Influence of pre-fire beetle kill on post-fire Hairy Woodpecker (*Leuconotopicus villosus*) abundance in the Southern Rocky Mountains, Colorado

Honors Thesis

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Abstract:

Increasing wildfire frequency and severity in the western United States, combined with widespread bark beetle outbreaks, have significantly altered forest ecosystems in the Rocky Mountains. These interacting disturbances are reshaping post-fire habitats, particularly for cavity-nesting birds such as the Hairy Woodpecker (*Leuconotopicus villosus*). This study aimed to assess how proximity to beetle-killed forest stands influenced Hairy Woodpecker relative abundance following the 2020 Cameron Peak Fire in the Southern Rocky Mountains, Colorado. We deployed automated recording units (ARUs) at 19 sites within and around the burn perimeter during summer 2023. Recordings of bird calls were analyzed using acoustic identification software to quantify woodpecker detection. Distances to beetle-killed areas were calculated using U.S. Forest Service data and geospatial analysis. A linear regression model revealed a significant negative relationship between woodpecker abundance and distance to beetle-killed forest stands ($p < 0.01$), with closer proximity associated with higher abundance. These results provide valuable insight into habitat selection by cavity-nesting woodpeckers, demonstrating how forest structure shaped by beetle activity can influence post-fire wildlife use. As climate change drives more frequent and intense disturbances, it is important that forest management strategies account for the lasting impacts of compound events like beetle outbreaks and wildfire to promote wildlife resilience.

Introduction:

The presence of wildfire is becoming exceedingly widespread. In 2020 almost every continent on Earth experienced their own megafire–a spatial and temporally continuous fire that arises from a single ignition or multiple relation ignition events that exceed 10,000 ha in area (Nolan et al. 2022, Linley et al. 2022). Fire activity in the Rocky Mountains subalpine forests is dramatically increasing, with more intense wildfires recorded in recent years than at any other time in the past several millennia (Higuera et al. 2021). This change can be contributed to a higher frequency of warm, dry weather and fuel aridity related directly to anthropogenic climate change that has resulted in the total area of burned forests doubling over the past three decades (Schoennagel et al. 2004, Abatzoglou & Williams 2016, Nagy et al. 2018, Mansoor et al. 2022).

Furthermore, there has been an increase in beetle-cause tree mortality due to impact of invasive bark beetles, *Dendroctonus spp.* (hereafter beetle, Hicke et al. 2012, Saab et al. 2014).

There is currently one of the largest outbreaks of beetles in recent history, as more than 47 million ha of subalpine and boreal forest in the western United States have been affected by these invertebrates (Raffa et al. 2008). These beetle infestations are especially rampant in the Southern Rockies, causing concern for forest health and increasing the risk of wildfires due to increased dead fuels (Black et al. 2013). Beetle outbreaks have also been shown to modify the microclimate of affected forest stands by opening the canopy, indirectly affecting fire behavior and possibly contributing to the spark of the Cameron Peak megafire that burned an estimated 219,019 acres throughout the Southern Colorado Rocky Mountains from August through December 2020 (Simard et al. 2011, Swayze et al. 2021, Rodman et al. 2022).

While wildfires are known to be cases of extreme disturbance to ecosystems, previous studies show that many woodpecker species are attracted to and even benefit from post-fire habitats due to their higher abundance of bark and wood-dwelling arthropods (Saab et al. 2002, Covert-Bratland et al. 2010). This includes the Hairy Woodpecker (*Leuconotopicus villosus*) (hereafter hairy woodpecker), a species commonly present in the Rocky Mountains, that are known to forage in areas of high bark beetle density and commonly nest in snags generated by wildfire (Edworthy et al. 2011, Campos et al. 2020)

Understanding the interactions between beetle infestations, post-fire landscapes like the Cameron Peak Fire area, and hairy woodpecker foraging strategies is essential for informing forest management and conservation efforts in the Southern Rockies. Such insights can guide post-fire rehabilitation and biodiversity preservation in these evolving landscapes. This study aims to assess the relationship between hairy woodpecker relative abundance and beetle-killed trees in relation to the Cameron Peak fire. We hypothesize that there is a greater woodpecker abundance observed near areas dominated by forestry of pre-fire beetle mortality.

Methods:

Study Area

Our study area was located in the Southern Rocky Mountains, in Larimer County, Colorado. All survey locations were located within the Arapaho and Roosevelt National Forest,

both within the Cameron Peak burn perimeter, and in unburned locations which acted as a control for pre-fire habitat. The natural setting is dominated by steep mountainous terrain, narrow valleys, and forests. The forest composition affected included predominantly trembling aspen (*Populus tremuloides*), blue spruce (*Picea pungens*), Engelmann spruce (*Picea engelmannii*), ponderosa pine (*Pinus ponderosa*), lodgepole pine (*Pinus contorta*), and Douglas fir (*Psuedotsuga menziesi*).

