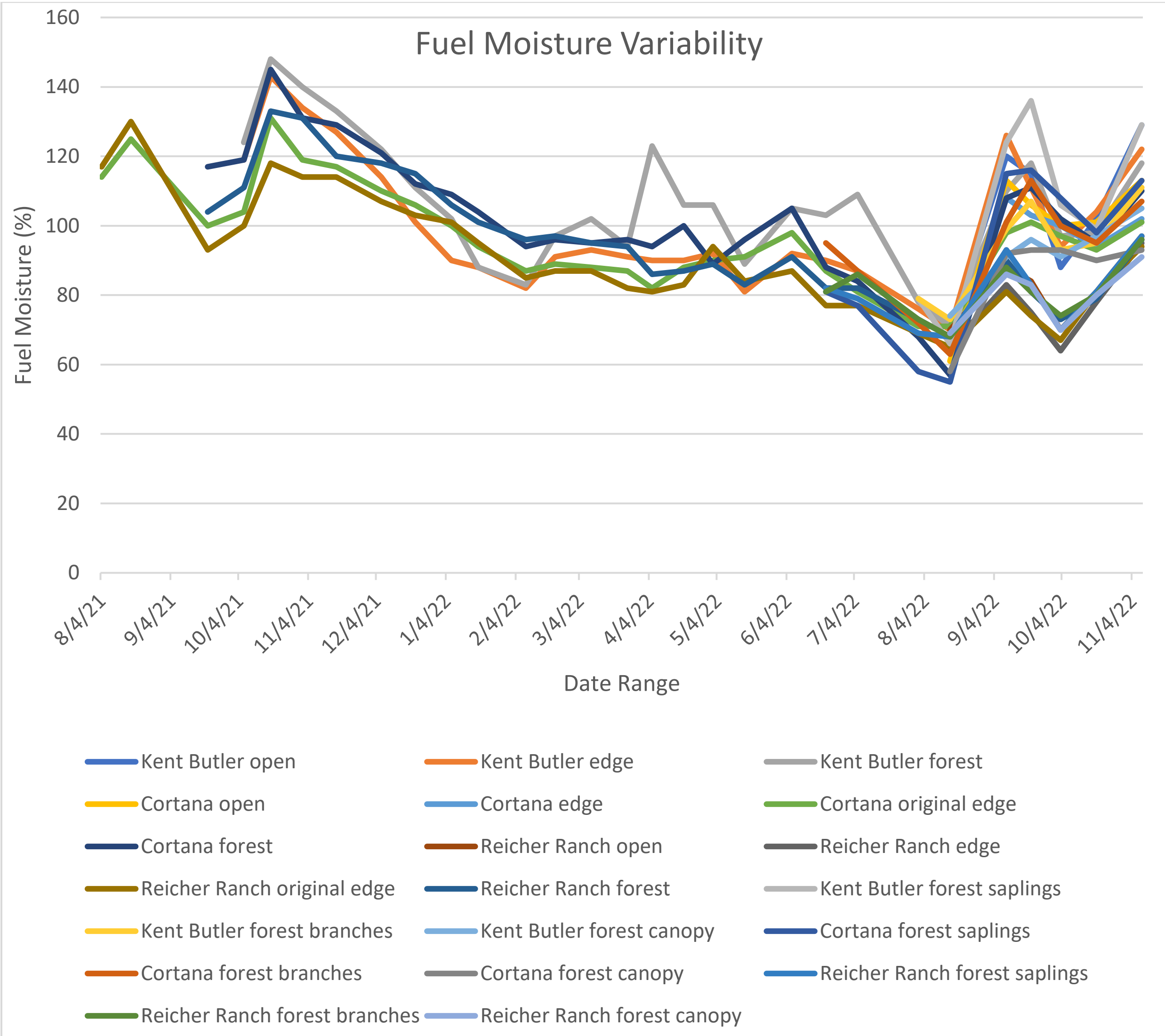

Figure 4. **Fuel Moisture Variability –** Live Fuel Moisture Content values shown across all sites, plots, and forest vertical strata from August 2021 to November 2022.

At all sites, forest plots contained higher average LFMC than edge plots and the difference was significant [paired t-test: Cortaña ($t = 5.853$, $P < 0.001$); Reicher Ranch ($t = 6.884$, $P < 0.001$); Kent Butler ($t = 3.743$, $P < 0.001$)]. Across the entire sampling period, from 20 September 2021 to 8 November 2022, overall average LFMC was 101% on forest plots compared to 94% on edge plots. During fall through early spring, from 6 October 2021 to 19 April 2022, average LFMC was 10% higher on forest plots than on edge plots. During late spring through summer, from 5 May to 15 August 2022, average LFMC was 4% higher on forest plots than on edge plots (Figures 5 - 7).

