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Early Decomposition of Ashe Juniper (*Juniperus ashei*) Wood in Open and Shaded Habitat

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Abstract

Grasslands of the Edwards Plateau of central Texas have been extensively altered through woody species encroachment, particularly as a result of increasing abundance of the invasive native shrub, Ashe juniper (*Juniperus ashei*). Over the last several decades there has been widespread mechanical removal of the species. The wood is often left in place to decompose, either mulched or not. Where the wood is left to decompose might have some bearing on its rate of decomposition. This study was conducted to determine the rates of Ashe juniper wood decomposition as a function of open vs. shaded habitat and the potential effect of wood decomposition on nutrient inputs into this system. Wood decomposition in this arid ecosystem might be expected to occur more rapidly in shaded habitat where the moisture and temperature regimes would be more favorable for wood-decomposing fungi. On the other hand, during times of low rainfall we might expect wood to decompose more rapidly when exposed to high levels of ultraviolet radiation. In our experiment, we found no difference between open and shaded treatments. Wood biomass loss occurred rapidly over the first 3–4 mo of the study and slowed for the remaining 2 yr. Wood carbon (C) increased only slightly (7.3%), but nitrogen (N) increased significantly (176%). As a consequence of changes in wood nitrogen, C:N decreased through time. Results of this study suggest that the wood decomposition process in open and shaded habitats in this arid ecosystem during a time of low rainfall do not differ. Our findings also suggest that land managers aiming to establish native species following felling of Ashe juniper should do so in the first year when nutrient release from decomposing wood is the highest.

Resumen

Los pastizales del Edwards Plateau del centro de Texas han sido extensamente alterados a través de la invasión de especies leñosas, particularmente como resultado del incremento en abundancia de un arbusto nativo invasor, el *Juniperus ashei*. En el transcurso de las últimas décadas la remoción mecánica de esta especie ha sido generalizada. La madera es frecuentemente dejada en el lugar para su descomposición ya sea intacta o en forma de mulching. El sitio en el que se deja la madera podría influenciar la tasa de descomposición. Este estudio determinó las tasas de descomposición de la madera de *J. ashei* en función de hábitats abiertos o sombreados y el efecto de la descomposición sobre los aportes de nutrientes al sistema. En este ecosistema árido, es de esperar que la descomposición de la madera ocurra más rápido en lugares sombreados en los que los regímenes de humedad y temperatura serian más favorables para los hongos que descomponen la madera. Por otra parte, durante periodos de baja precipitación es de esperar que la madera se descomponga a tasas más altas cuando se la expone a niveles altos de radiación UV. En nuestro experimento, no se encontraron diferencias entre sitios abiertos y sombreados. La pérdida de biomasa de madera ocurrió rápidamente durante los primeros tres a cuatro meses del estudio, y decreció durante los dos años restantes. El carbono (C) en la madera solo aumentó levemente (7.3%) mientras que el nitrógeno (N) aumentó significativamente (176%). Como consecuencia de los cambios en el nitrógeno de la madera, la relación C:N decreció a través del tiempo. Los resultados de este estudio sugieren que en este ecosistema árido el proceso de descomposición de la madera en hábitats abiertos y sombreados durante períodos de baja precipitación no es diferente. Nuestros resultados también sugieren que quienes manejen los pastizales con el objetivo de establecer especies nativas luego de la remoción de *J. ashei* deberían hacerlo durante el primer año cuando la liberación de nutrientes de la madera en descomposición es máxima.

Key Words: Edwards Plateau, nutrient cycling, woody encroachment

INTRODUCTION

Anthropogenic disturbance has driven woody species encroachment of arid and semiarid grassland ecosystems (Van Auken 2000), resulting in more recalcitrant, lower nutrient cycling ecosystems, with higher biomass in aboveground lignified material (Boddy and Watkinson 1995). Grasslands of the Edwards Plateau of central Texas in the United States have been highly modified due to encroachment of the native *Juniperus ashei* J. Buchholz (Ashe juniper or "Cedar"; Cupressaceae; Van Auken et al. 1980). Ashe juniper is a dioecious, evergreen shrub frequently found throughout the Edwards Plateau in monotypic woodlands known as "cedar breaks" (Riskind and Diamond 1988). Wildlife biologists highlight the importance of conserving some mature Ashe juniper as nesting habitat for the endangered golden-cheeked warbler (J. Neal, Biologist, City of San Antonio Natural Areas, personal communication, March 2008). Nonetheless, the

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general consensus among wildlife biologists, local landowners, and grassland and rangeland managers is that Ashe juniper is a highly competitive species that displaces and suppresses other native woody and most herbaceous species.

