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To the Graduate Council:

I am submitting herewith a dissertation written by Mali M. Hubert entitled "Plant community responses to interactive anthropogenic disturbances along a natural-wildland-urban gradient and undergraduate students' attitudes toward disturbances." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Ecology and Evolutionary Biology.

Monica Papes, Major Professor

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Vice Provost and Dean of the Graduate School

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Plant community responses to interactive anthropogenic disturbances along a natural-wildland-urban gradient and undergraduate students' attitudes toward disturbances

A Dissertation Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

Mali Marie Hubert
May 2022

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DEDICATION

To my husband Dalton for his unwavering support and my son Wesley for his constant comedic relief.

I love you most.

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ABSTRACT

Anthropogenic disturbances are defined as any change caused by human activity that alters biodiversity. Wildfire and urbanization disturbances are among the most influential on the landscape because of their individual and interactive properties. Areas deemed wildland-urban interfaces (WUI; area where environment intermingles with human-built structures) are increasing near protected lands because of human population growth and movement, which often facilitates fire ignitions by humans. Houses that are adjacent to or overlap with wildland vegetation can complicate protection of urban development and wildlands from fires. The expansion of the WUI due to population growth will exacerbate fire risk, which can ultimately cause shifts in plant community composition and diversity in densely populated regions like the eastern United States (U.S.). A fire that began in the Great Smoky Mountains National Park (GSMNP), Tennessee, U.S. in November 2016 and quickly spread to the neighboring town of Gatlinburg, Tennessee, created a natural experiment to investigate the interaction of fire and urbanization disturbances along the WUI and within the GSMNP.

To assess the impacts of wildfire and urbanization, consideration must be given to the direct impacts from human activities and the indirect consequences of human views toward such disturbances. Research has focused on understanding differing views and attitudes toward climate change, yet few studies have been conducted with a college-aged demographic to understand attitudes toward combined anthropogenic disturbances at a local scale.

Throughout my dissertation work, I investigated how the combined and individual effects of wildfire and urbanization affect both plant diversity and undergraduate students' attitudes. I provide evidence that: 1) the compounded disturbances of wildfire and urbanization are affecting plant community composition and diversity through time following the Chimney Tops 2 fire and 2) following a classroom intervention, undergraduate beliefs towards the deleterious effects of wildfire and urbanization on the environment increase, thus also increasing their intention to act.

Results from this dissertation will be useful in assessing general human impact on plant diversity in the southern Appalachian region, informing policy decisions at the regional level, and understanding how people feel toward anthropogenic disturbances in a region experiencing an increase in interacting disturbance events.

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INTRODUCTION

Disturbance is a natural component of ecological systems that can drive spatial and temporal heterogeneity of a community's composition and function (Turner 2010). At the same time, shifts in the natural disturbance regime due to human activity are among one of the greatest threats to biodiversity (Turner 2010). Increasing anthropogenic pressures (e.g., pollution, logging, human-caused wildfire, and urban encroachment) have created a need to understand not only the individual effects of anthropogenic disturbance events on ecosystems, but also the interactive effects of multiple co-occurring disturbances. Worldwide, extensive research across ecosystem and habitat types has been conducted to understand the effects of singular disturbances (e.g., Soulé et al., 1992; McKinney 2008; Mollot, Pantel, and Romanuk 2017; Bär, Michaletz, and Mayr 2019; Matula et al., 2020); however, multiple interacting disturbances are what ecosystems commonly experience, which can cause unexpected responses and alter ecosystem resistance and resilience (Turner 2010).

Linked and compounded disturbances alter community responses

Feedback between a post-disturbance landscape and subsequent disturbance events can drive ecosystem resistance and resilience, often termed "linked" or "compounded" disturbances (Buma 2015). A "linked" disturbance can alter the resistance of an ecosystem by increasing or decreasing the effect (i.e., severity, intensity, or likelihood) of subsequent disturbances (Simard et al., 2011; Buma 2015). Linked disturbances are spatially and/or temporally related and can be additive, synergistic (i.e., positive), or negative based on the legacy of the prior disturbance (Buma 2015). "Compounded" disturbances can interact by altering the resilience of a community to additional disturbances whereby the interaction determines the recovery time and state of the community (Paine et al., 1998; Buma and Wessman 2011; Simard et al., 2011; Buma 2015). Depending on prior disturbance history, species may benefit from multiple disturbance events due to competitive release or heterogenous forest structure (Buma 2015). Ultimately, linked disturbance events are driven by the legacy of a previous disturbance, whereas compound disturbances can create new novel conditions post-disturbance (Buma 2015). Though these terms are not interchangeable, both linked and compound disturbance reactions can arise from the same events. Historically, compound disturbance ecology has had a disproportionate focus on disturbance interactions involving fire, wind, and salvage logging (Buma 2015). To date, few studies have been conducted to understand compounding effects of urbanization and fire, especially within the wildland-urban interface.

Fire risk is increasing with population growth in the wildland-urban interface

The frequency and magnitude of wildfires are shifting with the progression of contemporary climate change and human population growth (Balch et al., 2017; Tepley et al., 2018). Human-induced climate change increases the likelihood of wildfire events through an increase in fire weather, which leads to an increase in the frequency and severity of wildfire events (Westerling et al., 2016). Additionally, the number of people living in the wildland-urban interface (WUI) can be an indicator of potential ignition points for wildfires (Pausas and Keeley 2021). The WUI is an area where houses are adjacent to or overlap with wildland vegetation and pose an increased fire risk (Cohen 2000; Cardille et al., 2001; Winter and Fried 2001; Radeloff et al., 2005). Radeloff et al. (2018) estimated that WUI area covers approximately 9.5% of the contiguous United States (U.S.) and is the fastest growing land-use type. Management strategies of wildlands and urban areas can shift depending on human population growth and economic priorities, with strategies ranging from allowing fires to burn in wilderness areas to intensive management in the WUI (Bowman et al., 2020). Large numbers of ignitions from human sources, ineffective fuel treatments, and poor urban planning leaves the WUI particularly vulnerable to disastrous effects from fire events (Bowman et al., 2020). The eastern U.S. specifically contains about 83% of the total WUI area nationwide (Theobald and Romme 2007). WUI areas are considered one of the main drivers of fire risk, because as a WUI fire spreads across various types of flammable sources it can cause structural damage, economic impacts, property losses, and loss of human and wildlife (Ganteaume et al., 2021).

Vegetation in the WUI is heterogenous and often consists of both native and exotic species which is different than vegetation in wildlands because it can provide horizontal fuel continuity (Ganteaume et al., 2021). Variations in WUI vegetation can act as a vector facilitating fire propagation from the WUI towards the wildland (Ganteaume et al., 2021).

Wildfire as an individual disturbance to plant communities in the eastern U.S.

Wildfire is well recognized for its capacity to (re)define plant communities (Pickett and White 1985; Petraitis et al., 1989; Huston 1994; Mackey and Currie 2000). Whether it is a result of anthropogenic or natural causes, wildfire (and the lack thereof) can determine the progression, distribution, structure, and function of vegetation across entire ecosystems (Bond et al., 2005; Bond and Keeley, 2005; Cowling et al., 2005). In addition to fire risk from an increase in the extent of WUI, there is increasing concern about the prospects of greater fire activity in southern Appalachia because decades of fire suppression have led to increased fuel load and the persistence of fire-intolerant plant communities. Fire suppression efforts have largely contributed to the creation of denser, more mesic forests often termed "mesophication" (Nowacki and Abrams 2008; Oakman et al., 2019). Fire-suppression coupled with moist microhabitat created by a closed-canopy, high tree densities, and smaller tree size (Parsons and Debenedetti 1979; Naficy et al., 2010; Scholl and Taylor 2010) supports the encroachment of fire-sensitive vegetation, like eastern white pine (*Pinus strobus*), red maple (*Acer rubrum*), yellow-poplar (*Liriodendron tulipifer*), American beech (*Fagus grandifolia*), and black gum (*Nyssa sylvatica*) (Brose et al., 2001; Nowacki and Abrams 2008; Oakman et al., 2019). Not only has the encroachment of these species collectively resulted in increased fuel loading, but also in increased over story basal area and landscape-level forest homogenization which can negatively influence future successional patterns (Oakman et al., 2019). Fire-intolerant plant communities in conjunction with a growing population have iteratively increased the likelihood of intense, potentially catastrophic, fire disturbance that was originally uncharacteristic of the southern Appalachian region (Allen 2007; Collins et al., 2011).

Fire severity has proven to be a useful metric for explaining post-fire reassembly of plant communities across affected landscapes. For example, well dispersing, pioneering species may be eliminated by competitive displacement following low severity fires (Gleeson and Tilman 1990). In contrast, frequent high severity fire disturbance often does not allow competitively stronger species (i.e., species with fast resource acquisition/depletion; Navas and Violle 2009) enough time to become established prior to the next disturbance. Variation in fire intensity can, however, translate to intermediate levels of severity, which can enhance plant productivity and richness (Beckage and Stout 2000). Accordingly, it has been proposed that site-specific species diversity occurs in areas subject to intermediate disturbance regimes that allow competitively stronger and high-dispersive species to co-exist (Connell 1978; Huston 1979; Beckage and Stout 2000).

Disturbance-adaptation in plant communities

While anthropogenic disturbances can cause direct selective pressures on organisms that live within the disturbance matrix, these disturbance pressures may also indirectly select for certain taxa. Plants found in areas with frequent low-intensity fire regimes are adapted to, and commonly dependent upon, fires (Beschta et al., 2004). These plant species often exhibit morphological, physiological, or reproductive characteristics that promote tolerance to fire or may even be required for species persistence (Beschta et al., 2004). Evidence from Lentile et al. (2007) suggests that the rise of increasingly severe fire regimes will favor the spread of exotic species that are tolerant of fire. Not only could this further enhance and encourage more frequent wildfire by increasing the continuity of fine fuel loads, it would likely elevate associated pressures (e.g., competition) that could speed the displacement or loss of at-risk native plants (Brooks et al., 2004; Fusco et al., 2019).

Similarly, urban areas often have homogenized plant diversity due to commonalities between urban areas such as: high coverage of impervious surfaces, and high occurrences of anthropogenic disturbance events that filter for species with similar traits and characteristics (Aronson et al., 2016). Some traits associated with adaptation to urban environments include biennial or perennial life cycle, wind pollination and dispersal mechanisms, flowering in mid-summer, seed and vegetative reproduction, and having a high demand for light and nutrients (Lososová et al., 2006; Aronson et al., 2016). Fragmentation in urban areas can also isolate certain plant populations, restrict pollinator services, and reduce competitive interactions to limit traits that select for competition characteristics (Dubois and Cheptou 2017). Expansion of the WUI can reinforce growth and establishment of plant communities that are already disturbance adapted, potentially prolonging biotic homogenization.

Attitudes toward disturbance can impact disturbance mitigation

Our ability to sustain forest health and reduce the risk of anthropogenic disturbance consequences rests on our capability to not only understand the effects of disturbance on the plant community, but also to recognize the existing attitudes and preconceived notions of humans that can influence policy or management actions. The literature has focused largely on understanding attitudes and feelings toward anthropogenic climate change (Hanrahan and Shafer 2019), but little attention has been given to other related disturbances. Our capability to initiate and inspire broad mitigation efforts toward anthropogenic disturbance events depends on the scientific understanding and attitudes of the community. Conceptualizing undergraduates' attitudes toward anthropogenic disturbances, specifically wildfire and urbanization, can inspire curriculum changes that could help connect anthropogenic disturbance concepts in introductory science courses. This connection could reach a much higher proportion of undergraduate students in broad disciplines to increase scientific literacy and raise awareness of the importance of these issues (Aubrecht 2018).

In the individual chapters below, I investigate how plant communities are responding to combined disturbances of wildfire and urbanization in one of the fastest growing WUIs in the U.S. and how undergraduate student attitudes vary toward these topics. Using the 2016 Chimney Tops 2 Fire in the Great Smoky Mountains National Park (GSMNP) and Gatlinburg, Tennessee, I examine the interactive effects of urbanization and wildfire on plant communities. In chapters I & II I found that: 1) compounded disturbances increased plant abundance and richness, but not diversity; 2) variation in plant composition was explained by fire severity; 3) sites with strongest compounded disturbances (i.e., high burn in exurban locations) had lower abundance and lower plant richness than sites with the least disturbance (i.e., no burn in natural locations), and 4) turnover in understory plant communities in the GSMNP and Gatlinburg was not exacerbated by wildfire; however, areas of compounded disturbance are experiencing seasonal increases in β-diversity, suggesting that environmental filtering is selecting disturbance-adapted plant taxa. In chapter III I found that: 1) student beliefs and intentions from pre- to post-intervention were positively correlated; 2) student beliefs toward urbanization were significantly different from pre- to post-intervention Wildfire and Urbanization Attitude Survey (WUAS), whereas wildfire beliefs and intention to act were not; and 3) student beliefs and intention to act toward anthropogenic disturbances generally did not differ between major or video types.