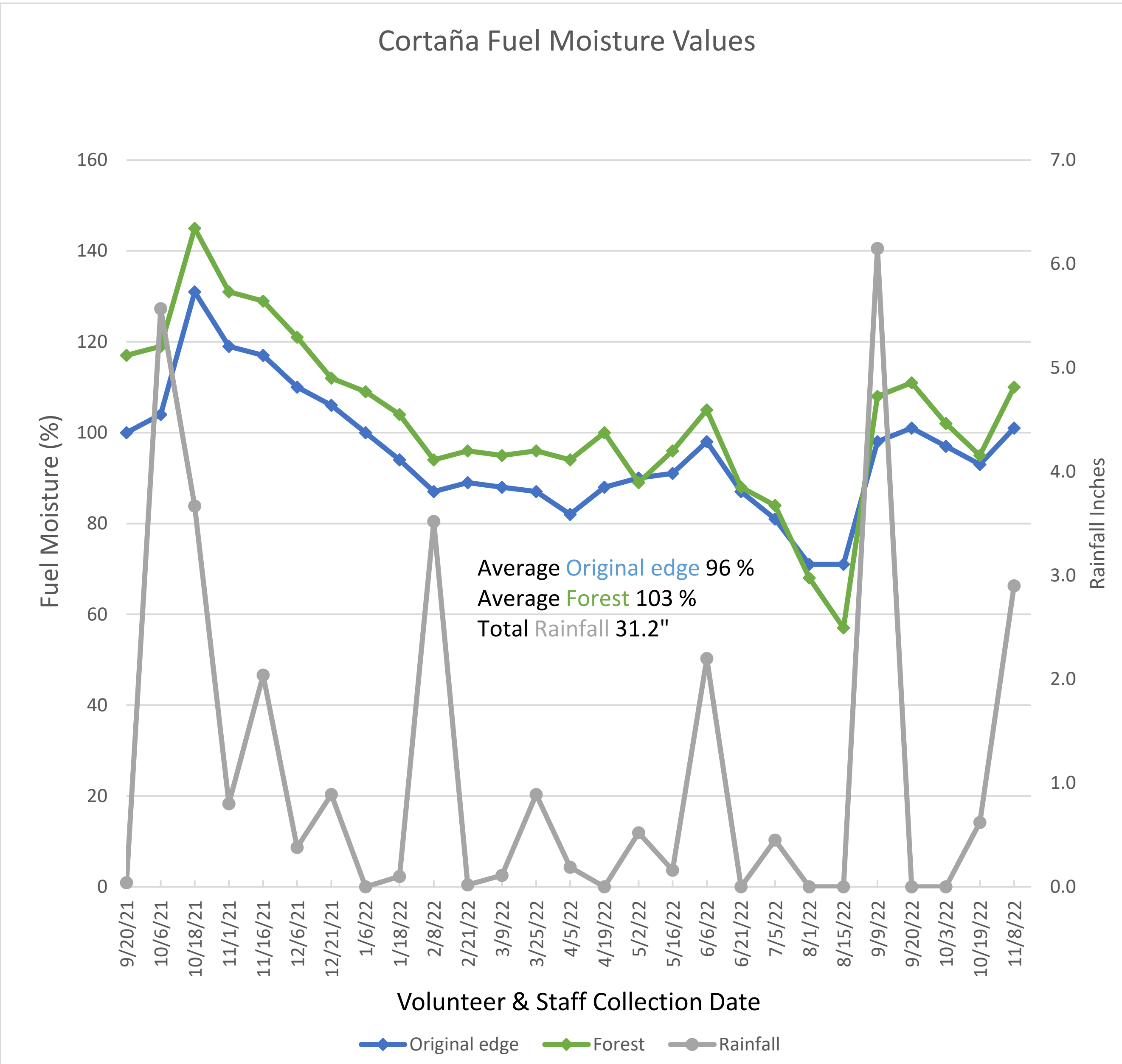

Figure 5. **Cortaña Fuel Moisture Values** – Original edge is long term plot containing juniper-oak forest bordering scrubland. Forest plot is closed canopy, juniper-oak forest interior. Rainfall increments measure accumulation since previous collection date.