In an effort to increase grassland abundance, Ashe juniper is the focus of an aggressive removal campaign employing fire, herbicides, specialized "cedar eaters," and chainsaws (Wink and Wright 1973; Bryant et al. 1983; Owens and Schliesing 1995). Where mechanically removed, the wood is either left intact or mulched using a wood chipper. Then, it either is spread over property and allowed to decompose naturally, or is removed for use elsewhere or for resale. Where other more desirable woody species are present (e.g., plateau live oak, *Quercus fusiformis* Small; Fagaceae) they are left in grouped stands, creating a pattern of open and shaded grassland, typical of savannoid ecosystems. The felling of Ashe juniper generally results in increases in grassland biomass; however, there is currently no guidance for land managers regarding the value of decomposing wood of this nondesired species or where the wood should be placed to facilitate its decomposition and capitalize on nutrients released for subsequent grassland restoration.

Decomposition of woody plant material is a critical ecosystem function (Schowalter 1991) and a highly complex and variable process that depends on the chemical and physical structure of the substrate and climatic factors such as precipitation and temperature (Boddy and Watkinson 1995; Whitford 2002). Studies conducted in lower latitudes, where water is more limiting than the length of the growing season, provide support for soil water content being a driver of the rate of decomposition. This has been shown for wood decomposition in studies comparing mesic and xeric sites (Abbott and Crossley 1982), as well as along a precipitation gradient (Schowalter 1991). At smaller scales in arid ecosystems, Whitford (2002) suggests that the location of plant litter likely is of greater importance as a factor in the decomposition process than its physical and chemical structure. In addition, in semiarid and desert ecosystems, evidence suggests that abiotic factors, such as ultraviolet (UV) radiation, rain drop impact, and temperature, might play an equally or more important role in the decomposition process than biotic processes (e.g., Pauli 1964; Schaefer et al. 1985; Montana et al. 1988; Steinberger and Whitford 1988; Moorhead and Reynolds 1989; Austin and Vivanco 2006; Throop and Archer 2009).

The Edwards Plateau is considered to be a semiarid ecosystem and is characterized by high intra- and interannual variability. To date, little work has been done in this ecosystem to assess the rates of decomposition of felled Ashe juniper or the effect of microhabitat on the wood decomposition process. Wood decomposition in this arid ecosystem might be expected to occur more rapidly in shaded habitat where the moisture and temperature regimes would be more favorable for wood-decomposing fungi. On the other hand, during times of low rainfall, we might expect rates of wood decomposition to be determined by incident UV radiation. In this study, we employed the litter bag method to determine rates of Ashe juniper wood decomposition and nutrient release as a function of open vs. shaded habitat in a savannoid grassland. We also tracked wood carbon and nitrogen content through time. The goal of the study was to provide guidance to land managers regarding placement of felled, nondesired woody species to capitalize on nutrient inputs in grassland ecosystems.

MATERIALS AND METHODS

Study Site

We established our experiment on the C. L. Browning Ranch, east of Johnson City, Blanco County, Texas, USA (lat 30°16′11″N; long 98°20′20″W) in the Balcones Canyonlands of central Texas, along the southeastern edge of the Edwards Plateau. We chose this property because it is representative of Ashe juniper managed rangeland in this area; although all cattle were removed from the property in 2003 (Gardner 2009), the ranch has a long history of moderate to intense grazing. In addition, litter bags could be left in place safely for several years and owners of the property permitted regular access.

The 26-ha area chosen for the experimental site was located at the eastern edge of the property (lat 30°15′53″N; long 98°19′43″W) on a northwest-facing hillside of mixed oak–juniper woodland with a 10–15% slope. Ashe juniper had been cleared from the area in June–September 2004 and the intact, felled wood was left in place. The site consists of shallow, undulating Inceptisols typical of eroded slopes in humid and subhumid areas on limestone substrate (Riskind and Diamond 1986; US Department of Agriculture 1999). The soils are of the Brackett–Real association on Glen Rose limestone formation (Dittemore and Allison 1979). Vegetation at the site is characterized by isolated tree/shrub complexes, dominated by plateau live oak and open native grasslands.