Results from these studies demonstrate the importance of: 1) compounded anthropogenic disturbances as drivers of plant community change and disturbance adaptation; 2) continuous monitoring of plant communities within WUI as human population expansion continues; 3) recognizing existing attitudes toward such disturbances to develop anthropogenic disturbance curricula at the college level, and 4) understanding how people feel about anthropogenic disturbances to inform policy and management decisions within the WUI.

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CHAPTER I:
CONTRASTING EFFECTS OF URBANIZATION AND FIRE ON UNDERSTORY PLANT COMMUNITIES IN A NATURAL SETTING AND A WILDLAND-URBAN INTERFACE

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ABSTRACT

As human populations expand and land-use change intensifies, terrestrial ecosystems can experience concurrent disturbances (e.g., urbanization and fire) that may interact and compound their effects on biodiversity. Unfortunately, this increases the susceptibility of ecosystems to biological invasions and altered ecosystem functioning. In the urbanizing landscapes of the southern Appalachian region of the United States of America (U.S.), fires in mesic forests have increased in frequency in recent years. However, 80 years of forest management practices aimed at fire suppression in this region may have decreased landscape resistance and/or resilience to high severity fire. Simultaneously, housing development is rapidly expanding in the wildland-urban interface, creating opportunities to examine the combined effects of urbanization and fire disturbances on plant communities when fires occur. Here, we investigated how understory plant communities were affected by a fire that varied in severity at sites in both Gatlinburg, Tennessee, and in the adjacent Great Smoky Mountains National Park. Our goal was to disentangle the individual and combined effects of fire and urbanization on plant community composition in the second growing season after a fire. Overall, we found a significant interaction effect of fire severity and location on total plant abundance, richness, and plant composition, whereas plant diversity was not significantly affected by this interaction. We infer that the understory plant communities in exurban locations (low-density residential development located near protected lands) were resilient following the pulse disturbance event (fire) because of their consistent exposure to the press disturbance of urbanization. Thus, our study indicates that understory plant communities exposed to press disturbances may have the capacity to respond more positively to subsequent disturbances. Our findings contribute new insights into how disturbances can interact to potentially alter patterns of biodiversity in the southeastern U.S.

INTRODUCTION

Spatial and temporal heterogeneity of biodiversity on a landscape is often influenced by anthropogenic disturbances that drive the function and succession of ecosystems (Turner 2010; Chang and Turner 2019; Danneyrolles et al., 2019), as well as population and community assemblages and ecological processes post-disturbance (Dale et al., 2002; Hillebrand and Kunze 2020). Humans have promoted heterogeneity intentionally and unintentionally through press and pulse disturbance practices such as land-use change and human-caused fire (Turner 2010), often at the same time (i.e., compounded disturbances; Paine et al., 1998). Pulse disturbances (e.g., storms, droughts, floods, pest outbreaks, fires) are stochastic events that alter the composition and biomass of ecological communities (Jentsch and White 2019; Hillebrand and Kunze 2020). On the other hand, press disturbances persist temporally and are chronic within an ecosystem (Collins et al., 2011). Ecosystems may be exposed to various environmental press events (e.g., eutrophication, nitrogen deposition), including those exacerbated by global change events due to human activity (e.g., sea-level rise, mean temperature increase; Collins et al., 2011). Over time, press and pulse events, individually and combined, change community composition and its relationships to ecosystem functioning (Smith et al., 2009; Collins et al., 2011).

Compounded disturbances may produce an increased (i.e., synergistic) change in the landscape compared to the sum of the individual effects of each disturbance, depending on the state of an ecosystem when it was disturbed (Paine et al., 1998; Turner 2010; Buma 2015). If a landscape has not recovered from an initial disturbance event, or if the initial disturbance is on-going, the effects of a second disturbance may be stronger than it may have been individually (Turner 2010). With expanding human populations, land-use change, and altered disturbance regimes, there is growing need to understand how multiple disturbances interact (Turner 2010; Buma 2015; Kleinman et al., 2019). Because disturbances may alter the resilience of forests to future disturbances (Paine et al., 1998; Bigler et al., 2005), understanding the effects of compounded disturbances is critically important for predicting landscape-level changes and to successfully meet management goals (Kleinman et al., 2019). As global change pressures from human populations intensify, interpreting how compounded disturbances transform forests may depend on complex biotic relationships (Tepley et al., 2018).

Fire is an ecological disturbance that is altering plant communities in many regions globally and that is expected to become more frequent and intense due to climate change (Abrahamson et al., 2021). Human activities, combined with more frequent droughts, are likely to increase the frequency and intensity of fires across the U.S. (Pederson et al., 2010; Davidson et al., 2012; Burkle et al., 2015). Beyond its direct impacts on plants, fire can also alter soil water availability by changing hydrophobicity and nutrient availability through volatilization, among other effects (Certini 2005), and may ultimately change native plant community composition and structure (Thonicke et al., 2001; Rieske 2002). At least a few years following a fire, plant abundance and diversity may be lower in high severity burn areas compared to other burn severities, while species richness may initially increase rapidly post-fire and then plateau (Romme et al., 2016; Strand et al., 2019). Although recent notable forest fires in the U.S. have occurred in the west, Radeloff et al., (2018) identified eastern U.S. as a growing concern, particularly in areas with rapid population growth.

Human population growth increases fire risk in areas denoted as a wildland-urban interface (WUI) (Radeloff et al., 2005; Appendix I: Figure 1.1). In WUI areas, houses are adjacent to or overlap with wildland vegetation, a setting that complicates protection of urban development from fires (Cohen 2000; Winter and Fried 2001; Radeloff et al., 2005) and that often facilitates fire ignitions by humans (Cardille et al., 2001). Beyond fires, native plant communities in the WUI are also threatened by fragmentation and introduction of non-native species (Gonzalez-Abraham 1999; Radeloff et al., 2018). Radeloff et al. (2018) estimated that WUI area covered approximately 9.5% of the conterminous U.S. in 2010, and specifically highlighted an area of rapid development in Gatlinburg, TN. Disturbances associated with WUI can lead to changes in native vegetation structure and more pronounced conditions for fire (Bowman et al., 2011; Radeloff et al., 2018). The expansion of urbanized areas (such as the WUI) has been associated with the homogenization of plant communities (McKinney 2006; Walker et al., 2009) and limited native species richness and species dispersal (Freitas et al., 2020). Interactions between fire and urbanization will likely exacerbate fluctuations in plant communities through land-use changes and other anthropogenic pressures (Halofsky et al., 2020). The proximity of urbanization to protected areas such as the Great Smoky Mountains National Park (GSMNP) requires forest fire suppression, thus studies at the WUI in this region are paramount for understanding the interaction of two impactful disturbance types to mitigate effects and restore natural plant communities.

A fire that began in GSMNP in November 2016 and quickly spread to the neighboring town of Gatlinburg, TN (Appendix I: Figure 1.2) created a natural experiment to investigate the coupling of fire (discrete; pulse disturbance) and urbanization (gradual; press disturbance) along the WUI. Using this natural experiment of varying fire severity in both natural (GSMNP) and exurban (Gatlinburg) locations, we addressed the separate and combined roles of these disturbances on the composition of understory plant communities. We tested two specific hypotheses: **H1.** Plant abundance and alpha (α) diversity will be negatively affected by the compounded effect of fire and urbanization, while fire alone will have a positive effect by increasing landscape heterogeneity, and **H2.** Individual effect of fire severity on community homogenization will be stronger than the individual effect of urbanization, while the combined effect of fire severity and urbanization will change the composition of plant communities. The results of this study provide new insights into the combined effects of urbanization and fire disturbances on forest understory plant composition.

METHODS

Study Area

This study took place in the WUI between Great Smoky Mountains National Park (GSMNP) and the exurban Gatlinburg, Tennessee, U.S. The plant communities in GSMNP are diverse, consisting of about 1,600 species of flowering plants, including approximately 100 native tree species and over 100 native shrub species (Jenkins 2007). The composition of plant communities in the GSMNP is shaped by strong variation in topography, moisture, and other environmental gradients (Whittaker 1956; Kumar et al., 2015). Gatlinburg is an exurban community located in Sevier County, Tennessee, adjacent to GSMNP, with an estimated U.S. Census resident population of 4,144 in 2018 (United States Census Bureau, 2018).

Before fire suppression practices began in GSMNP in the 1930s, pine-oak forests experienced fire frequently, with a return interval of approximately 4-8 years (Flatley et al., 2013), which maintained fire-resistant pine (*Pinus*) and oak (*Quercus*) species (Harmon 1982; Reilly et al., 2006). However, fire suppression efforts within the park has homogenized forests with tree species such as red maple (*Acer rubrum*), black gum (*Nyssa sylvatica*), eastern hemlock (*Tsuga canadensis*), and sourwood (*Oxydendrum arboreum*) that are shade-tolerant and fire-sensitive. These homogenized forests also have a well-developed shrub layer that includes mountain laurel (*Kalmia latifolia*), blueberry (*Vaccinium*) species, and huckleberry (*Gaylussacia*) species (Reilly et al., 2006; Knott et al., 2019).

Sampling Design

We surveyed plant communities after the 2016 fire at sites in and around Gatlinburg (hereafter "exurban") and in GSMNP (hereafter "natural"). Exurban sites are "low-density residential development scattered outside of suburbs and cities, and as commercial strip development along roads outside cities" (Daniels 1999). We used stratified random sampling in ESRI ArcMap to select 18 sites, nine in natural locations and nine in exurban locations, and to represent fire severity categories, three no burn, three low/medium burn, and three high burn, in each of the two location types. We obtained fire severity information from a GIS map provided by the National Park Service (NPS) and generated by U.S. Forest Service Remote Sensing Application Center using delta normalized burn ratio (dNBR) calculated from Landsat satellite images (spectral bands) directly after the fire in December 2016 as:

$$\text{dNBR} = \text{NBR pre-fire} - \text{NBR post-fire}$$

where NBR is the normalized burn ratio:

$$\text{NBR} = \frac{\text{LandsatBand4} - \text{LandsatBand7}}{\text{LandsatBand4} + \text{LandsatBand7}}$$

The dNBR scores are used to differentiate between unburned and burned areas, the latter separated in vegetation fire severity categories. No burn sites are within the footprint of the fire but did not experience fire damage directly. All sites were chosen based on dominant forest vegetation type and elevation to minimize the potential confounding effects of these variables (Appendix I: Table 1.1) and were within 300 m from a road or trail to ensure that they could be accessed safely. Field data collection took place May to September of 2018, the second growing season after the 2016 fire. Sampling dates were set to capture seasonal differences in plant community composition (spring, summer, and fall).

We also used the normalized difference vegetation index (NDVI) derived from satellite MODIS data at 250 m resolution (Didan 2015) to calculate, for each site, delta normalized difference vegetation index (dNDVI) of the growing season before fire, in 2016, and after fire, in 2017. We downloaded the MODIS NDVI from United States Geological Survey (USGS) Land Processes Distributed Active Archive Center with the AppEEARS tool (AppEEARS Team 2020). To calculate dNDVI scores, we subtracted the NDVI average of June, July, and August 2017 (after the fire) from the NDVI average of months June, July, and August 2016 (before the fire). Resulting dNDVI scores were used in addition to burn categories based on dNBR, to quantify fire damage to forest canopy in the first leaf-on season post-fire, relative to canopy greenness in the leaf-on season before the fire. Higher dNDVI scores indicate greater change in forest canopy between the two growing seasons, thus a higher severity of fire. By contrast, the NPS fire severity map was created in December 2016 (leaf-off season), immediately after the fire.