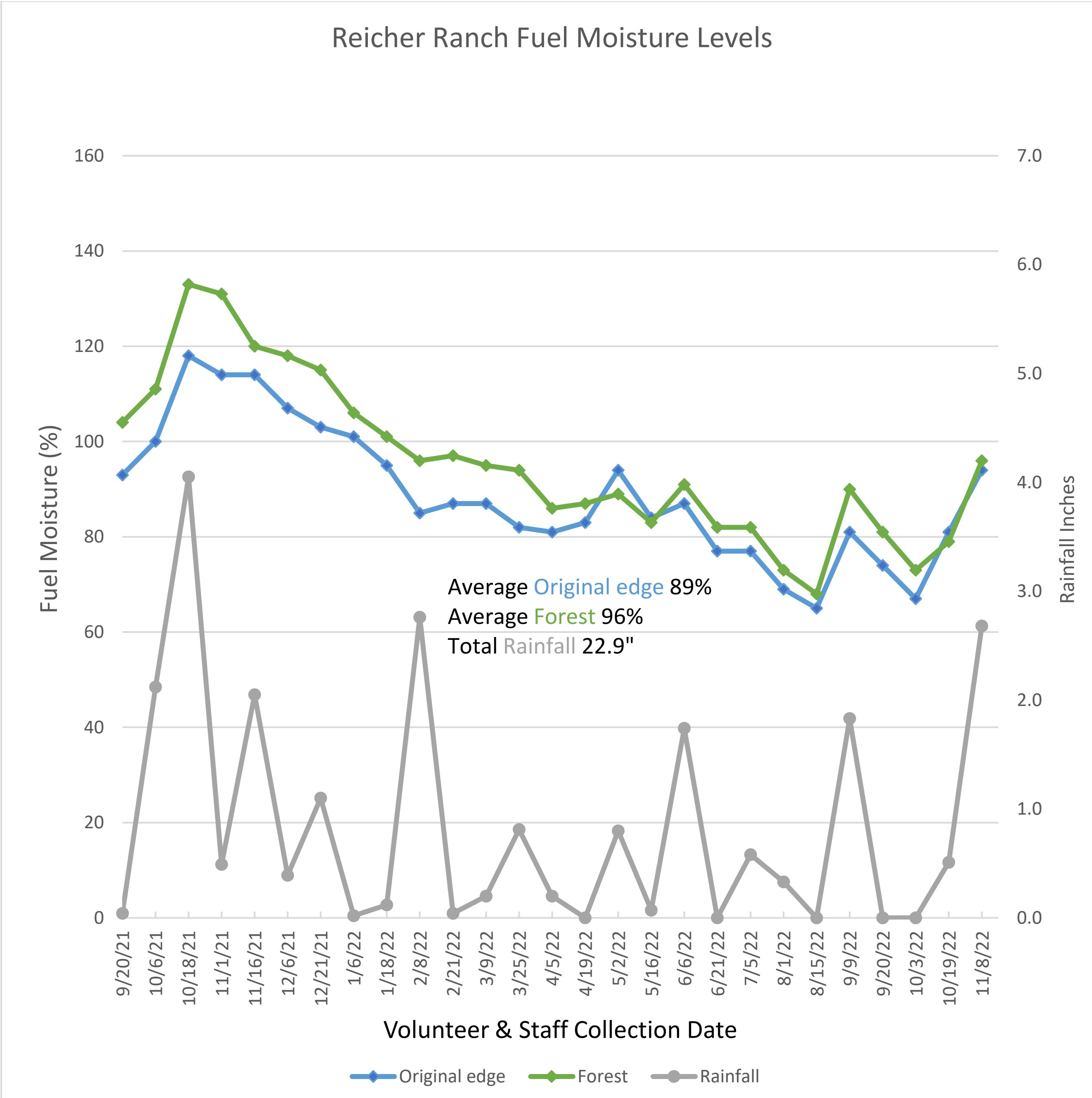

Figure 6. **Reicher Ranch Fuel Moisture Values** – Original edge is long term plot containing juniper-oak forest bordering scrubland. Forest plot is closed canopy, juniper-oak forest interior. Rainfall increments measure accumulation since previous collection date.

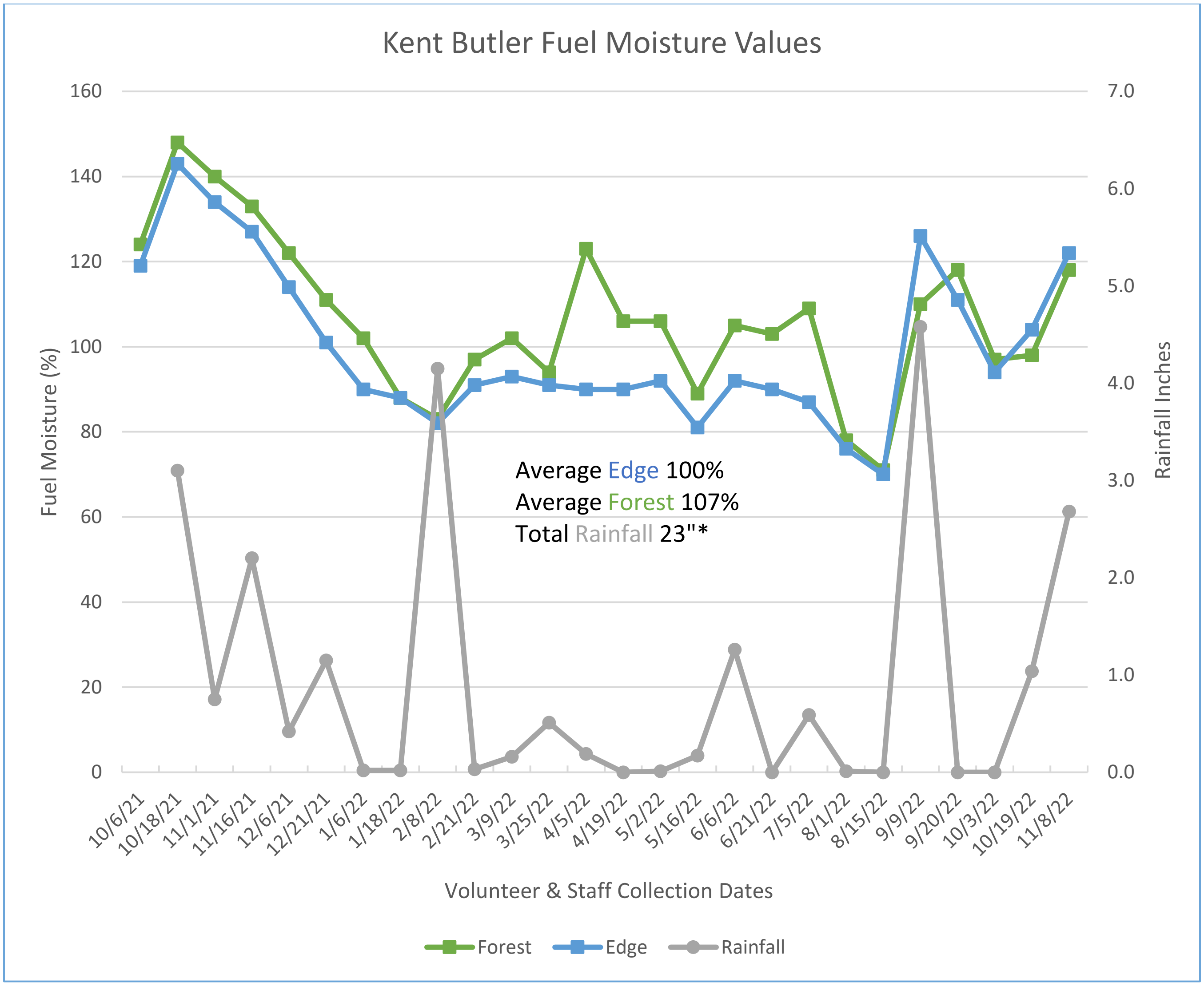

Figure 7. **Kent Butler Moisture Values** – Edge plot is juniper-oak woodland bordering scrubland. Forest plot is closed canopy, juniper-oak forest interior. Rainfall increments measure accumulation since previous collection date. *Total rainfall contains one less measurement on 10/6/22 compared to Cortaña and Reicher Ranch sites.

From 15 August to 8 November 2022, we found no difference in LFMC between forest, edge, and open plots within sites. [ANOVA Single Factor: Cortaña (F = 1.001, P = 0.905), Reicher Ranch (F = 0.385, P = 0.687), Kent Butler (F = 0.082, P = 0.923)]. Results were consistent across sites, even though Reicher Ranch recorded only 5.0” of cumulative rainfall since 15 September, compared to 8.3” at Kent Butler and 9.7” at Cortaña (Figures 8 - 10).