The climate of the Edwards Plateau is subtropical–subhumid, characterized by dry winters and hot summers, with a mean annual temperature of 20°C (Larkin and Bomar 1983). It exists along a rainfall gradient of approximately 38 $cm \cdot yr^{-1}$ in the west to 84 $cm \cdot yr^{-1}$ in the east (Van Auken et al. 1979) and extends over 93 240 km^2 (Riskind and Diamond 1986). We obtained meteorological information from the nearest National Oceanic and Atmospheric Administration (NOAA) Satellite and Information Service, National Environmental Data and Information Service (NESDIS) at Johnson City, Texas, 8.85 km west of our experimental site.

Experimental Design

Wood of Ashe juniper was collected 15 February 2005 from a ranch north of San Antonio, Texas (lat 29°48′30″N, long 98°44′30″W), where cedar had been cleared on 29 January 2005 and mulched into pieces of various sizes using a wood chipper. The collected wood was passively dried in open paper bags in the laboratory for 6 wk prior to processing for use in the study. The wood was not oven-dried due to concerns that it would degrade through the drying process. A wet-mass correction was made using initials for the first day of the study (see below). On 1 April 2005, the wood was sifted through a 5-mm-mesh screen to separate it from non-Ashe juniper herbaceous litter and soil. A total of 110 16 × 16 cm fiberglass mesh litterbags with 1.0-mm openings were constructed following the procedure of Robertson et al. (1999). Wood fragments, consisting of heartwood and sapwood without periderm, measuring 5–10 cm × 1–2 cm were selected for the study. A mass of 20 g was placed in each bag.

We selected five replicate locations within the experimental site in which to establish our experiment. Within each location, four 2-m-long decomposition "transects" were established in an east–west orientation with two paired transects in open habitat ("OPEN") and two paired transects under closed canopy ("SHADE"). Transects consisted of aircraft cable stretched between rebar posts and were separated by approximately 1 m. Paired OPEN and SHADE habitats within a location were established no more than 20 m from each other and treatment pairs were located at least 100 m apart (range of 105–300 m).

On 8 April 2005, litterbags were transported to the field. Using plastic zip ties, the bags were attached to the cable with five on each transect. Bags were separated by approximately 10 cm. The majority were oriented to the outer edge of the paired lengths of aircraft cable, with the exception of a few in the shade treatment that were turned in as necessary to address space constraints. Ten bags served as initials. These bags were taken to the field on the day the experiment was established and then returned, dried for 48 hr at 70°C, and the contents weighed. The average initial dry weight of these 10 bags served as the starting weight for our experiment.

At the outset of the experiment, bags were retrieved from the field at 1–2-mo intervals and at much longer intervals as the experiment progressed. The investigation was conducted for 2.5 yr until November 2007, when the last bag was collected. For each collection date, two bags were collected for each habitat (2) by location (5) combination. The location of bag collection within a transect pair was decided randomly; however, among all transect pairs, bags were collected from the same position at each collection date. Litterbags were carefully extracted from any plants that were growing into them and were placed in paper coin bags to ensure that no material was lost. In spring 2007, one open treatment bag was lost during a land management procedure. Each May and September, the rainiest 2 mo in central Texas, soils were analyzed for water content to assess differences between habitats. At each site, two 5 cm × 15 cm cores were taken from each habitat and combined in a polyurethane bag. Samples were returned to the laboratory and analyzed by gravimetric analysis (per Robertson et al. 1999).

Once collected, litterbags were returned to the lab and dried for 48 hr at 70°C. The litterbags were then cut open and the litter weighed. Approximately half of the wood from each bag was randomly sampled and sent to the Stephen F. Austin State University Soil, Plant and Water Analysis Laboratory (Nacogdoches, Texas) for carbon (C) and nitrogen (N) analysis. Samples were coarsely ground using a Wiley mill, then by a cast iron mortar and pestle, and then ground into a powder using an Udy Cyclone mill. A 0.20-g subsample of each was analyzed for total C and N using an Elementar Vario Macro Carbon-Nitrogen Combustion Analyzer (Elementar Corp., Germany).