Data Collection

We used automated recording units (hereafter ARU) to monitor forest birds during the months of June through October 2023. One Song Meter Mini Bat 2 AA bioacoustics recorder (Wildlife Acoustics**,** Marynard, MA 2023) was deployed per point. Points were spaced with a minimum of 1 km between each point. We attached each ARU to securely placed posts, approximately 2 meters above the ground. Each ARU was set to record for one hour from the start of sunrise and the hour prior to sunset. ARUs were deployed for 7-14 days. A total of 19 points were sampled during the study period.

We used BirdNET **(**Kahl et al. 2024) to detect and identify bird call recordings by breaking the hour-long recordings into 3-second segments when a call was detected. Each of these segments was then reviewed in Raven Lite (K. Lisa Yang Center for Conservation Bioacoustics 2024) to accurately proof and identify the species of each audible call. Only the audio recordings that had a ≥0.95 BirdNET confidence score were used to calculate the total number of species identified per point and the number of sitings per species. The confidence score reflects the probability that a detection is correctly classified; a threshold of 0.95 minimizes false positives while retaining high detection sensitivity (Wood & Kahl 2024).

Pre-fire beetle kill data was obtained from the U.S. Forest Service National public dataset titled Western Bark Beetle Strategy (USFS 2025). We used data from 2016-2019, which gave us 5 years of pre-fire data. We used ArcGIS Pro (Esri 2024) to map each study location and the polygons from the Beetle Kill Strategy. We then used the Near tool in ArcGIS Pro to measure the distance between each survey location and the nearest beetle kill area in kilometers, using a search radius of 50 km.

Analysis

A linear regression model was used to determine the relationship between relative abundance (hereafter RA) at specific points and the distance to beetle-killed trees at these points. Only 14 of the 19 sampled sites were included in these analyses due to selecting from the ≥0.95 BirdNET confidence score. To determine the final abundance matrix of hairy woodpeckers, we used the R package funrar (Grenié et al. 2017). To plot the RA in comparison to the distance to beetle kill cites, we used the R package ggplot2 (Wickham 2016).

Results:

Across all sites included in the analysis, a total of 2,707 hairy woodpecker detections were recorded. We saw a broad range in the number of detections across sites, ranging from 687 detections at the highest and 2 detections at the lowest.

There is a significant negative relationship between the relative abundance of hairy woodpeckers and the distance to beetle-killed forest stands. The linear regression model indicated that sites located closer to beetle kill zones had a notably higher RA of hairy woodpeckers. The relatively narrow confidence bands shown in Figure 2 reflect consistency in this relationship across the 14 survey sites included in the analysis.

The model estimated a regression coefficient of -11.53 (± 0.47 SE) for distance to beetle kill, indicating that each additional kilometer away from a beetle-killed area corresponded to a decrease of approximately 11.5 units in relative abundance. This relationship was highly significant ($t = -24.62$, $p < 0.01$).

The linear regression model had a residual standard error of 0.236 and an R^2 value of 0.183. This suggests that about 18.3% of the variation in hairy woodpecker RA can be explained by distance to beetle kill alone. Although other factors not measured in this study likely contribute to woodpecker abundance, the model still demonstrates a statistically sound trend.