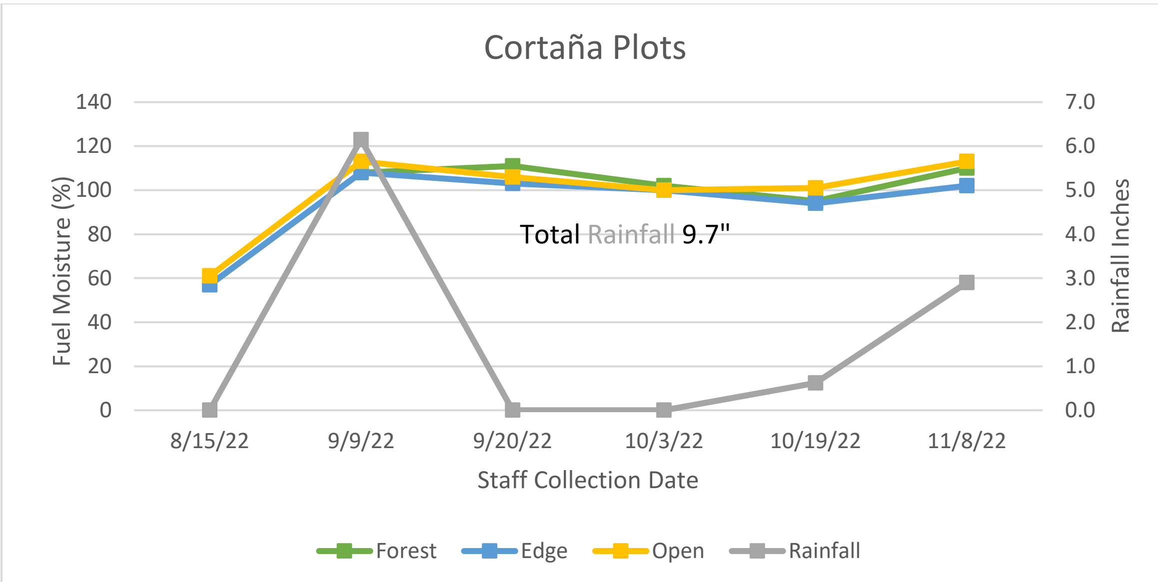

Figure 8. **Cortaña Plots** – Forest is closed canopy, juniper-oak forest interior. Edge is juniper-oak forest bordered by scrubland. Open is scrubland with isolated mottes surrounded by grassland. Rainfall increments measure accumulation since previous collection date.

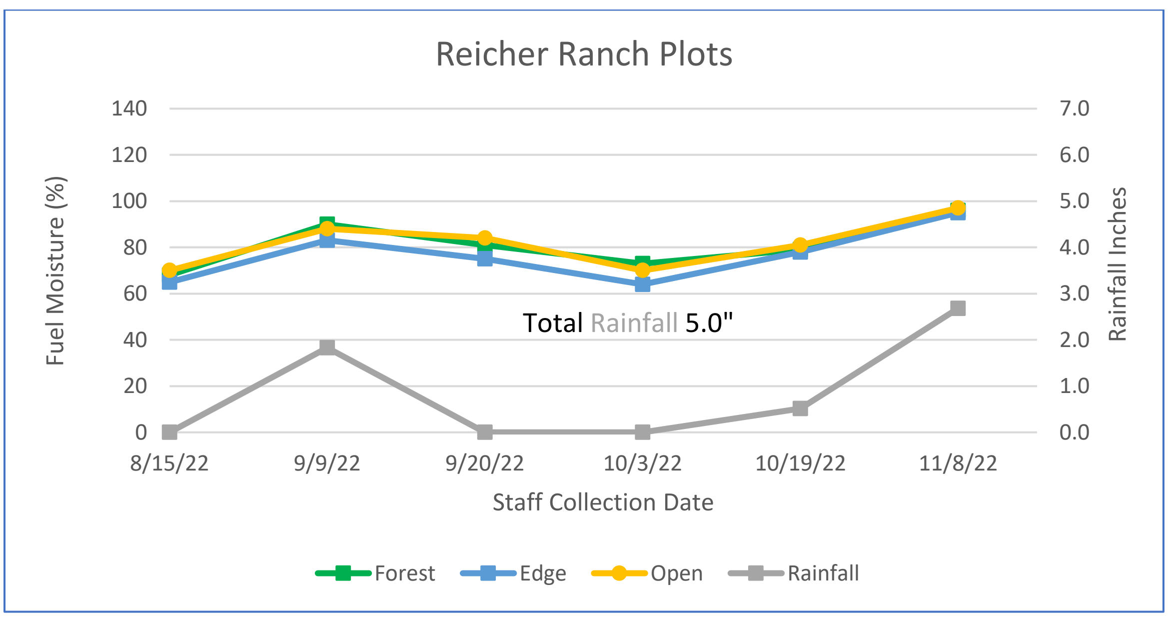

Figure 9. **Reicher Ranch Plots** – Forest is closed canopy, juniper-oak forest interior. Edge is juniper-oak forest bordered by scrubland. Open is scrubland with isolated mottes surrounded by grassland. Rainfall increments measure accumulation since previous collection date.