Trends in the data through time and as a function of open vs. shaded habitat were analyzed using repeated measures analysis of variance (ANOVA). We used simple linear and single-exponential models to assess the trends in decomposition through time. Wieder and Lang (1982) recommend the use of single-exponential models for decay functions because they are generally a better fit for the trends in these data and allow for more accurate extrapolation through time. Differences in soil

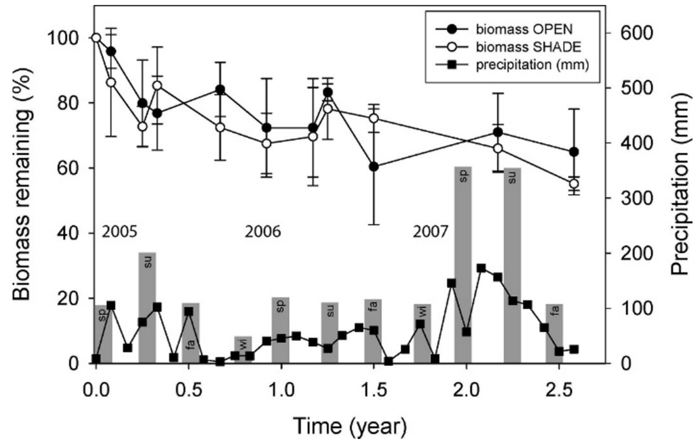

Figure 1. Ashe juniper wood percent biomass remaining (circles) as a function time and SHADE vs. OPEN treatment. Also shown are monthly (solid squares) and total seasonal (shaded columns) precipitation. Experiment was conducted April 2005 to November 2007, as indicated on graph. sp (spring) indicates March, April, May; su (summer), June, July, August; fa (fall), September, October, November; wi (winter), December, January, February. There is no significant difference between open and shaded treatments in percent biomass remaining through time (repeated measures: $F = 1.463$, $P = 0.2657$). Linear: $r^2 = 0.333$; $F = 50.89$; $P < 0.0001$; single-exponential: $r^2 = 0.307$; $F = 45.17$; $P < 0.0001$.

water content between OPEN and SHADE treatments were analyzed by one-way ANOVA. All statistical analyses were done using JMP (SAS 2005). A yearly decay rate was calculated using the single-exponential decay equation: $mass_t = mass_o e^{-kt}$ (Jenny et al. 1949), based on the assumption that the rate of decomposition is constant (Weider and Lang 1982). In this equation $mass_o$ and $mass_t$ are the initial and final biomass, respectively, and t is time expressed as years.

RESULTS

Biomass

The biomass of Ashe juniper wood litter declined over the 29 mo of this experiment (Fig. 1). We found no significant difference in biomass loss between the open and shaded treatments (Fig. 1). A simple linear equation explains 33% of variability in biomass loss as a function of time whereas the single-exponential model explains a slightly smaller percentage (31%; Fig. 1). We expected rainfall to affect the rates of wood decomposition; however, when amount of rainfall over a decomposition interval (time between each collection date) was used as a covariate in our model we found no statistically significant correlation. The yearly decay rate for Ashe juniper for the duration of the study using combined habitat treatments was $k = 0.176$.

Rainfall and Soil Water Content

Figure 1 also shows the average monthly and seasonal precipitation through time in the Edwards Plateau region. The local average yearly precipitation for the years in which we conducted our study (2005–2007) was 659.3 mm (NOAA NESDIS). This is below the low end of the range for average