Data Collection

Each randomly selected site in ESRI ArcMap represented a 90 x 90 m area of a single burn severity category. In the field, from the center point of the 90 x 90 m site, we randomly selected two 1x1 m permanent plots that we marked with metal pins and flags. We used a 1x1 m quadrat to survey and record all plant taxa at all 18 sites. Our plot size selection was based on

National Ecological Observatory Network protocol (NEON; Elmendorf 2020). We surveyed the 36 plots five times in 2018 (spring: 20 April-4 May; summer: 4-6 June, 16-18 July, 13-15 August; and fall: 14-16 September). We used field guides and dichotomous keys (Petrides 1986; Horn and Cathcart 2005; Chester et al., 2015) to identify to genus and species all herbaceous plants and tree seedlings within the quadrat and counted the number of individuals of each taxon. Unidentified plants were photographed, and specimens were collected from outside of the plots to reduce disturbance within the established long-term plots. Samples and photographs were keyed and verified with herbarium specimens at the University of Tennessee, Knoxville Herbarium (TENN Herbarium). Individuals that could not be identified to at least genus level due to immature characteristics or herbivore damage were assigned observational taxonomic unit numbers.

Data Analysis

We calculated two levels of plant taxonomic diversity: α (within a site) and *β* (among sites). For α diversity, we pooled the data from the two 1x1 m plots and calculated three different diversity indices corresponding to Hill numbers of orders 0 (^0D; taxa richness), 1 (^1D; Shannon diversity; Shannon 1948), and 2 (^2D; Simpson diversity; Simpson 1949), which represents diversity of all taxa, common taxa, and the most dominant taxa, respectively (Chao et al., 2014). Quantifying diversity using Hill numbers is advantageous because each Hill number represents "the effective number of species" in a community, defined as the count of equally abundant species which gives the same diversity metric value as the focal assemblage (Jost 2006; Chao et al., 2014). Quantifying diversity using Hill numbers of orders 0, 1, 2 also provides diversity metrics that vary in terms of their sensitivity to relative taxa abundances. ^0D, commonly known as taxa richness, counts the number of unique taxa regardless of their abundances whereas ^1D, the Shannon diversity, weighs species proportional to their relative taxa abundance, and ^2D, the Simpson diversity, weighs abundant taxa more heavily than in ^1D (Chao et al. 2014). We report ^1D (Shannon diversity) as:

$$^1D = -\sum_{i=1}^{S} p_i \ln p_i$$

where p_i is the proportion of the *i*th taxa (Shannon 1948).

We only analyze and report results for ^0D (richness) and ^1D (Shannon diversity) in the text (see Appendix I: Table 1.1 for analyses using ^2D). To calculate *β* diversity, we used Whittaker's multiplicative equation (Whittaker 1960):

$$ß = \frac{\gamma}{\alpha}$$

where *α* is the site diversity (^0D, richness) and *γ* is the diversity resulting from pooling data across all sites to analyze change along the fire severity gradient and between locations. Beta diversity values were calculated for each fire severity and location combination (Appendix I: Table 1.1).

To test H1, that plant abundance and α diversity will be negatively affected by the compounded effect of fire and urbanization, while fire alone will have a positive effect by increasing landscape heterogeneity, we fitted generalized linear mixed models (GLMMs) that modeled site-level abundance (individual stem counts) and taxa richness (^0D) in a given sampling season as a function of three fixed effect variables: dNDVI (quantitative measure of fire severity), location type (natural, exurban), sampling month, and their pairwise interactions. Site was included as a random intercept to account for the repeated sampling of sites across seasons. To assess the effect of fire severity and urbanization on Shannon's diversity (${}^{1}D$) we used linear mixed models (LMM), with site as the random effect in a given sampling season and three fixed effect variables: dNDVI, location type, sampling month, and their interactions. The response variables of the GLMMs (abundance and ${}^{0}D$) were modeled as having Poisson errors to account for sampling across multiple months at each site, and we included a random intercept for each site; ${}^{1}D$ for LMM was modeled as having a Gaussian distribution instead of Poisson since it is not count data. Models using the Poisson distribution were assessed for over-dispersion and were corrected by incorporating over-dispersion into the model using an observation-level random effect.

We also hypothesized (H2) that the individual effect of fire severity on community homogenization will be stronger than the individual effect of urbanization, while the combined effect of fire severity and urbanization will change the composition of plant communities. To test for community homogenization in natural and exurban locations, we used the betadisper function in the R package vegan (Oksanen et al., 2016) that evaluated whether dispersion of variances among sites within location was homogenous. Then, we used the adonis function of the same R package to run a non-parametric permutational analysis of variance (PERMANOVA; Anderson 2001; Anderson 2006) to test whether community composition in natural and exurban sites was significantly different under each fire severity category; in other words, we examined whether fire severity determined plant compositional differences between location types (natural and exurban). We organized our data in site-by-taxa matrices of taxa presence-absence data (converted to Sørensen distances) and abundance data (converted to Bray-Curtis distances). To facilitate visual interpretation, we used a three-dimensional non-metric multidimensional scaling (NMDS) ordination on plant abundance. The NMDS was performed by using the metaMDS function with Bray-Curtis dissimilarity index in the R package vegan (Oksanen et al., 2016).

All statistics and graphical representation were performed using the packages: "BiodiversityR", "car", "dplyr", "ggarrange", "ggplot2", "lme4", "MASS", "multcomp", "tidyverse", "vegan" and "viridis" in RStudio v. 4.0.3.

RESULTS

We identified a total of 223 plant taxa in the understory at 18 sites in natural and exurban locations in 2018. Overall, the understory consisted of 89% perennial and 11% annual taxa, separated in forbs (61%), graminoids (6%), shrubs (9%), subshrubs (4%), tree saplings (12%), and vines (8%). The most abundant herbaceous taxa among all sites included: *Viola spp.* (Violet), *Urtica dioica* (Stinging Nettle), *Toxicodendron radicans* (Poison Ivy), and *Packera aurea* (Golden Ragwort). The most abundant tree saplings were *Acer* (Maple), *Pinus* (Pine), and *Quercus* (Oak) species; see Appendix I: Table 1.2 for taxa by location and fire severity.

Across the natural sites, we observed the highest richness (as measured by ${}^{0}D$) at no burn sites (${}^{0}D = 30.7$), followed by the low/medium burn sites (${}^{0}D = 27.3$); high burn sites had the lowest richness (${}^{0}D = 10.7$; Appendix I: Table 1.1). Within the exurban locations, we recorded the highest taxa richness at high burn sites (${}^{0}D = 21.7$), followed by low/medium burn (${}^{0}D = 18.3$), and no burn sites (${}^{0}D = 17.7$). Similar to ${}^{0}D$, α diversity (Shannon's diversity, ${}^{1}D$) across the natural locations was lowest at high burn sites (${}^{1}D = 4.199$; Appendix I: Table 1.1), whereas the highest was at the low/medium burn sites (${}^{1}D = 6.565$), followed by no burn sites (${}^{1}D = 4.798$). In contrast with natural locations but similar to ${}^{0}D$ results, exurban locations exhibited the highest α diversity at high burn sites (^1D = 7.117), followed by no burn sites (^1D = 5.559) and low/medium burn sites (^1D = 4.432). When examining diversity among sites, we obtained the highest β diversity at exurban no burn sites (β = 5.714), followed by exurban high burn sites (β = 5.319); the natural high burn sites had the lowest β diversity (β = 3.424; Appendix I: Table 1.1).

The GLMMs and LMM found partial support for our H1: increased fire severity had a significant negative effect on abundance and richness (^0D) between natural and exurban locations, but not on Shannon's diversity (^1D). Specifically, our GLMMs indicated significant differences of total plant abundance (Appendix I: Table 1.3; Figure 1.3A) and richness (Appendix I: Table 1.3; Figure 1.3B) by the interaction of fire severity measured by dNDVI scores and location. In natural locations, abundance in high burn sites was 130% lower relative to no burn sites, whereas in exurban locations abundance in high burn sites was 30% greater than in no burn sites (Appendix I: Table 1.1). Abundance in low/medium burn sites was 51% lower in exurban locations than low/medium burn sites in natural locations (Appendix I: Table 1.1). Similarly, in natural location richness in high burn sites was 96% lower relative to no burn sites, whereas in exurban locations richness in high burn sites was 20% greater than no burn sites; lastly, richness in low/medium burn sites at exurban locations was 39% lower relative to low/medium burn sites at natural locations (Appendix I: Table 1.1). The results of LMM, evaluating the effect of location and fire severity on Shannon's diversity (^1D) showed only marginal significance (Appendix I: Table 1.3; Figure 1.3C).

We found compositional differences among sites, providing support for our H2. Specifically, beta dispersion analysis confirmed that the variances were homogeneous within exurban and natural locations, across fire severities (F = 1.086, P = 0.300), thus providing support for the first part of our H2, that the individual effect of fire severity on community homogenization will be stronger than the individual effect of urbanization. The result of homogeneity of variances allowed us to run PERMANOVA analyses and test the second part of H2, that the combined effect of fire severity and urbanization will change the composition of plant communities. We found that the variance in composition between the location types and across fire severity categories, and the interaction between location and fire severity, were significant (Appendix I: Table 1.4). This indicated that plant composition was different in multivariate space among sites. The PERMANOVA also showed that the individual effect of fire severity on community compositional differences was stronger than the individual effect of urbanization (R^2; Appendix I: Table 1.4), thus providing additional support for the first part of our H2. Plant composition was statistically different among sites due to location and fire severity and their interaction, with most of the variation in composition explained by fire severity. An NMDS of the abundance data showed separation for all fire severities at natural locations and relative overlap in community composition between the fire severity categories across sampling months in exurban locations (Appendix I: Figure 1.4). The overlap of the ordination hulls in exurban locations indicates that the sites across fire severities are compositionally similar, whereas the separation between the hulls in natural locations across fire severities indicates compositional dissimilarity.

DISCUSSION

In this study, we analyzed differences in understory plant communities in the second growing season after a mixed-severity fire affected both natural and exurban areas in the southern Appalachian region. Our results show that plant community abundance and richness differ in response to fire severity depending on the degree of urbanization. The pulse fire disturbance in 2016 heterogenized community composition in the GSMNP whereas in the city limits of Gatlinburg it promoted disturbance-adapted plant community dynamics established from press urbanization disturbance. Overall, we found: (i) a significant fire severity by location interaction such that total plant abundance was highest in natural areas but total plant abundance increased with increasing fire severity in exurban areas (Appendix I: Figure 1.3A); (ii) a significant fire severity by location interaction such that total plant richness peaked at intermediate fire severity in natural locations, but also peaked in unburned sites and decreased with fire severity in exurban locations (Appendix I: Figure 1.3B); (iii) increased fire severity and location did not have an effect on α diversity (Appendix I: Figure 1.3C); and (iv) a significant effect of fire severity by location interaction on plant composition (Appendix I: Figure 1.4).

Intermediate fire severity can encourage diversity in natural locations

Disturbance processes, especially fire, have been known to drive diversity in ecosystems (Connell 1978; Huston 1979, 2014; Pausas and Riberio 2017). A study by Lentile et al., (2007) noted that plant cover was dominated by forbs after a high severity fire, but that abundance and richness varied, regardless of burn severity. In our study, plant abundance decreased in natural areas as fire severity increased, but generally increased in exurban locations such that there was a greater abundance in burned exurban sites than natural sites. Similarly, as fire severity increased, plant taxa richness in natural areas peaked at intermediate disturbance then declined but showed the opposite pattern in exurban locations. Forest vegetation is often resilient following a high severity fire, despite the creation of a fragmented landscape, compared to pre-fire vegetation and environmental conditions (Lentile et al., 2007). Three studies within a review by Miller and Safford (2020) found that richness peaked at low to intermediate level fire severity because of the historic fire regime, which corroborates our findings in natural sites (DeSiervo, Jules, and Safford 2015; Morgan et al., 2015; Richter et al., 2019). The heterogeneity established by mixed-severity fires creates conditions suitable for multiple taxa, thus richness increases on the landscape (Strand et al., 2019). The increased richness in our natural sites could indicate that opportunistic and fire-adapted, early successional taxa are recolonizing from a historic seedbank or emigrating from a local species pool (Pearse et al., 2018).

In exurban landscapes where anthropogenic pressures are strong, biodiversity is often driven by human values, preferences, and activities (Aronson et al., 2016). Species in these areas often must pass through several filters (e.g., land-use history, microclimate, species interactions) to establish populations and persist (Aronson et al., 2016). In our study, plant taxa abundance and richness increased in exurban areas with increasing fire severity, in contrast with natural areas. This could indicate that the fire is creating more available niche space for taxa to persist. The fire disturbance may have reduced competitive pressure from other taxa that are more sensitive to anthropogenic pressures.