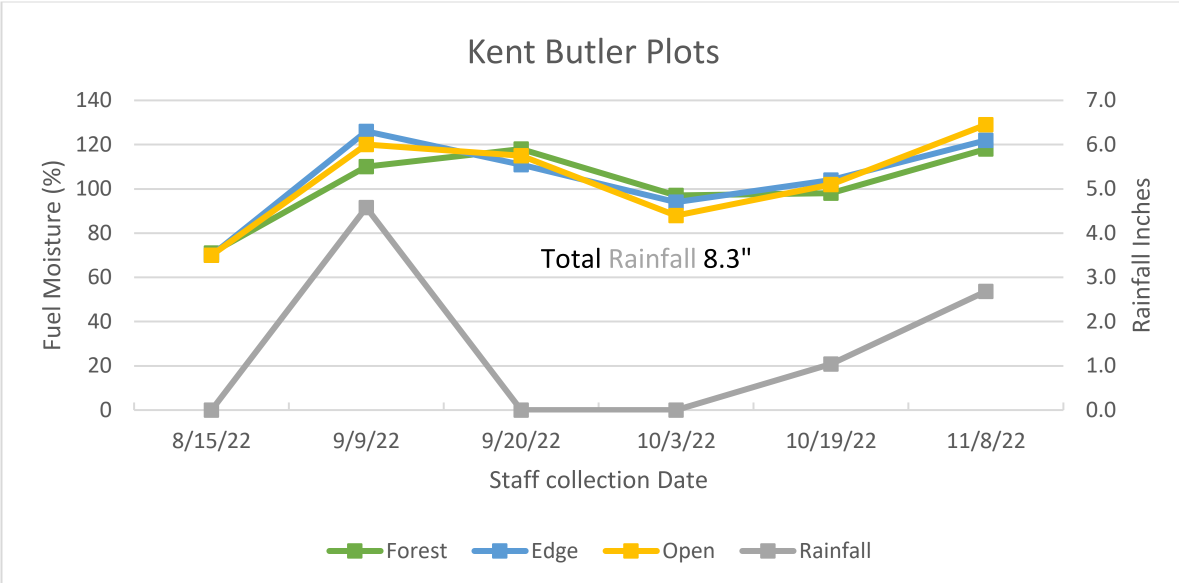

Figure 10. **Kent Butler Plots** – Forest is closed canopy, juniper-oak forest interior. Edge is juniper-oak forest bordered by scrubland. Open is scrubland with isolated mottes surrounded by grassland. Rainfall increments measure accumulation since previous collection date.

From 15 August to 8 November 2022, we found no significant difference in LFMC between saplings, lower branches, and upper branches in the canopy within sites. [ANOVA Single Factor: Cortaña ($F = 0.925$, $P = 0.418$); Reicher Ranch ($F = 0.069$, $P = 0.934$); Kent Butler ($F = 1.631$, $P = 0.229$)]. At Kent Butler and Cortaña, the two sites with highest accumulated rainfall, we found a slight difference in average LFMC between saplings and upper branches in the canopy with saplings having slightly higher LFMC [paired t- test: Cortaña ($t = 3.431$, $P = 0.018$); Reicher Ranch ($t = 1.547$, $P = 0.182$); Kent Butler ($t = 2.357$, $P = 0.065$)] (Figures 11-13).

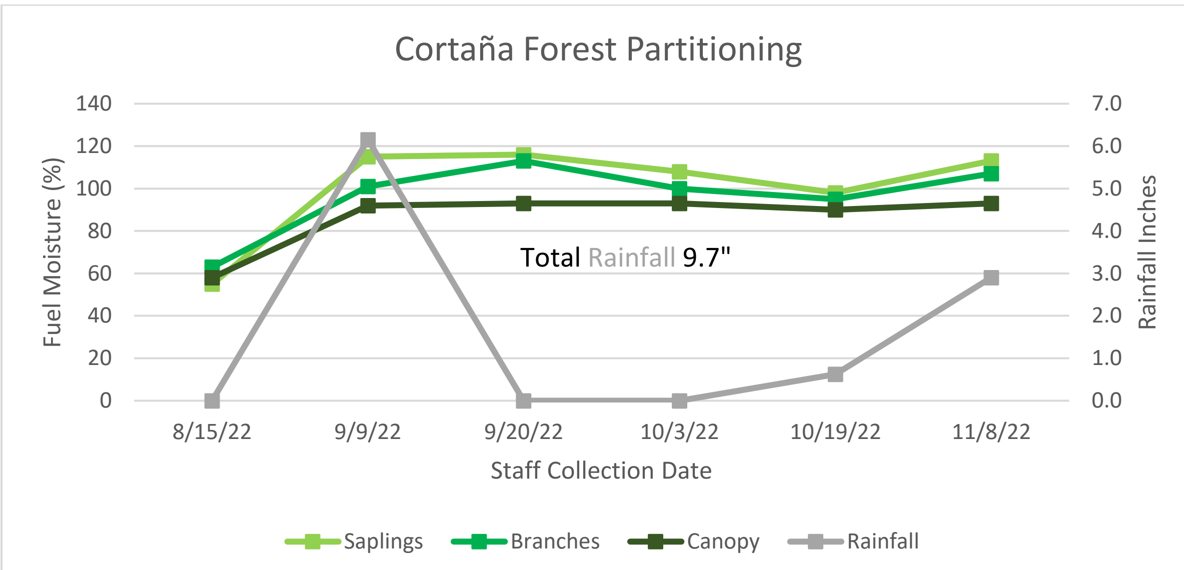

Figure 11. **Cortaña Forest Partitioning** - Saplings are 3 - 8 ft. tall. Lower branches are on trees 10 ft or taller. Canopy foliage trimmed from lower crown on trees 25 - 30 ft. tall. Rainfall increments measure accumulation since previous collection date.