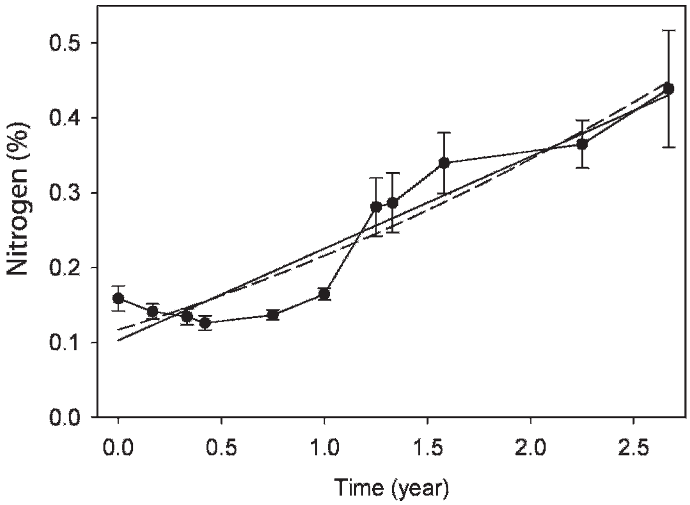

Figure 2. Ashe juniper wood change in percent nitrogen through time, shaded and open treatments combined. Linear fit (solid line): $r^2 = 0.794$, $F = 362.81$, $P < 0.0001$; single-exponential (dotted line): $r^2 = 0.787$, $F = 348.54$, $P < 0.0001$.

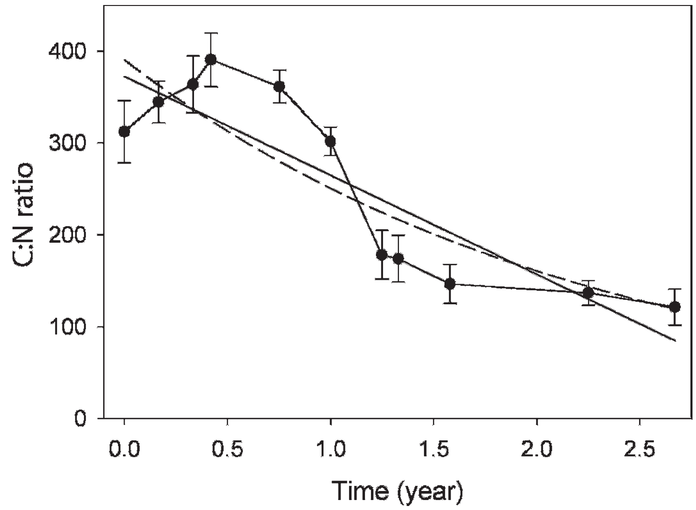

Figure 3. Ashe juniper wood change in carbon:nitrogen (C:N) through time, shaded and open treatments combined. Linear fit (solid line): $r^2 = 0.726$, $F = 246.44$, $P < 0.0001$; single-exponential (dotted line): $r^2 = 0.772$, $F = 315.86$, $P < 0.0001$.

precipitation for the region of 711.2–914.4 mm · yr^{-1} (Larkin and Bomar 1983). Average measures of soil water content for May were consistently higher than September measures (e.g., 2005: 30% vs. 16%). Measures of soil water content in SHADE were generally higher than OPEN (e.g., 2005: 26% vs. 31% in May and 16.3% vs. 15.2% in September). Nonetheless, we detected no significant differences in soil water content between open and shaded treatments for the six soil collection dates (May and September 2005, 2006, 2007; all P values > 0.05).

Carbon

Percent carbon in our samples began at 48% and ended at 51.5%, a 7.3% increase over time (data not shown). As with biomass, percent carbon did not differ significantly between habitat treatments through time ($F = 2.413$, $P = 0.1713$). Thirty-six percent of the variability in percent carbon is explained by time using the linear model ($r^2 = 0.356$, $F = 52.10$, $P < 0.0001$); the relationship between these variables is no better expressed using a single-exponential model ($r^2 = 0.351$, $F = 50.84$, $P < 0.0001$).

Nitrogen

Percent nitrogen of the wood tissue began at 0.15% and ended at 0.44%, a 176% increase over time (Fig. 2). As with biomass, there is no significant difference in percent wood nitrogen between the habitat treatments (not shown; $F = 0.118$, $P = 0.7426$). Linear regression explains slightly more of the variability in nitrogen through time than the single-exponential function (Fig. 2).

Carbon:Nitrogen

The ratio of carbon to nitrogen increased slightly from April 2005, when the study began, until July 2005 (Fig. 3). From July 2005 to March 2006 the C:N ratio dropped rapidly and then declined more slowly from March 2006 until June 2007, when the experiment was terminated. C:N as a function of time is slightly better explained by a single-exponential than a linear model (Fig. 3).