An increase in taxa diversity at intermediate disturbance levels is expected under the intermediate disturbance hypothesis (IDH; Huston 1979; Huston 2014), however we did not find support for it when analyzing Shannon's diversity (^1D) across fire severity or location; instead, site to site differences were more important to α diversity (Appendix I: Table 1.3). The lack of effect on ^1D can be explained by the fact that rare, low abundance, species are eliminated by fire (Appendix I: Figure 1.3C). Persistent land alteration and management can often homogenize communities and environmental conditions, which can additionally alter ecosystem stability (MacDougall et al., 2013). A study by MacDougall et al. (2013) found that persistent human activity can weaken diversity-related mechanisms needed to respond to sudden disturbances.

Rare species that were previously adapted to prior environmental conditions and are unable to persist after a new disturbance event are functionally eliminated or sparse.

The plant composition was generally heterogeneous across fire severities within natural sites (Appendix I: Figure 1.4), but composition was most variable at low/medium burn sites, potentially indicating that small gaps created in the canopy by fire are promoted plant community change. Contrary to this, the β diversity across low/medium burn sites in natural locations was low ($\beta = 4.453$; Appendix I: Table 1.1). A study by Reilly et al., (2006) proposed that life history characteristics of dominant trees and shrubs, and community resilience from fire-adapted taxa such as pine, could explain the minimal effect of fire on β diversity and taxa turnover. However, fire suppression in the GSMNP has generally limited the distribution of fire-adapted plant communities to higher elevations (Lafon et al., 2017). The prevalence of pine-oak dominated forests in the southern Appalachians that are associated with drier mid-elevation slopes and ridges can be attributed to past frequent fires (Whittaker 1956; Harmon 1982; Reilly et al., 2006).

Exurban conditions alter plant responses to other disturbances

Due to population growth and expansion, urbanized areas are more likely to experience additional disturbance events compared to more natural landscapes (Beal-Neves et al., 2020). In our study, exurban areas experienced an increase in plant abundance and richness as fire severity increased, whereas natural areas experienced a decrease (Appendix I: Figure 1.3). The increase in plant abundance in exurban areas could be attributed to taxa with short time to reproductive age and press disturbance (i.e., urbanization) limiting competition with taxa more sensitive to disturbance (Kondoh 2001; O’Connor et al., 2017). Additionally, the increase in richness with fire severity could be explained by the moderate levels of human disturbance at our exurban sites, promoting coexistence among disturbance-adapted taxa (McKinney 2008). Further evidence for community persistence in exurban areas was given by the significant individual effects of fire severity and urbanization (and their interaction) on plant composition. While plant composition was homogeneous at exurban locations (Appendix I: Figure 1.4), more research is needed to fully understand community responses to these combined pulse and press disturbances.

Interactions of successive disturbances

Studies have shown that prior disturbance events can strongly influence the response of plant communities to successive disturbances and that low-severity press disturbances may be beneficial to increase resilience to more severe disturbances (Kulakowski and Veblen 2002; 2007; Davies et al., 2009). However, the effects of successive disturbances on the community depend heavily on the impact of the preceding disturbance (Shinoda and Akasaka 2020). The negative impact of a subsequent disturbance can be amplified by the negative effect of an initial disturbance (Paine et al., 1998) and increases in fuels from prior disturbances can increase fire severity (Kulakowski and Veblen 2007). Pulse disturbance characteristics reflect ecosystem resistance and define the level of resilience of that ecosystem (Jentsch and White 2019). In our study, fire severity effects on plant communities in exurban locations may have been stronger due to the ongoing disturbance of urbanization. The significant increase of plant abundance, richness, and change in community composition by fire severity in exurban locations indicate a positive effect of press disturbance (urbanization) after a subsequent disturbance event (fire).

Fire suppression creates homogenized fire-intolerant plant communities

Fire-adapted species may propagate to mesic landscapes; however, community resilience is weak in absence of recurrent fire, with fire-intolerant and shade-tolerant species promoting mesophication, which leads to fire-intolerant communities such as mesophytic hardwoods

(Nowacki and Abrams 2008). In absence of fire, forest mesophication in GSMNP may suggest that the landscape has become homogenized with species that are intolerant of fire (Nowacki and Abrams 2008). In our study, plant composition was statistically different when considering fire severity and location type, as well as the interaction of the two disturbances. This may indicate that the recurrent mesophication that GSMNP has been experiencing for decades hindered community resilience and resistance to high severity fire. In exurban areas, increases in abundance and richness with increasing fire severity could be occurring because of environmental filtering, effectively selecting for disturbance resilient and resistant taxa thus changing the community composition of the area (Pearse et al., 2018). The rate of expansion of the WUI is faster than any other land cover categories (water, developed, barren, forested upland, shrubland, non-natural woody, herbaceous upland, natural/semi-natural vegetation, herbaceous planted/cultivated, and wetlands) included in the National Land Cover Database (NLCD) (Homer et al., 2015; Radeloff et al., 2018). This expansion implies an increased risk of fire (Radeloff et al., 2018), which poses risks for humans, in addition to native plant diversity.

Conclusion

Compounded disturbance ecology is a relatively understudied field that has a focus on fire, wind, and salvage logging (Kleinman et al., 2019) and minimal investigations of urbanization, even though WUI areas are expanding with human population growth. Our study addresses this gap by examining the effects of a pulse fire event in conjunction with the press disturbance of urbanization on herbaceous understory plant communities in the southern Appalachian region. Our study found that compounded disturbance increased plant abundance and richness (^{0}D), but not diversity (^{1}D). Additionally, plant composition was statistically different among sites, with most of the variation in composition explained by fire severity. The sites with strongest compounded disturbance (i.e., high burn exurban locations) had lower abundance and lower ^{0}D than sites with the least disturbance (i.e., no burn natural locations). Moreover, compounded disturbance sites experienced greater abundance and richness than sites with only fire disturbance (i.e., high burn natural locations). Taxa at exurban sites may be subjected to additional environmental filtering from the natural pool of species (i.e., GSMNP) and therefore may be inherently more disturbance-adapted and resilient following a subsequent pulse disturbance event (i.e., fire). The differences in plant community response due to varying degrees of disturbance will require nuanced management strategies going forward.

Future work on compounded disturbances will likely reveal further important patterns in plant communities that will have extended consequences for overall forest dynamics, but also the associated species that depend on plants as well as ecosystem processes that emerge from these species' interactions. Thus, compounded pulse and press disturbances have the potential to make wholesale changes to forest ecosystems.

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APPENDIX I

TABLES

Table 1.1. Hill numbers ^0D (average species richness), ^1D (Shannon diversity), ^2D (Simpson diversity), and β (Beta diversity) associated with location, fire severity, ecogroup (dominant forest vegetation type, source: National Park Service, IRMA Portal, Geospatial data for the Vegetation Mapping Inventory Project of Great Smoky Mountains National Park), and elevation (m; measured in the field with a GPS unit).

Location	*Fire severity*	*Ecogroup*	*Elevation*	*Diversity indices*			
				^0D	^1D	^2D	β
Natural	High burn	Chestnut Oak	547.4	8	6.337	6.962	3.424
Natural	High burn	Chestnut Oak	547.4	15	3.490	9.085	
Natural	High burn	Chestnut Oak	547.4	9	2.769	2.390	
Natural	Low/Medium burn	Chestnut Oak	630.0	28	9.030	4.005	4.453
Natural	Low/Medium burn	Montane Oak-Hickory	576.7	30	6.508	6.731	
Natural	Low/Medium burn	Chestnut Oak	628.8	24	4.157	2.804	
Natural	No burn	Montane Oak-Hickory	517.1	34	5.359	9.449	4.650
Natural	No burn	Successional Hardwoods	407.0	25	6.041	5.196	
Natural	No burn	Successional Hardwoods	428.7	33	2.994	4.751	
Exurban	High burn	*Unspecified*	570.1	21	5.324	8.918	5.319
Exurban	High burn	*Unspecified*	392.3	18	6.664	6.321	
Exurban	High burn	*Unspecified*	585.0	26	9.363	5.158	
Exurban	Low/Medium burn	*Unspecified*	535.0	21	3.152	6.878	4.362
Exurban	Low/Medium burn	*Unspecified*	579.0	18	4.156	10.75	
Exurban	Low/Medium burn	Human Influence	415.5	16	5.987	9.276	
Exurban	No burn	*Unspecified*	408.8	18	5.555	5.895	5.714
Exurban	No burn	*Unspecified*	415.4	22	7.237	4.614	
Exurban	No burn	Montane Oak-Hickory	524.2	13	3.884	5.525	

Table 1.2. Common taxa observed across natural and exurban locations by fire severity. Common is defined as more than 50 individuals within the taxa observed per location and fire severity.

Location	*Fire severity*	*Taxa*
Natural	High burn	*Kalmia latifolia*
		Smilax spp.
	Low/Medium burn	*Acer spp.*
		Euonymus americanus
		Fagus spp.
		Liriodendron tulipifera
		Lysimachia quadrifolia
		Oxydendrum arboreum
		Packera aurea
		Pinus spp.
		Potentilla canadensis
		Smilax spp.
	No burn	*Acer spp.*
		Bignonia capreolata
		Euonymus americanus
		Galium aparine
		Hepatica spp.
		Packera aurea
		Toxicodendron radicans
		Viola spp.
Exurban	High burn	*Chamaenerion angustifolium*
		Packera aurea
		Panicum spp.
		Pinus spp.
		Smilax spp.
	Low/Medium burn	*Acer spp.*
		Lysimachia quadrifolia
		Panicum spp.
		Robinia pseudoacacia
		Smilax spp.
	No burn	*Acer spp.*
		Amphicarpaea bracteata
		Glechoma hederacea
		Impatiens capensis
		Toxicodendron radicans
		Urtica dioica

Table 1.3. Effects of fire and urbanization analyzed with generalized linear mixed models (for abundance and plant richness) and a linear mixed model (for plant diversity). Estimate (E), standard error (SE), z/t value, and associated P-values (*P*) for three response variables (total abundance, richness, and Shannon's diversity) in exurban and natural locations, across a fire severity gradient indicated by dNDVI (delta normalized difference vegetation index).

	Total abundance				*Richness* (^0D)				*Shannon diversity* (^1D)			
Predictors	*E*	*SE*	*z*	*P*	*E*	*SE*	*z*	*P*	*E*	*SE*	*t*	*P*
Random effect: Site	4.062	0.126	32.34	2.00×10^{-16} ***	2.221	0.062	35.67	2.00×10^{-16}	5.546	0.553	10.02	9.10×10^{-8} ***
dNDVI	0.377	0.152	2.490	0.013 *	0.123	0.075	1.640	0.101	-0.076	0.665	-0.114	0.912
Location	-0.079	0.176	-0.450	0.655	0.163	0.085	1.920	0.055	1.488	0.774	1.920	0.075
Month	0.122	0.045	2.700	0.007 **	0.058	0.035	1.640	0.102	0.075	0.175	0.427	0.670
dNDVI * Location	-0.910	0.188	-4.850	1.22×10^{-6} ***	-0.426	0.093	-4.590	4.47×10^{-6} ***	-0.964	0.820	-1.177	0.259
dNDVI * Month	0.035	0.034	1.030	0.305	0.024	0.025	0.950	0.344	0.199	0.127	1.579	0.119
Location * Month	0.035	0.065	0.540	0.588	0.003	0.048	0.060	0.953	-0.035	0.252	-0.139	0.890

Statistical significance is denoted by the following: p < 0 '***', p < 0.001 '**', p < 0.01 '*', p < 0.05 '.'

Table 1.4. Effects of fire and urbanization on herbaceous plant community composition. Differences in plant community composition were measured by location (natural and exurban), fire severity (high burn, low/medium burn, no burn), and their interaction. Sum of squares (sum of sqs), R^2 value, F value (*F*), and associated P-values (*P*) are reported.

Fixed effects	*Sum of Sqs*	*R^2*	*F*	*P*
Location (Exurban and Natural)	1.624	0.045	5.320	0.001 ***
Fire severity	5.563	0.152	9.113	0.001 ***
Location * Fire severity	3.623	0.100	5.936	0.001 ***

Statistical significance is denoted by the following: p < 0 ‘***’, p < 0.001 ‘**’, p < 0.01 ‘*’, p < 0.05.