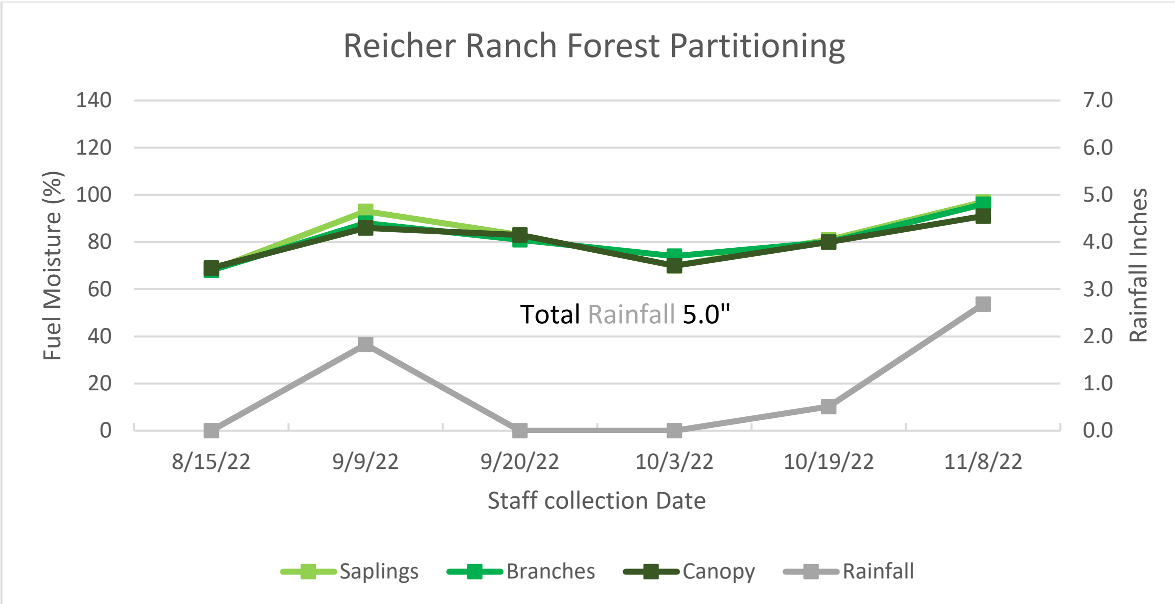

Figure 12. **Reicher Ranch Forest Partitioning** - Saplings are 3 - 8 ft. tall. Lower branches are on trees 10 ft or taller. Canopy foliage trimmed from lower crown on trees 25 - 30 ft. tall. Rainfall increments measure accumulation since previous collection date.

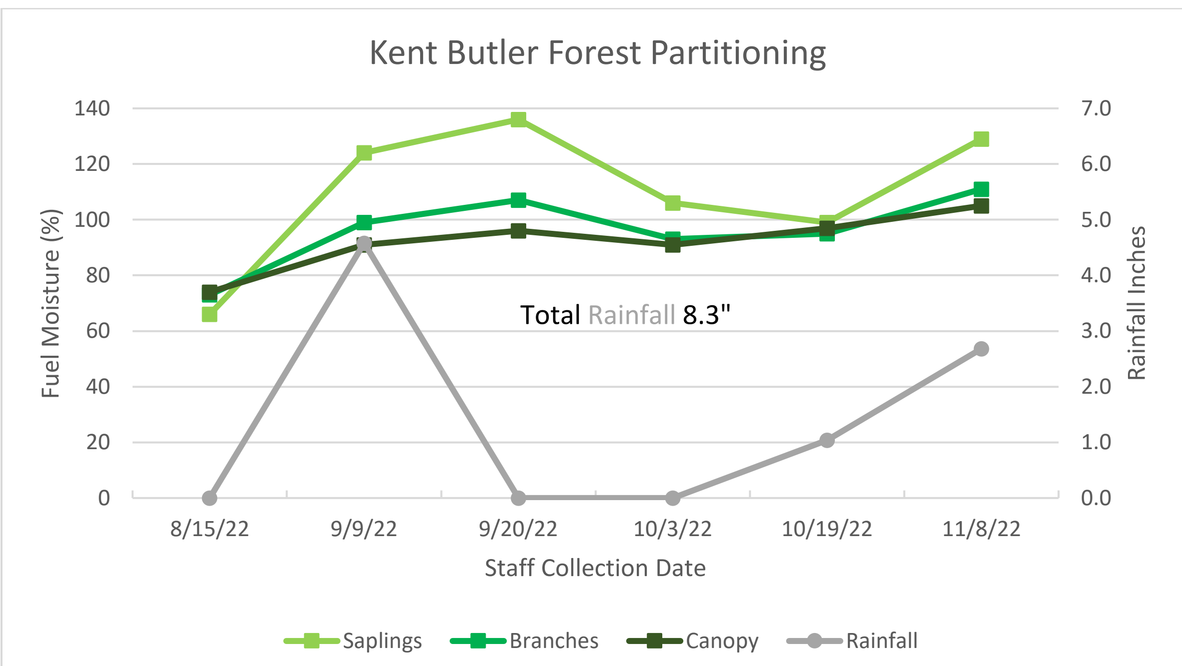

Figure 13. **Kent Butler Forest Partitioning** - Saplings are 3 - 8 ft. tall. Lower branches are on trees 10 ft or taller. Canopy foliage trimmed from lower crown on trees 25 - 30 ft. tall. Rainfall increments measure accumulation since previous collection date.

LFMC increases with accumulated rainfall over time (Figure 14). The highest LFMC value was recorded at Kent Butler on 18 October 2021. The lowest LFMC value was recorded at Cortaña on 15 August 2022.