DISCUSSION

Through this 29-mo study, we aimed to determine the rate of decomposition and elemental composition of Ashe juniper wood in open and shaded habitats in a savannoid grassland. We found significant linear and single-exponential relationships between time and all response variables measured: percent remaining biomass, percent carbon and nitrogen, and C:N. Trends in biomass loss follow a negative exponential model (Harmon et al. 2000; referred to as the single-exponential model by Weider and Lang 1982) with rapid early decomposition followed by a slower phase. In a review of models commonly used in decomposition experiments employing litterbags, Weider and Lang (1982) conclude that exponential models (either single or double) best described decay dynamics, whereas asymptotic, linear, quadratic, and higher-order models presented a number of inherent problems. Research on wood decomposition consistently shows that during the early, quick phase of wood decomposition, less recalcitrant soluble components of plant tissue are utilized, such as simple sugars, starches, and proteins (Swift 1977; Weider and Lang 1982; Mattson et al. 1987; Fogg 1988; Schowalter 1991; Boddy and Watkinson 1994). This rapid decomposition is slowed when more recalcitrant substances, such as lignin, cellulose, fats, and waxes, dominate the substrate (Weider and Lang 1982; Mattson et al. 1987; Schowalter 1991; Boddy and Watkinson 1995; Mackensen et al. 2003).

In our study, percent nitrogen increased substantially more than carbon (176% vs. 7.5%). The decline in C:N through time therefore was driven by increases in percent nitrogen. C:N has long served as a measure of plant litter quality and, although it might be expected to increase as nitrogen is removed from the tissue and the recalcitrant carbon is left behind, declines in the ratio are common (e.g., Levi and Cowling 1969; Vossbrinck et al. 1979; Lambert et al. 1980; Foster and Lang 1982; Schowalter 1991; Heal et al. 1997; Laiho and Prescott 2004). An increase in percent nitrogen might be due to the loss of carbon through respiration and subsequent concentration of other elements in the tissue. Other processes such as nitrogen fixation, leaching, and fragmentation can cause nutrients to be concentrated (Harmon et al. 2004). It is also feasible that percent nitrogen of the wood increased as microbial colonizers mobilized nitrogen into their tissues from the soil environment (Schlesinger 1997; Whitford 2002).

An increase in nitrogen in decomposing tissue might be expected if Ashe juniper wood were unusually low in nitrogen, requiring microbes to seek and mobilize other sources of the element. In a study of the role of nitrogen in the decomposition process in a temperate forest, Levi and Cowling (1969) found that sapwood of the species with the lowest C:N ratio in their study (*Quercus falcata* Michx.) was 220:1, but the heartwood for this species was 550:1. On the high end, *Picea sitchensis* (Bong.) Carr. had sapwood with C:N of 740:1 and heartwood of 1 250:1. The initial C:N of Ashe juniper in our study was 306:1. This suggests that the C:N in the wood used in our study was on the low end of the range. Although low C:N ratio is generally considered an indication of high wood quality, low C:N ratios have been found in substrates that are slow to decompose (Meentemeyer 1978). Wood is a highly variable substrate and carbon resources vary in their accessibility. Therefore, structural correlates can be poor indicators of litter quality, particularly in desert ecosystems (Schaefer et al. 1985). On the other hand, *Juniperus* species are generally expected to be recalcitrant due to their high levels of antiherbivore and antimicrobial secondary metabolites (Blanchette 1995). As a result, their rates of decomposition are expected to be low, regardless of the availability of nitrogen.

Ashe juniper in this study decomposed with a decay rate (k) of 0.176. Given the presumably high secondary metabolite content of the wood of *Juniperus* and low rainfall during our study, we expected to find a relatively slow rate of decomposition. In a comparison of wood decomposition studies using snags, logs, and boles of 24 conifer and angiosperm species in temperate ecosystems, Harmon et al. (2004) report a range of decay rates of k from 0.009 to 0.354 among 85 measures. In a study of decay rates of 17 different woody species in a clear-cut forest of Southern Appalachians, Mattson et al. (1987) report a range of k from 0.015 to 0.261. Comparisons among studies utilizing a variety of species, substrate types, and sizes and habitats must be made with caution; however, these data suggest that the decay rate found for mulched Ashe juniper wood falls in the middle of the extremes (0.009 and 0.354).