FIGURES

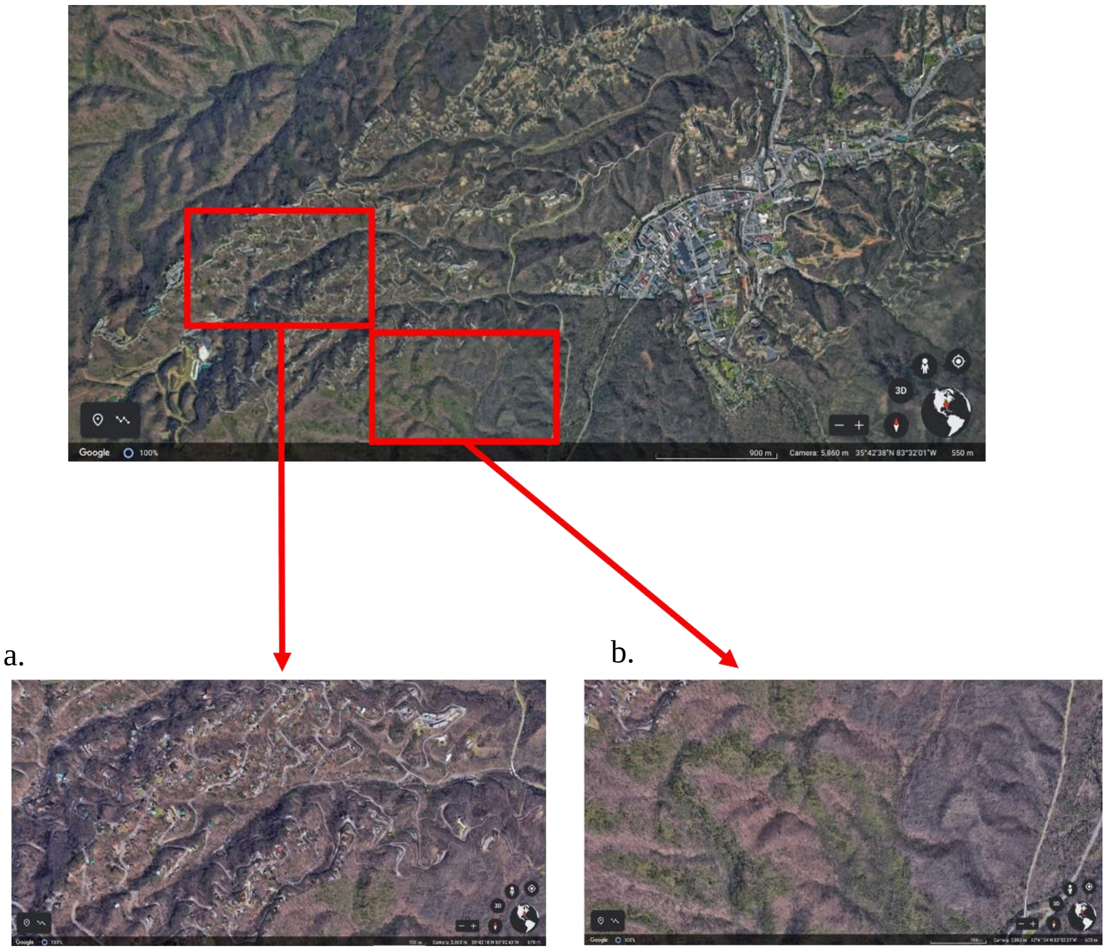

Figure 1.1. An aerial image of Gatlinburg, Tennessee as an example of a wildland-urban interface (WUI). Residential and commercial structures (**a**) are scattered at the edge of the Great Smoky Mountains National Park (**b**), creating a fire hazard that was realized in the Chimney Tops 2 fire of 2016. Map of Gatlinburg, TN from: *Google Earth* V 9.124.0.1. Gatlinburg, Tennessee, USA. 35° 42’ 54”N, 83° 30’ 36”, http://www.earth.google.com [Accessed 29 March, 2022].

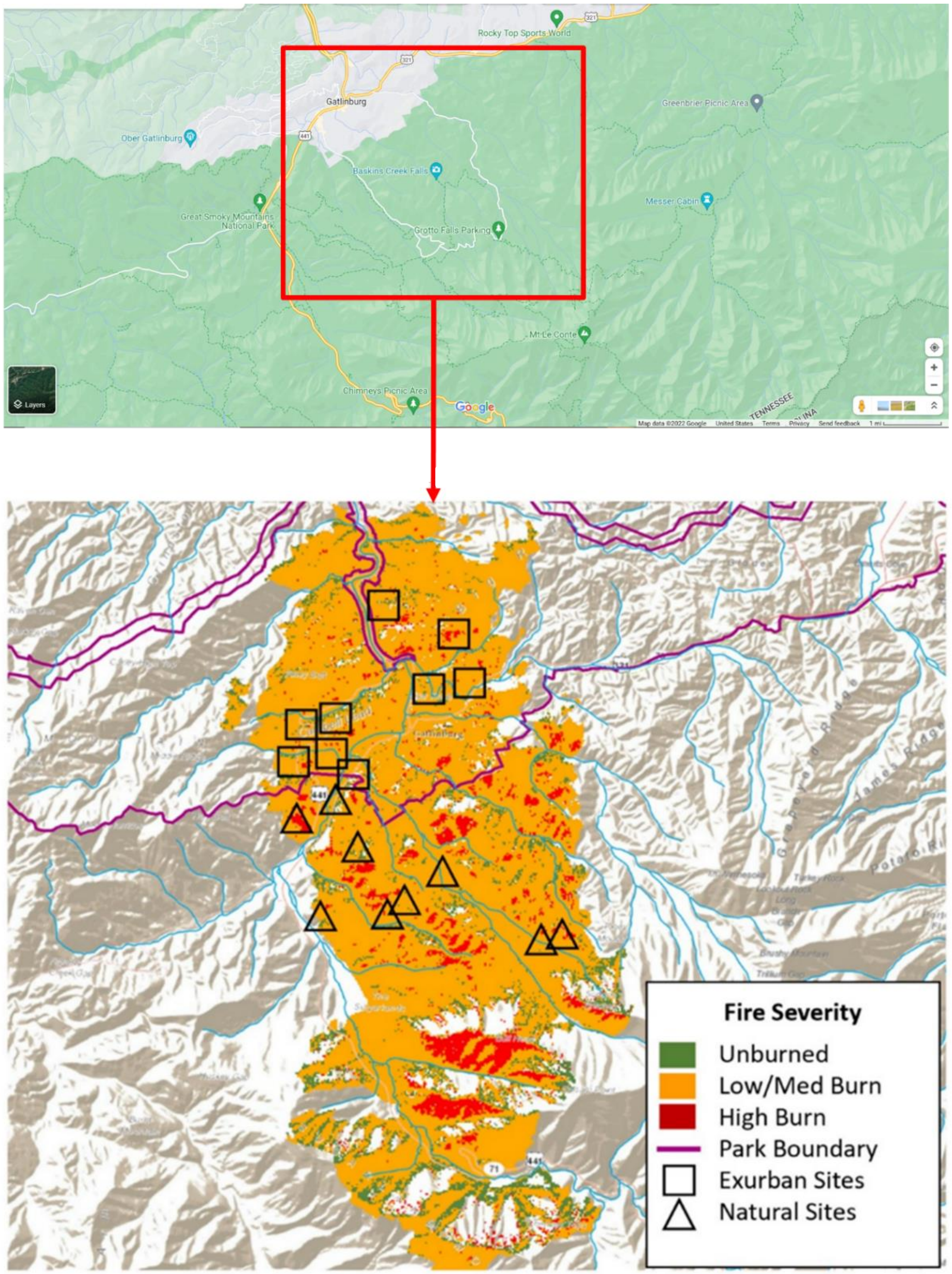

Figure 1.2. Map of 2016 fire (Chimney Tops 2) in the Great Smoky Mountains National Park and Gatlinburg, divided into fire severity categories, and the locations of vegetation sampling sites (natural and exurban). Map of Gatlinburg, TN from: "Gatlinburg, Tennessee." Map, Google Maps, National Park Service IRMA Portal. Accessed 29 March, 2022.

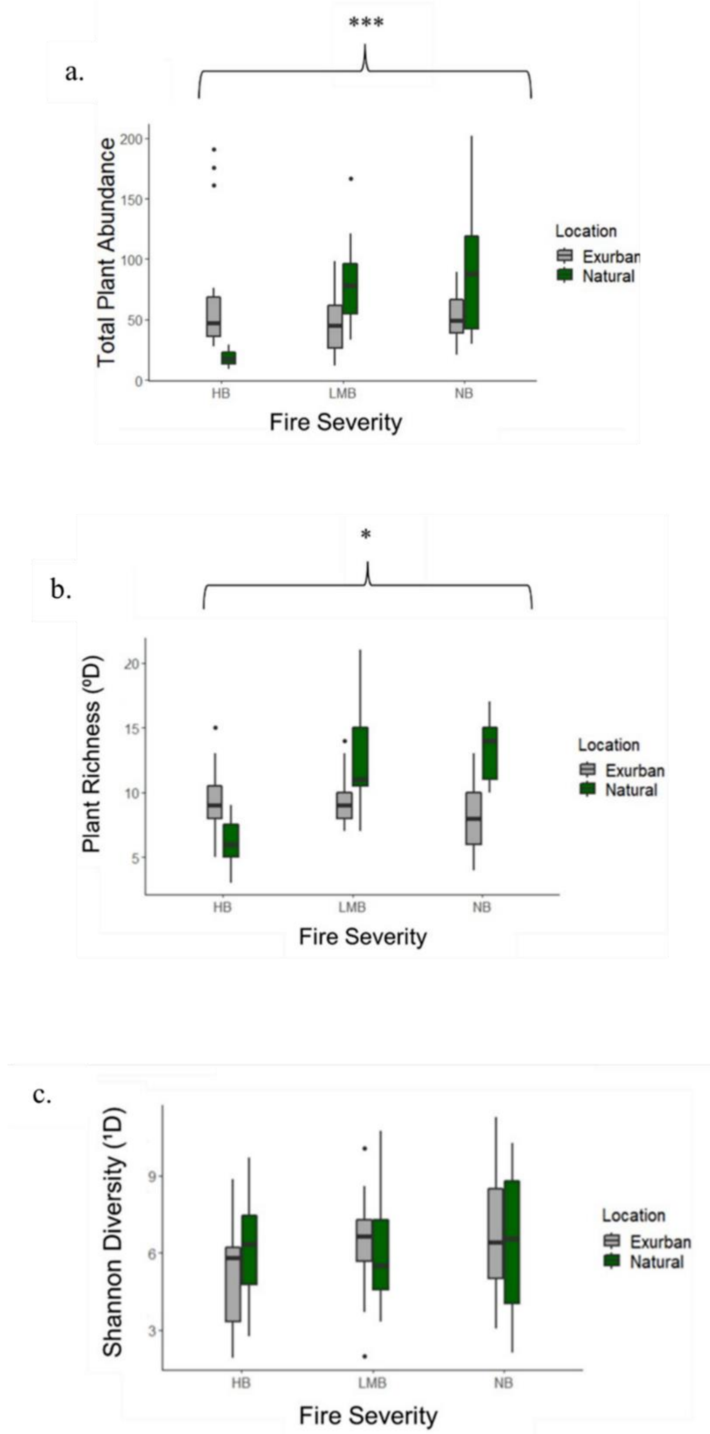

Figure 1.3. Variation in plant abundance and *α* diversity calculated as richness (^{0}D) and Shannon's diversity (^{1}D) in relation to fire severity from high burn (HB), low/medium burn (LMB), to no burn (NB), in both natural and exurban locations surveyed in 2018. Plant abundance (**a**), plant richness (**b**), and ^{1}D (**c**), are lower in LMB and NB areas in exurban locations, but abundance and richness are higher in HB areas compared to natural locations. Statistical significance is denoted by the following: p < 0 '***', p < 0.001 '**', p < 0.01 '*', p < 0.05.