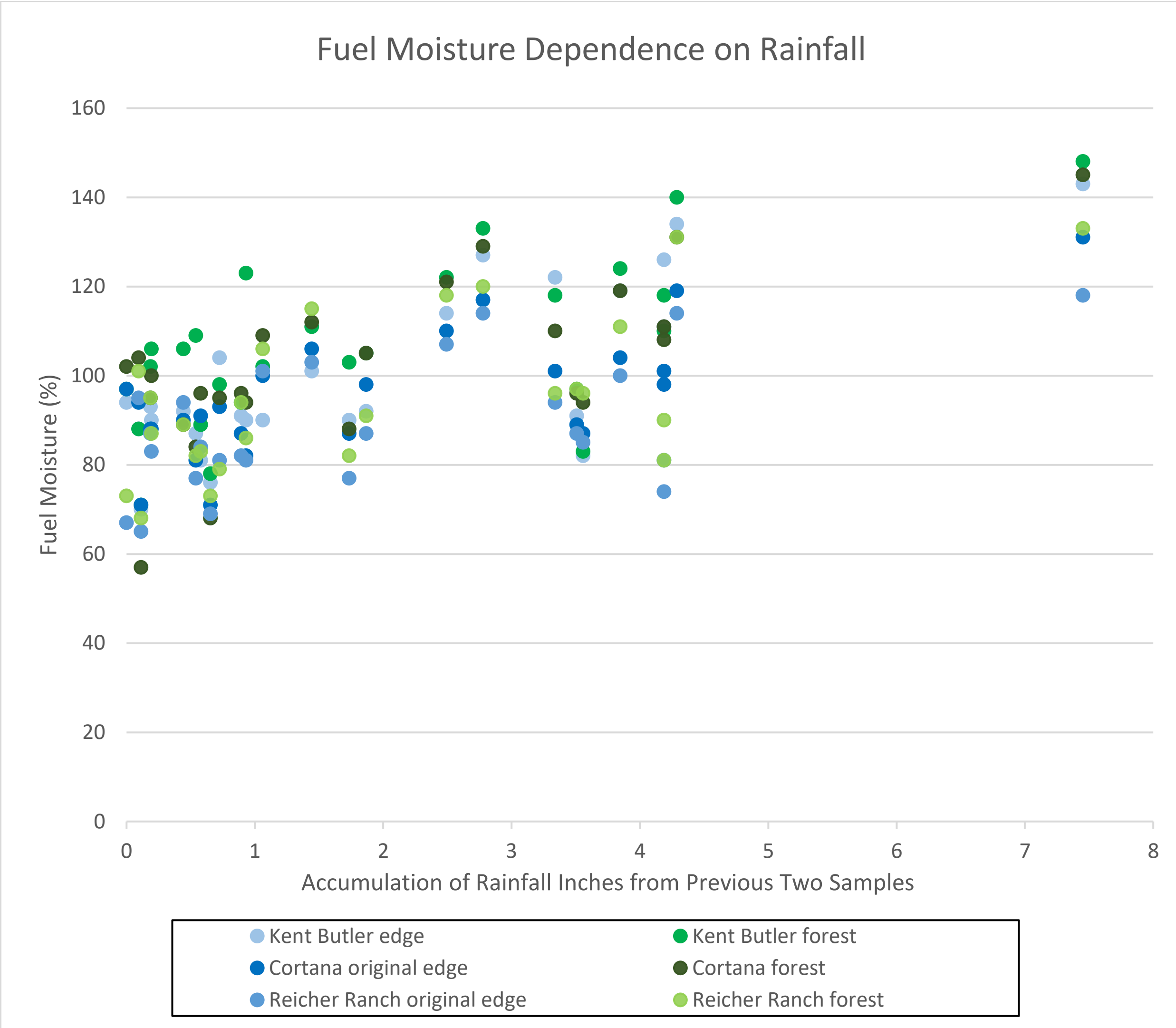

Figure 14. **Fuel Moisture Dependence on Rainfall** – Live Fuel Moisture Content on forest and edge plots at all three sites plotted against sum of average rainfall inches from current and previous collection date between 6 October 2021 – 8 November 2022.

DISCUSSION

Rainfall is the principal driver for variation in LFMC. During our sampling period, we experienced a wetter than average winter in late 2021, a severe to extreme drought in summer of 2022, followed by the resumption of seasonal rainfall beginning in September 2022 (National Weather Service 2022).

Forest interior contained higher LFMC than forest edge. Edges tend to be drier and warmer due to the effects of insolation, wind, and evapotranspiration (Crockatt and Bebber 2014). Canopy cover shades the forest floor, which results in lower air temperature and higher relative humidity compared to adjacent edge (Young and Mitchell 1994, Gelhausen et al. 2000).

During winter and spring, from October 2021 to April 2022, average LFMC was 10% higher on forest plots than on edge plots. Below average rainfall began in May and persisted through August 2022. By mid-August, local rainfall was approximately 10” below average (National Weather Service 2022). LFMC levels declined to 60% - 70% in August on all plots as drought conditions intensified, although overall average LFMC on forest plots was still 4% higher than on edge plots.

McCaw et al. (2018) recorded large variation in LFMC values (46% - 186%) during summer in juniper-oak woodlands of Central Texas, whereas, during the winter, LFMC values ranged between 79% - 120%. In contrast, Povovaroff et al. (2019) found that LFMC varied widely among shrub species during wet winter months but converged during summer months in the Mediterranean-type climate conditions of southern California. Our data suggest that closed canopy forests average higher LFMC values than forest edge during typical rainfall patterns, but fuel moisture decreases across the landscape during periods of very low cumulative rainfall.

We expanded our sampling effort to three plots on all three sites at the end of the drought just prior to fall rains. In response to rainfall in early September, all plots recorded a 20% - 50% increase in LFMC and LFMC continued to track rainfall patterns throughout the fall. However, by 8 November 2022, annual rainfall accumulation remained approximately 10” below average and there was no difference in average LFMC between forest, edge, and open plots.

After severe drought in 2009, Dammeyer et al. (2016) found that drought effects on transpiration outlasted meteorological conditions by several months for live oaks and Ashe junipers in Central Texas. Both species were too severely damaged by drought to recover instantaneously with the onset of precipitation in September, and only recovered from drought impacts during the subsequent growing season.

We also expanded our sampling effort to investigate how LFMC is distributed vertically across strata on the closed canopy, forest interior plots just prior to fall rains. Sapling foliage responded differently than canopy foliage to significant rain events at Cortaña and Kent Butler sites, which recorded 6.2” and 4.6” rainfall respectively on 9 September. Through 3 October, LFMC in saplings was higher than canopy foliage, although LFMC values equilibrated between saplings and canopy foliage by 19 October, even though both sites recorded approximately 1” rainfall on 19 October. At Reicher Ranch, which recorded only 1.8” rainfall on 9 September, LFMC of saplings and canopy foliage remained roughly similar. Saplings have less biomass and shallower roots than taller trees, so likely respond more rapidly to increased surface moisture following significant rain events.