Ashe juniper wood decomposition might be expected to occur more rapidly under tree–shrub complexes than in open grassland conditions, where is it is assumed that temperatures are higher and soils are drier. Abbott and Crossley (1982) demonstrate support for our initial assumptions in a study of the rate of decomposition of *Quercus prinus* L. wood in mesic and xeric sites in North Carolina. They found that the rate of decomposition for all size classes (diameter) of wood occurred more rapidly in mesic, clear-cut sites ($k = 0.139$) than xeric, clear-cut sites ($k = 0.059$), a finding they attributed to differences in soil moisture content. Likewise, Schowalter (1991) found that among four sites in North America, rates of wood decomposition for several *Quercus* spp. increased with increasing summer precipitation. Nonetheless, our results show that the rate of wood decomposition as well as carbon and nitrogen mineralization over a 2-yr period is equivalent in open and shaded microsites. Our ability to detect differences in mass loss between habitats might have been affected by the large variability in weights among wood samples. We attribute this variability, in part, to the lack of correction for mineral content in our samples. The lack of a difference between microsites also might be due to undetectable differences in soil water content between open and shaded treatments in the months with the highest average rainfall. It is noteworthy that this study was conducted in particularly dry years for this region. Therefore, we suspect that water was a limiting resource for both open and shaded treatments, reducing differences in rates of decomposition.

The effect of rainfall on the rate of decomposition in arid ecosystems is uncertain and remains an area of active research. Studies following leaf litter decomposition as a function of rainfall conditions in arid and semiarid ecosystems demonstrate contradictory results (Whitford et al. 1986; Montana et al. 1988; Moorhead and Reynolds 1989; Steinberger et al. 1990). It was long thought that the majority of decomposition in deserts occurred following rainfall events, when microbes and soil invertebrates were active; however, growing evidence from long-term studies suggests that in deserts and other arid ecosystems rainfall and rates of evapotranspiration are poor predictors of decomposition rates and processes (Schaefer et al. 1985; Whitford 2002; Throop and Archer 2009). It is now widely accepted that where water is a limiting resource, abiotic factors such as exposure to UV light, temperature, and fragmentation by raindrop impact might be more important predictors of the decomposition process than biotic factors (Pauli 1964; Schaefer et al. 1985; Montana et al. 1988; Steinberger and Whitford 1988; Moorhead and Reynolds 1989; Austin and Vivanco 2006; Throop and Archer 2009). Indeed, in a recent manipulative study under ambient conditions, Austin and Vivanco (2006) demonstrated that photodegradation (due to UV light exposure) was the dominant driver of leaf litter decomposition in the arid Patagonian steppe of Argentina.

Although central Texas is not a desert ecosystem, it is most certainly semiarid. Our study was not designed to address water, per se, as a factor in the decomposition process; however, we attribute the lack of difference in rates of decomposition in our wood to a lack of rainfall over the course of the study that reduced detectable differences in soil moisture. In addition, although not directly investigated here, we suggest that it also is possible that the lack of a difference in open and shaded treatments could be due to biotic and abiotic degradation processes variably dominating the two microclimates but operating at similar rates. This is clearly an area for further research.

MANAGEMENT IMPLICATIONS

Our finding that Ashe juniper mulch decomposes at similar rates in open and shaded habitat suggests that, following felling, placement of logs or mulch in shaded habitat will not increase wood decomposition during relatively dry periods and for the first 2 yr of decomposition. More important are the implications of our findings for nutrient cycling. This semi-tropical grassland ecosystem has undergone a transformation wherein large amounts of carbon and nutrient stores have shifted from belowground herbaceous biomass to aboveground woody biomass, a change that has likely resulted in slower nutrient cycling. The results of this study suggest that sites where Ashe juniper is cleared and left in place will experience an initial flush of nutrients, followed by a period of slower decomposition with limited nutrient input from the decomposing wood. We therefore recommend that land managers, aiming to reestablish grasslands, capitalize on the initial nutrient release by seeding or plugging within the first year of clearing. If grasses and forbs are established quickly following Ashe juniper removal there might be less competition for nutrients between plants and soil microbes.

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