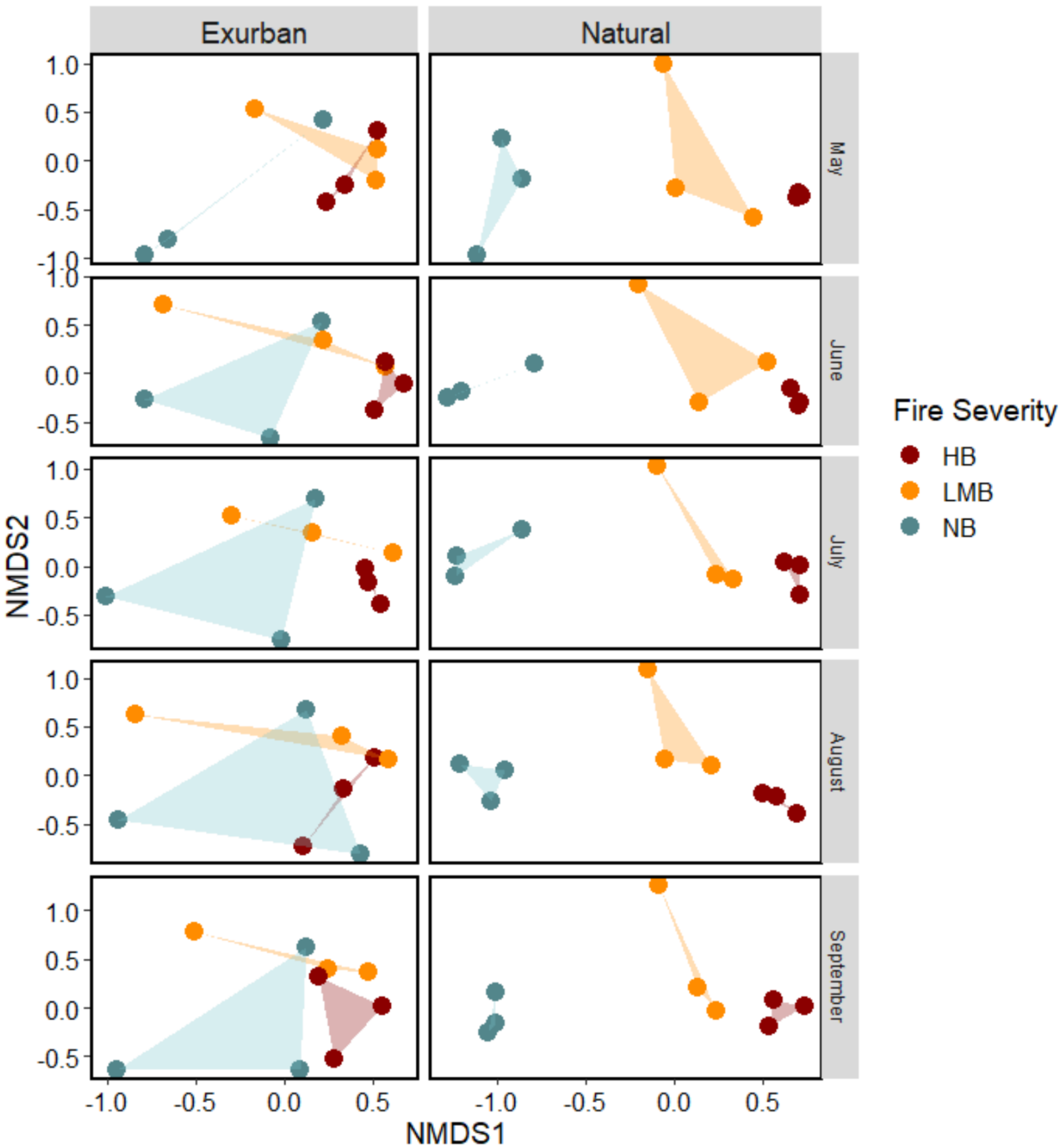

Figure 1.4. Ordination by non-metric multidimensional scaling (NMDS) of species abundance grouped by fire severity (HB = high burn, LMB = low/medium burn, NB = no burn) within location (exurban and natural) and sampling month (May, June, July, August, and September). Each point represents a sampling occurrence at a site. Stress = 0.122.

CHAPTER II:
UNDERSTORY PLANT COMMUNITY DOMINANCE IS ALTERED FOLLOWING A WILDFIRE IN A NATURAL SETTING AND IN A WILDLAND-URBAN INTERFACE

ABSTRACT

Anthropogenic disturbance is one of the greatest threats to biodiversity worldwide, especially as human populations encroach into wildland vegetation. Native plant communities are threatened by human encroachment especially in areas deemed wildland-urban interfaces, where wildfires are often more frequent. Due to decades of fire suppression in the southern Appalachian region of the United States (U.S.) to protect growing human populations, forests that were once adapted to fire have shifted to dominance of species that are shade-tolerant, a process called "mesophication". Though plant communities within wildlands have experienced decades of fire suppression, they may be disturbance-adapted and be able to resist community change after wildfire. Here, we investigated five metrics of plant community turnover over time in the wildland-urban interface and in the Great Smoky Mountains National Park (GSMNP) after the Chimney Tops 2 fire in the GSMNP) and Gatlinburg, Tennessee. Overall, we found that the individual effect of fire severity, the interactions of fire severity by location (natural and exurban), and fire severity by sampling year had a significant effect on taxa gains. Taxa gains were the most apparent in the fall sampling seasons of 2017 and 2018 in both natural and exurban areas. Additionally, we found that areas that had greater disturbance due to the combined effect of fire severity and location experienced greater instability and greater β-diversity (regional diversity), whereas location individually had a significant effect on species diversity. This study contributes new insights to the direct impacts of wildfire and urbanization on understory plant communities that have historically experienced fire suppression but have maintained resilience to other disturbances (urbanization) through time.

INTRODUCTION

Humans alter disturbance regimes, both deliberately and accidently, through their activities on the landscape (Navarro et al., 2015). One of the most consequential effects of human activities is the modification of fire regimes, which can cause profound changes to ecosystem structure and function (Parisien et al., 2016). Fire regimes can be altered from human activities due to the increased risk of ignition to wildland vegetation in densely populated areas (Carcaillet et al., 2009; Bowman et al., 2011). Balch et al. (2017) notes that between 1992 and 2012 humans extended the spatial and seasonal fire niche in the United States (U.S.), accounting for 84% of all wildfires and 44% of total area burned (excluding prescribed fires). The human-caused fire season was three times longer than the lightning-caused fire season across the U.S. and people have added an average of 40,000 wildfires per year; however, fire suppression and management to extinguish these large fires is practiced frequently across the U.S. (Stocks et al., 2002; Stephens 2005; Parisien et al., 2016; Balch et al., 2017). Because decades of fire suppression have increased fuel mass, large human-caused fires are becoming more frequent as fire regimes shift with warming temperatures (Parisien et al., 2016; Halofsky et al., 2020), wildland mesophication (Nowacki and Abrams 2008), and especially human encroachment into wildland areas (Radeloff et al., 2018).

Human influence on fire activity is exceedingly variable in the U.S.; however, areas with high human populations are often most at risk for high severity wildfires (Parisien et al., 2016). Approximately one-third of all homes in the U.S. are surrounding or within wildland vegetation which creates the wildland-urban interface ([WUI]; Radeloff et al., 2018; Kramer et al., 2019). WUIs are areas where houses are adjacent to or overlap with wildland vegetation, which complicates human populations from the protection from wildfire (Cohen 2000; Winter and Fried 2001; Radeloff et al., 2005) and additionally increases risk for high severity wildfire from human ignitions (Cardille et al., 2001). With the expansion of the WUI, it becomes increasingly problematic to protect homes in the event of wildfire (Radeloff et al., 2018), which generates the need for fire suppression (Gude et al., 2013; Hand et al., 2016; Kramer et al., 2019). Wildfires are necessary in some ecosystems to maintain fire-dependent species; however, as human populations encroach into wildlands, increasing WUI area, large fires become a mounting threat to infrastructure, natural and cultural resources, human health, and forest ecosystem resilience (Johnston et al., 2012; Ward et al., 2012; Bowman and Johnson 2014; Thomas et al., 2017; Rogers et al., 2020). The southeastern U.S. specifically has become densely populated over the last several decades, and as a result, management strategies include fire suppression, prevention, and prescribed burning (Mitchell et al., 2014).

Fire regimes in the southeastern U.S. are now largely human-dominated (Waldrop et al., 1992; Slocum et al., 2007; Parisien et al., 2016). Many of the ecosystems in the southeastern U.S. are dependent upon prescribed fire to maintain fire-adapted communities (e.g., pine-oak forests) and at the same time fire-sensitive communities (e.g., mesic forests) rely on fire suppression (Mitchell et al., 2014). Fire-adapted taxa were abundant and widespread in eastern Appalachian forests prior to fire exclusion practices that began in the 1930s, as land development and permanent settlement expanded (Arthur et al., 2021). The absence of periodic fire management created a shade-tolerant midstory of red maple (*Acer rubrum*) throughout the eastern U.S. and southern Appalachia (Lorimer 1984; Abrams 1998) that has only increased the last several decades (Arthur et al., 2021). Fire suppression results in an ongoing transition to increasingly closed canopy stands with a higher abundance of fire-sensitive, shade-tolerant species that alters ecosystem properties and interactions (Arthur et al., 2021).

Even in a period of fire suppression, plant communities can become resilient to other disturbances (Keeley et al., 2011; Chambers et al., 2014; Seipel et al., 2018); though shifts in disturbance frequency or additional disturbances can transition plant communities to an alternative stable state (Scheffer et al., 2001; Hobbs et al., 2006; Davies et al., 2012; Seipel et al., 2018). In addition to decreased community resilience to fire, chronic disturbance exposure (i.e., urbanization) may cause the decrease of native plant diversity and increase community homogenization. Urbanization can homogenize communities due to the immigration of generalist and non-native species over time and the extinction of specialist species (Schwartz et al., 2006; Zeeman et al., 2017). When immigration and extinction co-occur, plant composition is simplified, and diversity is often reduced, resulting in homogenization (McKinney and Lockwood 1999; Olden et al., 2004; Zeeman et al., 2017), which may decrease resilience to subsequent disturbance and environmental change (Smith and Knapp 2001; McGrady-Steed et al., 2007; Zeeman et al., 2017). Heterogeneous landscapes containing multiple species and forest types are likely to be more resilient to disturbance through functional redundancy and variation in response to different disturbance types (Folke et al., 2004; Oliver et al., 2015). Understanding plant community response to disturbance is important for managing communities in light of an expanding WUI and increasing human-dominated fire regime.

Fire suppression and prevention have been prominent in the Great Smoky Mountains National Park (GSMNP) and surrounding WUI since the 1930s (Harmon 1982). Though the GSMNP has a fire plan to conduct prescribed burns, decades of fire suppression likely increased fuel loads that, combined with a growing WUI and an unusually dry fall season, generated the conditions for a human-caused fire that occurred in November 2016. The objective of this study was to investigate understory plant community changes over three years after the Chimney Tops 2 fire event that occurred in the GSMNP and its surrounding WUI (Gatlinburg, Tennessee). Assuming post-fire community homogenization and dominance by disturbance-adapted taxa, we tested two hypotheses contrasting community changes in GSMNP (hereafter "natural" locations) and WUI (hereafter "exurban" locations), across a fire gradient (from low to high severity): **H1.** Understory community turnover will be lowest at highest disturbance over time (high severity fire and exurban locations; Appendix IIA: Figure 2.1S), and **H2.** Plant taxa diversity will decrease as the disturbance gradient increases (location and fire severity). We predict that understory community turnover will be lowest at highest disturbance because of disturbance-adapted species that are currently established in high disturbance areas. Additionally, plant taxa diversity will decrease at these high disturbance areas because rare plants will be eliminated (due to the presence of fire) and plant communities will be homogenized with disturbance-adapted species.