During our 13-month sampling period, LFMC varied significantly ranging from approximately 55% - 150%. The response of LFMC to rainfall is known to be complex and lagged (Hiers et al 2019). Precipitation history may contribute more to LFMC than recent rainfall. Our highest LFMC values were recorded from all sites on 18 October 2021, after average accumulated rainfall exceeded 3" on both 6 October and 18 October. Water availability is likely the primary driver, but other factors that may affect LFMC include air temperature, relative humidity, season, soil type, and root zone depth.

LFMC values can serve as an indicator for how susceptible vegetation is to wildfire. Fuel moisture is a fundamental factor in the ignition and spread of wildland fires (Varner & Keyes 2009). Our goal was to measure LFMC for the purpose of informing potential wildfire behavior in different habitats within the BCP. Our data show that forest interior plots contain higher average LFMC than forest edge plots bordering scrubland. Structural components that contribute to higher LFMC, such as mid and understory vegetation, also increase wind drag, which can slow fire spread and reduce fire intensity in the forest interior depending upon seasonality and fuel conditions (Banerjee et al. 2020).

Our data also show that LFMC values in each of the three habitat types declined in response to very low cumulative rainfall. Schoenberg et al. (2003) found that wildfire risk increases as LFMC decreases until a threshold is reached, and then fire risk can become constant and high. McCaw et al. (2018) estimated that, contingent upon fine fuel loading and climatic conditions, Ashe juniper LFMC of 80% is a rough threshold below which there is potential for independent crown fire. Armstrong (2004) estimated that fuel moisture levels greater than 70% are resistant to burning, and that dense stands of Ashe juniper can serve as natural firebreaks and help reduce the risk of wildfire spread. We recommend coordinating our data collection with fire practitioners and modelers to better predict and minimize wildfire risks in different habitat types.

ACKNOWLEDGEMENTS

This project would not be possible without the assistance of several dedicated volunteers. We would like to acknowledge R. Jain for his assistance with figures and analysis; B. Brown for his help managing field data collection and processing samples; D. Dunlap, T. Phillips, B. Brown, and C. McLellan for assistance in field data collection.

LITERATURE CITED

Armstrong, B. 2004. Conducting cool season prescribed fires: the Kerr Wildlife Management Area experience. Texas Parks and Wildlife Department report, PWD BK W7000-2065 (3/04). Austin, Texas.

Banerjee, T., W. Heilman, S. Goodrick, J. K. Hiers, and R. Linn. 2020. Effects of canopy midstory management and fuel moisture on wildfire behavior. Scientific Reports 10, 17312. https://doi.org/10.1038/s41598-020-74338-9

Crockatt, M. E. and D. P. Bebber. 2014. Edge Effects on moisture reduce wood decomposition rate in a temperate forest. Global Change Biology 21(2):698-707. https://doi.org/10.1111/gcb.12676

Dammeyer, H. C., S. Schwinning, B. F. Schwartz, and G. W. Moore. 2016. Effects of juniper removal and rainfall variation on tree transpiration in a semi-arid karst: evidence of complex water storage dynamics. Hydrological Processes 30: 4568-1481. https://doi.org/10.1002/hyp.10938

Gelhausen, S. M., M. W. Schwartz, and C. K. Augspurger. 2000. Vegetation and microclimatic edge effects in two mixed-mesophytic forest fragments. Plant Ecology 147:21-35. https://www.jstor.org/stable/20050900

Hiers, J. K., C. L. Strauhammer, J. J. O'Brien, H. L. Gholz, T. A. Martin, J. Hom, and G. Starr. 2019. Fine dead fuel moisture shows complex lagged responses to environmental conditions in a saw palmetto (*Serenoa repens*) flatwoods. Agricultural and Forest Meteorology 266–267: 20-28. https://doi.org/10.1016/j.agrformet.2018.11.038

McCaw, W. M., D. M. Grobert, S. B. Brown, S. Strickland, G. A. Thompson, G. Gilman, L. M. Ball, and C. D. Robinson. 2018. Seasonal patterns and drivers of Ashe juniper foliar live fuel moisture and relevance to fire planning. Fire Ecology 14(1): 50-64. https://doi.org/10.4996/fireecology.140150064

Povovaroff, A.L., N. Emery, M. R. Sharifi, M. Witter, J. E. Keeley, and P. W. Rundel. 2019. The effect of ecophysiological traits on live fuel moisture content. Fire *2*(2):28. https://doi.org/10.3390/fire2020028

Schoenberg, F.P., R. Peng, Z. Huang, and P. Rundel. 2003. Detection of non-linearities in the dependence of burn area on fuel age and climatic variables. International Journal of Wildland Fire 12(1):1–6. https://doi.org/10.1071/WF02053

Sharma, S., and K. Dhakal. 2021. Boots on the ground and eyes in the sky: A perspective on estimating fire danger from soil moisture content. *Fire 4* (3): 45. https://doi.org/10.3390/fire4030045

United States. National Weather Service. 2022. Local Climate Graphs Austin/San Antonio, Texas. https://www.weather.gov/ewx/climategraphs

Varner, J. M. and C. R. Keyes. 2009. Fuels treatments and fire models: Errors and corrections. Fire Management Today 69 (3): 47-50. https://www.researchgate.net/publication/234153713

Young, A. and N. Mitchell. 1994. Microclimate and vegetation edge effects in a fragmented podocarp-broadleaf forest in New Zealand. Biological Conservation 67(1): 63-72. https://doi.org/10.1016/0006-3207(94)90010-8

Zahn, S., and C. Henson. 2011. Fuel moisture collection methods – A field guide. U.S. Department of Agriculture, Forest Service. 5100—Fire Management 1151 1803—SDTDC.