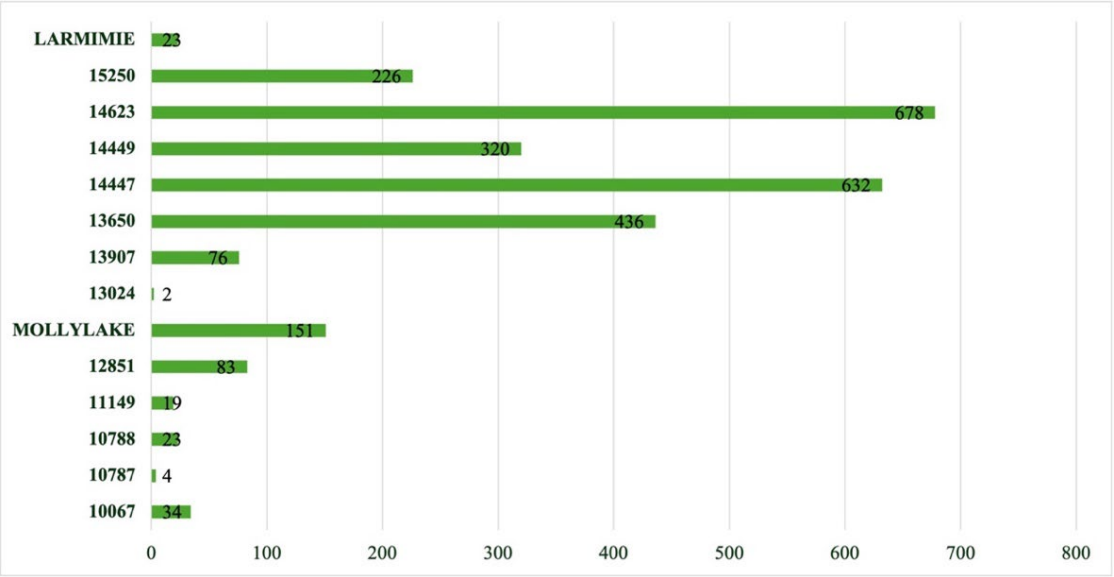

Figure 1. Number of hairy woodpecker detections at each survey location within the Cameron Peak Fire burn perimeter. Data represents detections with a BirdNET confidence score ≥0.95. Only 14 of the 19 sampled sites are included due to this confidence threshold.

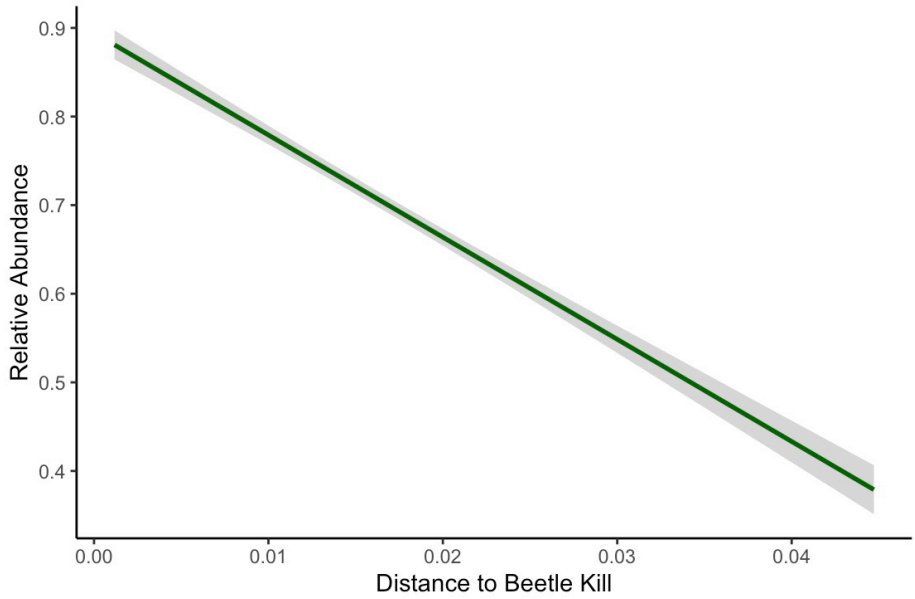

Figure 2. Relationship between Hairy Woodpecker (*Leuconotopicus villosus*) relative abundance and distance to pre-fire beetle-killed trees in Cameron Peak fire area, Colorado. The x-axis represents distance (km) from each survey point to the nearest beetle-killed area (2016-2019 data from USFS). The y axis represents the relative abundance of hairy woodpeckers, calculated using acoustic detections. Data was collected in June through October 2023 using automated recording units and analyzed using BirdNET and Raven Lite for species identification.

Discussion:

Our results show a significant negative relationship between the relative abundance of hairy woodpeckers and the distance to beetle-killed forest stands in the post-fire landscape of the 2020 Cameron Peak Fire. Sites located closer to beetle-killed areas had higher woodpecker activity, with a strong and statistically significant trend showing an increase in abundance as proximity to beetle-impacted areas increased. The linear regression model explained 18% of the variation in RA and showed strength and consistency of the trend across all survey sites, suggesting that proximity to beetle-killed trees is a meaningful predictor of post-fire woodpecker distribution. These findings are consistent with the predicted hypothesis and agree with previous literature that the combination of wildfire and beetle outbreaks creates notably favorable foraging and nesting habitats for woodpeckers (Nappi et al. 2003, Hutto 2006).

Woodpeckers are likely to be attracted to beetle affected forests due to increased prey availability and suitable nesting substrates. Bark beetles cause widespread tree mortality, leading to the rapid reproduction of beetle larvae (Saint-Germain et al. 2004). When wildfire is introduced to these areas, it often enhances the accessibility of these resources by reducing canopy cover and creating snags (Saab et al. 2004, Kozma & Kroll 2013). Hairy woodpeckers are known to take advantage of this abundant insect prey and readily available cavity excavation sites provided by beetle-infested snags and fire-killed trees (Edworthy & Martin 2013). The trend observed in our study supports these mechanisms, with woodpecker abundance dropping off as distance from beetle-killed patches increases. This suggests that beetle outbreaks not only alter forest structure and composition but also have prolonged ecological legacy that extends into the post-fire period. The dead trees they leave behind serve as crucial resources for cavity-nesting birds like the hairy woodpecker **(**Kulakowski & Veblen 2007, Hutto 2008).