METHODS

Study Area

This study was conducted in the southern Appalachian region of the U.S., in the GSMNP and the adjacent WUI of Gatlinburg, Tennessee, after the Chimney Tops 2 wildfire that occurred in November 2016. The southern Appalachian region consists of a mosaic of forest communities comprising approximately 2,250 species of vascular plants and 140 tree species (Simon 2005). Forest cover type throughout this region is predominately oak-hickory; however, elevation strongly influences forest composition (Simon 2005). Low elevation forests consist mostly of hardwood trees, whereas at middle elevations xeric-to-submesic oak-pine forest is present on drier slopes and ridges (Simon 2005). Wetter slopes are covered in cove forests that are diverse in spring ephemeral wildflowers and canopy trees but dominated by mesic fire-intolerant species (McNulty et al., 2013). High elevation forests are dominated by red spruce (*Picea rubens*) and Fraser fir (*Abies fraseri*) (Simon 2005). Throughout the low and mid-elevations, shade-tolerant, fire sensitive species such as *Acer rubrum*, *A. pensylvanicum*, *Fagus grandifolia*, *Nyssa sylvatica*, *Oxydendrum arboreum*, *Ostrya virginiana*, *Kalmia latifolia*, and *Rhododendron maxium* occur often as a result of decades of fire suppression (Simon 2005; Arthur et al., 2021).

Sampling Design

We investigated understory plant community turnover starting one year post-wildfire along a WUI (hereafter "exurban") and in the GSMNP (hereafter "natural"). Exurban sites are considered to be residential development outside of suburbs and cites (Theobald 2005). Exurban areas are one of the fastest growing land use types in the U.S. and occupy five to ten times more land than urban and suburban areas (Theobald 2000; NRCS 2001; Theobald 2001).

We selected the study sites following stratified random sampling in Geographic Information Systems (GIS) software (ESRI ArcMap) to represent three fire severity categories (no burn, low/medium burn, high burn) in two location types (natural and exurban). High burn natural sites were located in chestnut-oak forest, low/medium burn natural sites were a combination of chestnut-oak and montane oak-hickory forest, and finally no burn natural sites were a combination of montane oak-hickory and successional hardwood. The forest cover of most exurban sites was considered "human-influenced" or "unspecified", and remaining exurban sites were located in chestnut-oak, montane oak-hickory, pine, and successional hardwood forests Both forest cover type and fire severity maps were downloaded from the National Park Service IRMA Portal in GIS format. We used the MODIS normalized difference vegetation index (NDVI) GIS rasters from growing seasons of 2016 (before fire) and 2017 (after fire) at 250 m resolution (Didan 2015) to calculate delta normalized difference vegetation index (dNDVI). The larger the average dNDVI score, the greater the change in forest canopy between the two years, thus indicating a higher severity of fire at that location (see supplementary materials: Appendix IIA for equations). The dNDVI scores represent damage to vegetation during the growing (leaf-on) season (May-September) a year after the fire, as opposed to the NPS fire severity map which was generated during the leaf-off season in 2016, immediately after the fire.

A total of 18 sites was used in this study, nine representative of natural locations and nine representative of exurban locations. Within both natural and exurban locations, three sites were chosen to represent high burn, three low/medium burn, and three that did not receive direct fire damage (i.e., no burn). All sites were chosen based on their similarity in dominant forest vegetation type and elevation to minimize the potential confounding effects. Field data collection took place during the growing season from August to October in 2017 and from April to September in 2018 and 2019. Sampling dates were set to capture seasonal differences in plant community composition (spring, summer, and fall), as well as interannual differences (2017-2019).

Data Collection

Each site represented a 90 x 90 m homogeneous area of burn severity, selected randomly in ESRI ArcMap. In the field, we located the geographic coordinates of each site's center point and selected random placements for two 1 x 1 m permanent plots which we marked with metal pins and flags at each corner of the plot. At all 18 sites, we used the 1 x 1 m quadrats to survey and record all plant taxa within the plot boundaries. Our plot size selection was based on established protocols from the National Ecological Observatory Network (NEON; Elmendorf 2020). The two 1 x 1 m plots sampled in the field were combined into a single dataset for analysis (hereafter "site"). We surveyed the plots over two-week blocks in April (end)/May (beginning), June, and September to represent spring, summer, and fall plant communities respectively, in both 2018 and 2019. Sampling seasons from 2018 and 2019 are considered "full" seasons and thus were compared to one another. In 2017 each site was sampled only once, during the fall, and thus will be compared to the fall sampling seasons from 2018 and 2019. We identified all herbaceous plants and tree seedlings to genus and species (when possible) and counted the number of individuals of each taxon within the plot.. We used field guides and dichotomous keys (Petrides 1986; Horn and Cathcart 2005; Chester et al., 2015) to identify plants in the field. Unidentified plants were collected from outside of the plot to preserve the integrity of the community and long-term sampling of established plots. Samples and photographs of plants that could not be identified in the field were keyed and verified with herbarium specimens at the University of Tennessee, Knoxville Herbarium (TENN Herbarium). Individuals that could not be identified to at least genus level due to immature characteristics or damage were recorded as observational taxonomic units.

Data Analysis

We characterized temporal turnover in understory communities via the five community change metrics described in Hillebrand et al., (2018) and Kaarlejärvi et al., (2021) to address H1 that understory community turnover after the fire will be lowest in high severity fire areas and exurban locations. The community metrics consisted of richness change, taxa gains, taxa losses, species exchange ratio based on richness ($\mathrm{SER_r}$; richness turnover), and species exchange ratio based on abundance ($\mathrm{SER_a}$; abundance turnover) between the full sampling seasons in 2018 and 2019 and between fall sampling seasons in 2017, 2018, and 2019. We calculated each community change metric for each site through the sampling years. Richness change, taxa gains, taxa losses, and $\mathrm{SER_r}$ were calculated between 2018 and 2019 sampling periods, and between fall 2017, 2018, and 2019. $\mathrm{SER_a}$ was also calculated for full sampling seasons 2018 to 2019 but only fall sampling seasons 2018 and 2019 due to differences in taxa abundance measurements in 2017 (percent cover; compared to count of individuals in 2018 and 2019).

Richness change is calculated as the difference in richness between two time points (*t+1* and *t*) divided by the total number of unique taxa in both time points. A positive value represents an increase in richness over time and a negative value represents a decrease in richness. Taxa gains is calculated as the of number of taxa present at *t+1* that were not present at time *t* divided by the total number of unique taxa in both time points, thus representing the proportion of taxa that are gained. Finally, taxa losses are obtained by dividing the number of taxa lost from *t* to *t+1* by the total number of unique taxa in both time points, thus representing the proportion of taxa that are lost between the two sampling points. (Avolio et al., 2019).

$\mathrm{SER_r}$, which is comparable to Jaccard's similarity index (Jaccard 1912), is calculated as:

$$SER_r = \frac{S_{imm} + S_{ext}}{S_{tot}}$$

where $S_{imm}$is the number of new taxa immigrating, $S_{ext}$is the number of taxa lost, and S_{tot} is the total number of taxa from all time points. A $\mathrm{SER_r}$ value of 0 means there was no change in plant composition over time and a value of 1 indicates complete plant community turnover (Hillebrand et al., 2018).

A second approach for identifying temporal compositional change focuses on the differences between proportional abundances of taxa (i) at time point 1 (p_i) and time point 2 (p_i'), which is a complement to Wishart's similarity ratio (Wishart 1928). $\mathrm{SER_a}$is calculated as:

$$SER_a = \frac{\sum_i (p_i - p_i')^2}{\sum p_i{}^2 + \sum p_i{}'^2 - \sum p_i p_i{}'}$$

A $\mathrm{SER_a}$value of 0 means there was no change in plant composition and a value of 1 indicates complete plant turnover, similar to $\mathrm{SER_r}$ (Hillebrand et al., 2018). Common taxa have a stronger influence on $\mathrm{SER_a}$ than rare taxa. Compared to $\mathrm{SER_r}$ that quantifies presence/absence of taxa, $\mathrm{SER_a}$ is a more robust community metric because it captures shifts in dominant taxa, without being sensitive to changes in taxa richness or occurrence of rare taxa (Hillebrand et al., 2018; Kaarlejärvi et al., 2021). Comparative analyses of $\mathrm{SER_r}$ and $\mathrm{SER_a}$ allow the assessment of co-occurring dominance and identity shifts, which is a strong indicator of biodiversity change (Hillebrand et al., 2018). Richness-based turnover metrics (i.e., richness change, taxa gains, and taxa losses) were calculated using the codyn package in R (Hallett et al., 2016) whereas $\mathrm{SER_r}$ and $\mathrm{SER_a}$ were calculated using the above equations.

To test the statistical effect of fire severity and urbanization on the five calculated community metrics, we used linear mixed models (LMM), with site as the random effect in a given sampling year and three fixed effect variables and their interactions: dNDVI, location type, and sampling year. Because fire has been suppressed in the GSMNP for decades, we used these temporal turnover metrics to determine changes in short-term dominance of taxa post-Chimney Tops 2 wildfire. Correlative effects between the community metrics of $\mathrm{SER_r}$ and $\mathrm{SER_a}$were assessed using Pearson's product moment correlation coefficient in R.

We used the R package codyn to assess community stability as the ratio of mean of taxa abundances divided by the standard deviation of taxa abundances over the sampling years (Tilman 1999). We calculated changes in taxa composition and dispersion based on Bray-Curtis dissimilarity matrix of sampling periods by fire severity category for the full sampling years of 2018 and 2019 (Avolio et al., 2019). Composition difference values range from 0 to 1 for the distance between community centroids of fire severity categories, between sampling years. Homogeneous communities will return a value of 0 whereas highly heterogenous communities return a value of 1. Dispersion difference was calculated for each fire severity category as the average of distances between individual taxon abundance and the community abundance centroid (Avolio et al., 2019). A negative value means that there is convergence of taxa abundance between time points and a positive value indicates taxa abundances are diverging over time.

We calculated two levels of plant taxonomic diversity: α (site level) and β (among sites), to address H2 that plant taxa diversity will decrease as the disturbance gradient increases (fire severity and location). For α diversity, we calculated two different diversity indices corresponding to Hill numbers of orders 1 (^1D; Shannon diversity; Shannon 1948) and 2 (^2D; Simpson diversity; Simpson 1949), which represents diversity of common taxa and the most dominant taxa, respectively (Chao et al., 2014). We analyze and report results for ^1D (Shannon diversity) in the text; see supplementary materials: Appendix IIA for Hill number description and analyses using ^2D (Appendix IIA: Table 2.1S, 2.2S). We calculated α diversity at each site across the sample years in fall 2017, 2018, and 2019, and for the full sampling seasons 2018 and 2019. Additionally, we calculated β-diversity for each fire severity and location combination (representing the disturbance gradient) through the full sampling years 2018 and 2019 (Appendix IIA: Table 2.2S). The disturbance gradient ranges from low fire severity in natural conditions (GSMNP) to high fire severity in exurban (Gatlinburg) conditions (Appendix IIA: Figure 2.1S). To calculate β-diversity, we used Whittaker's multiplicative equation (Whittaker 1960):

$$\beta = \frac{\gamma}{\alpha}$$

where α is the site diversity represented by plant richness (^0D) and γ is the diversity resulting from pooling data across all sites to analyze change along the disturbance gradient.

We assessed the effect of fire severity, urbanization, and time on Shannon's diversity (^1D) with linear mixed models (LMM), with site as the random effect in a given sampling season and three fixed effect variables and their interactions: dNDVI, location type, and sampling year. To better fit the model, we scaled the predictor variables by centering and dividing the predictor variables by two standard deviations (Gelman 2008).

All exploratory analyses, reported statistics, and graphical representations were performed using the packages: "biodiversityR", "car", "codyn", "corrplot", "dplyr", "ggarrange", "ggplot2", "hillR", "MASS", "tidyverse", and "vegan" in RStudio v. 4.0.3.

RESULTS

Three of the initial 18 sites could not be located in fall 2019, resulting in a total of 15 sites that were consistently compared across the three sampling years. In fall 2017, we identified 63 plant taxa in the understory, whereas in fall 2018 we identified 101 taxa, and 64 taxa in fall 2019 at natural and exurban locations across the fire gradient. We identified a total of 129 plant taxa in the understory during the full sampling season in 2018, whereas during the full sampling season in 2019 we saw a reduction to 119 plant taxa. From the full sampling seasons in 2018 to 2019, there was an 8% decrease in average plant richness and a 13% decrease in taxa abundance overall.