The Cameron Peak Fire burned a mosaic of beetle-impacted and less-affected forest types across thousands of acres of the Southern Rockies (Swayze et al. 2021). Our study shows that the aftermath of beetle activity in a post-fire landscape plays a key role in determining woodpecker habitat quality in this post-fire landscape. While some literature has debated whether beetle outbreaks increase fire severity, more recent evidence suggests that beetle-affected areas can burn at variable intensities depending on variables such as time since infestation, fuel conditions, and weather (Simard et al. 2011, Hart et al. 2015). What remains true is that regardless of fire

behavior, beetle-killed forests remain structurally distinct for years, providing lasting habitat value for certain wildlife like a cavity nesting woodpecker species.

Despite this ecological advantage for certain species, it's important to recognize that beetle infestations still pose great concern for the overall health of forests and their potential for wildfires. In the past three decades approximately 6.6 million hectares of forested areas in the western US have been affected by beetle-caused tree mortality (Hicke et al. 2016). Large-scale tree mortality caused by beetles can increase fuel loads and alter forest composition in ways that heighten risk to wildfires (Jenkins et al. 2008). There is a necessity to better control invasive beetle outbreaks while managing their long-term impacts on forest structure and ecosystem dynamics. Other woodpecker species like the black-backed woodpecker (*Picoides arcticus*) also utilize post-fire and beetle-impacted landscapes due to their snag availability, however they are known to decrease their usage as the years post-fire increase (Nappi & Drapeau 2009). In contrast, some bird species are known to be negatively affected by bark beetle outbreaks in the Rocky Mountains. For example, the Brown Creeper (*Certhia americana*) prefers mature, dense forests with intact canopy cover, and their populations experience declines due to canopy loss or disturbance that follow beetle-caused tree stand mortality (Hejl et al. 1995). These patterns emphasize the important of managing beetle-driven forest changes in a manner that balances fire risk, biodiversity conservation, and the long-term resiliency of forests. Furthermore, it is possible that hairy woodpeckers are using beetle-killed stands not only for foraging, but also for nesting. Several studies demonstrated that hairy woodpeckers prefer to excavate nest cavities in fire-killed or beetle killed snags with softening wood (Farris et al. 2004, Saab et al. 2005). This adds further support to the idea that woodpeckers are using beetle-killed areas for both foraging and reproduction.

Our acoustic monitoring survey method captured presence/absence and relative calling activity but did not allow for the assessment of nesting behavior directly. Future work incorporating cavity surveys or camera monitoring could better assess the nesting role of these areas. Additionally, although our model used distance to beetle kill as a key predictor, this variable does not capture the intensity or size of beetle outbreak at each specific location. Forests heavily impacted by beetles may differ in resource availability compared to areas with more moderate mortality, which could influence woodpecker use patterns. Additional alternative explanations for our results may include other habitat variables that co-vary with beetle presence.

Beetle outbreaks often occur in mature, dense forest stands that already support high snag densities and complex structure which are favored by woodpeckers regardless of beetle history (Covert-Bratland et al. 2010). Therefore, beetle-killed areas may co-vary with other unmeasured habitat features like elevation, tree species composition, or post-fire vegetation regrowth that could influence hairy woodpecker abundance but were not accounted for in our model.

Our study contributes valuable evidence that beetle-killed forests continue to serve as important post-fire habitat for hairy woodpeckers, even several years after the fire. These findings have significant implications for forest management. Salvage logging of beetle-killed and fire-killed trees is a common practice aimed at reducing future fire risk, however removal of snags and coarse woody debris can degrade habitat quality for cavity-nesting species and reduce biodiversity (Saab et al. 2002, Hutto 2006, Lindenmayer & Franklin 2008). Our results suggest that controlling invasive beetle outbreaks is crucial due to their damaging effects on forest structure, however maintaining portions of beetle-killed stands within post-fire landscapes can still support woodpecker populations. As climate change continues to amplify both fire regimes and insect outbreaks, understanding their combined impacts becomes increasingly important (Seidl et al. 2017). The Rocky Mountain region is projected to experience more frequent droughts, higher temperatures, and altered precipitation patterns, all of which could accelerate tree stress and beetle activity (Hart et al. 2015). Our findings underscore the need for adaptive, disturbance-informed management strategies that reflect the complex and interconnected impacts of compound disturbances.

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