Within the natural locations across all fire severity categories, all but two sites showed a decrease in taxa richness from 2018 to 2019, whereas exurban locations experienced variable change, with most high burn and low/medium burn sites experiencing a decrease and no burn sites experiencing an increase in richness (Appendix II: Figure 2.1; Appendix IIA: Table 2.3SD). Alternatively, for the fall sampling seasons only, there was an increase in richness between fall 2017 and 2019 for low/medium burn sites, both in natural and exurban locations, and variable (increase or decrease) for the other fire severities in both exurban and natural sites (Appendix IIA: Table 2.3A). Richness increased at most natural and exurban locations between fall 2017 and fall 2018 (Appendix IIA: Table 2.3B). Finally, richness changes were variable between fall 2018 and 2019 for all sites (Appendix II: Figure 2.2; Appendix IIA: Table 2.3SC). Taxa gains and losses were consistent across time between all sampling events, with approximately 0.35 gains and 0.32 losses (Appendix IIA: Table 2.3S). Exurban areas experienced slightly higher taxa gains across the fire severity categories compared to the natural areas through time, whereas taxa losses remained relatively the same for all fire severity categories in natural and exurban locations (Appendix II: Figure 2.1; Figure 2.2).

Within natural and exurban locations, there were relatively high $\mathrm{SER_a}$ values at most sites from full sampling seasons 2018 to 2019 compared to small $\mathrm{SER_r}$ values, indicating changes in taxa dominance rather than taxa composition (Appendix II: Figure 2.1; Appendix IIA: Table 2.3SD). Alternatively, for fall, $\mathrm{SER_a}$ and $\mathrm{SER_r}$ values from 2018 to 2019 were relatively comparable in size (Appendix II: Figure 2.2; Appendix IIA: Table 2.3SB). As the $\mathrm{SER_r}$ increased through 2018 and 2019, there was a non-significant positive correlative relationship with $\mathrm{SER_a}$ (t = 1.389, $P = 0.185$; Appendix II: Figure 2.3). Additionally, $\mathrm{SER_r}$ values were relatively small, indicating little to no change in taxa composition (Appendix II: Figure 2.1; Appendix IIA: Table 2.3SA); we did not calculate $\mathrm{SER_a}$ values in 2017 because of differences in taxa abundance measurements.When analyzing only fall 2018 and fall 2019 we found negative richness-related changes at a subset of the sites with mid-range SER_r values and relatively high SER_a, regardless of location (Appendix II: Figure 2.2; Appendix IIA: Table 2.3SC). Small to no changes in SER_r and relatively large changes in SER_a indicate that there is a change in dominance structure without taxa replacements over time (Hillebrand et al., 2018).

The LMMs found partial support for H1: the individual effect of dNDVI, the interactions of dNDVI by location, and dNDVI by year had a significant effect on taxa gains. Our analyses indicated significant differences of taxa gains by sampling year for full and fall sampling seasons. However, location and year individually did not have a significant effect on any community metrics. For SER_r and SER_a, none of the fixed effects (or their interactions) had a significant effect (Appendix II: Table 2.1).

Community stability during the full sampling seasons 2018 and 2019 indicated that high burn/exurban sites were the least stable (CS = 4.581) and no burn/exurban sites were the most stable (CS = 20.506); no burn/natural sites also had low stability (CS = 4.853). Community stability metrics across the disturbance gradient (location and fire severity) in fall 2017 compared to fall 2019 showed that high burn/exurban sites were the most stable (CS = 7.639) whereas the no burn/exurban and low/medium burn/exurban were the least stable (CS = 1.684 and CS = 1.515, respectively). Alternatively, when assessing fall 2017 to fall 2018, high burn/natural sites were the most stable (CS = 9.334) with high burn/exurban sites being the least stable (CS = 1.156). Similarly, when assessing community stability across the disturbance gradient during the fall sampling seasons in 2018 and 2019, high burn/exurban sites were the least stable (CS = 1.061) and no burn/exurban were the most stable (CS = 9.758). Community stability values varied considerably between sampling years along the disturbance gradient, though generally there was seasonal (fall) variability across the disturbance gradient, with more disturbance indicating less stability.

We found that communities were moderately homogeneous in terms of composition among the fire severities based on Bray-Curtis dissimilarity, with small but positive dispersion rates in 2018 (Appendix IIA: Table 2.4SA) and 2019 (Appendix IIA: Table 2.4SB), indicating that communities are diverging (i.e., less dispersion in 2019). We can conclude that taxa turnover in high burn areas is comparable to other fire severities (low/medium and no burn) and may be site dependent.

For our H2, stating that plant taxa diversity will decrease as the location and fire severity disturbance gradient increases, we found that diversity metrics varied between the years. Across all fall sampling periods (2017, 2018, and 2019) at the natural sites, we observed the highest α diversity (Shannon's diversity, ^{1}D) value at low/medium burn sites, whereas the lowest value varied between high burn sites in 2017 and 2019 and no burn sites in 2018 (Appendix IIA: Table 2.1S). In contrast to natural locations, exurban locations exhibited the highest α diversity at high burn sites 2017, followed by no burn sites in 2018, and low/medium burn sites in 2019 (Appendix IIA: Table 2.1S). When examining diversity among sites, we obtained the highest *β*-diversity at high burn/exurban locations in 2017, no burn/exurban locations in 2018, and high burn/exurban locations in 2019 (Appendix IIA: Table 2.1S).

Across the full sampling periods (2018 and 2019) at the natural sites, we observed the highest α diversity at low/medium burn sites in 2018, and in no burn sites in 2019 (Appendix IIA: Table 2.2S). In contrast to natural locations, exurban locations exhibited the highest α diversity at high burn sites in 2018 and 2019 (Appendix IIA: Table 2.2S). When examining diversity among sites, we obtained the highest *β*-diversity at exurban/no burn locations in 2018 and exurban/high burn locations in 2019, similarly to the fall sampling periods (Appendix IIA:

Table 2.2S). The results of LMM, evaluating the effect of location, fire severity, and sampling year on Shannon's diversity (^1D) showed significant differences among the individual effect of location and marginal non-significance for dNDVI (Appendix II: Table 2.2). We can conclude that plant diversity (^1D and β-diversity) increases through time as the disturbance gradient increases, thus rejecting H2.

DISCUSSION

In this study, we analyzed three years of understory plant turnover and diversity after a fire surrounding and within a WUI in the southern Appalachian region. Overall, we found: (i) a significant effect of dNDVI, dNDVI by location (natural and exurban), and dNDVI by year on taxa gains (Appendix II: Table 2.1); (ii) plant communities were more stable in areas that were least affected by the fire, with communities in exurban sites being more stable than those in natural sites; (iii) location had a significant effect on ^1D (Appendix II: Table 2.2); and (iv) as the disturbance gradient increased, β-diversity increased. Our results suggest that though compositional turnover is comparable among sites (despite disturbance status), high burn and exurban areas (though generally unstable) have greater β-diversity. This could potentially be due to disturbance-adapted taxa presence and dominance restructuring within the plant community.

Mixed-severity fire has the potential to increase forest heterogeneity which can increase taxon diversity by promoting the coexistence of competitive and non-competitive taxa at the site level (Huston 1979; Denslow 1985; Reilly et al., 2006; Richter et al., 2019). Compounded disturbances, such as fire and urbanization, can change diversity by altering the dominance structure of a community. In our study, we found that the abundance-based community turnover metric, SER_a, was large relative to the richness-based community turnover metric, SER_r, at the site level (Appendix IIA: Table 2.1S). According to Hillebrand et al., (2018), high SER_a compared to relatively low SER_r is consistent with a community that is experiencing a shift in dominant plant taxa, but no change in taxa identity (i.e., no replacement of taxa). However, we did obtain a significant effect of dNDVI, the interactions of dNDVI by location, and dNDVI by year on taxa gains (Appendix II: Table 2.1). Secondary succession following a wildfire can include community turnover due to changes in the dominance structure of the plant community (Kaarlejärvi et al., 2021). Our finding that dNDVI by location and by year has an interactive effect on taxa gains (Appendix II: Table 2.1) may indicate that fire is an important driver (depending on location, natural or exurban) that promotes sapling recruitment, herbaceous cover, and opportunist taxa, which could explain the shift in dominance through time.

A disturbance that modifies environmental conditions can alter diversity through environmental filtering, changes in colonization from the species pool, or fluctuations in ecological drift (Myers et al., 2015). Directly after a wildfire, high severity burn areas in conifer forests of western U.S. may experience a decrease in local (α; ^1D) diversity and richness of plants (Safford and Stevens 2017; Shive et al., 2018; Steel et al., 2018; Richter et al., 2019); however, Reilly et al., (2006) hypothesized that β-diversity will increase at the site level with increasing fire severity due to competitive exclusion. In deciduous forests of the eastern U.S., Vander Yacht et al., (2020) found that reduction of leaf litter by fire was important for regeneration of herbaceous taxa, in addition to thinning treatments to reduce competitive exclusion by woody vegetation, thus aiding the regeneration of dominant taxa at high disturbance sites.

Heterogeneous landscapes that have experienced different types of disturbance (e.g., wildfire and urbanization) may determine spatial aggregation (clumping) of species (Myers et al., 2015), which can lead to greater β-diversity among communities with different disturbance levels. Chronic disturbances, such as urbanization, may increase β-diversity by creating heterogeneous landscapes that support a range of disturbance-tolerant and intolerant species (Myers et al., 2015; Aronson et al., 2015). Depending on the extent of the disturbance, species clumping may increase along a disturbance gradient, resulting in habitat filtering (Myers et al., 2015). In a study by Beal-Neves et al., (2020), plant species richness was predicted by the level of urbanization in grassland communities with no significant change to plant community composition or diversity. This may indicate that urbanization does not affect overall community dynamics; however, it may promote disturbance-adapted plant growth (i.e., increase in plant richness) when additional disturbances (i.e., fire) occur. After a fire, there may be an increase in clumping of fire-intolerant species in lesser-disturbed areas (Pausas and Verdú 2008; Crandall and Platt 2012), which can decrease the extent of fire-intolerant species across a disturbance gradient (Myers et al., 2015). A review by Miller and Safford (2020) found that an increase in diversity is more common in high severity fire areas (compared to lower fire severities) in ecosystems that were historically subjected to high severity, human-caused fire.

Historically, the southern Appalachian forests experienced high severity wildfire frequently until the 1930s, when fire prevention and suppression efforts began (Lafon et al., 2017). In our study, greater disturbance severity resulted in greater β-diversity, indicating that competitive exclusion may be occurring and disturbance-adapted species in exurban areas may not be affected by the additional disturbance of fire. Taxa clumping may be occurring in this case for fire-tolerant (or disturbance tolerant) taxa that have persisted in exurban sites with chronic disturbance. Residual growth from these disturbance opportunists may be continuing throughout the fall sampling seasons, a possible reason for the observed greater β-diversity in high burn, exurban sites, compared to less disturbed sites.

Conclusion

Through this study, we found that the turnover in understory plant communities in the GSMNP and Gatlinburg is not exacerbated by the Chimney Tops 2 wildfire. However, areas of greater disturbance (combined fire and urbanization) are experiencing seasonal increases in β-diversity, suggesting that environmental filtering is occurring to favor disturbance-adapted plant taxa. It is important to note that plant community responses to wildfire could be dependent upon historical fire regimes. A recent review by Miller and Safford (2020) found that plant species richness responses to fire severity depended to a great extent on the historical (e.g., pre-Euro-American occupation) disturbance regime of the ecosystem. Future research could focus on examining the historical plant communities in these areas to determine if the current disturbance-adapted communities are residual from a historical fire regime. Additionally, it is imperative to continue monitoring the plant communities to test whether additional shifts in dominance will occur over a longer timeframe than the one studied here (3 years after fire).

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APPENDIX II

TABLES

Table 2.1. Effects of fire and urbanization on turnover of understory plant communities in the southern Appalachian region (USA), analyzed with a linear mixed model. Community turnover was assessed with five metrics: change in richness, taxa gains, taxa losses, SER_r, and SER_a. Estimate (E), standard error (SE), t value, and associated P-values (P) are reported for the response variables in exurban and natural locations, sampling year, and across a fire severity gradient indicated by dNDVI (delta normalized difference vegetation index).

	Richness change				*Taxa gains*				*Taxa losses*				
Fixed effects	*E*	*SE*	*t*	*P*	*E*	*SE*	*t*	*P*	*E*	*SE*	*t*	*P*	
Random effect: Site	-0.012	0.290	-0.041	0.968	0.253	0.332	0.762	0.460	-0.434	0.252	-1.720	0.131	
dNDVI	2.747	2.620	1.048	0.325	-0.495	3.004	-0.165	0.872	7.503	2.274	3.300	0.014	*
Location	0.329	0.344	0.957	0.360	-0.079	0.381	-0.208	0.838	0.639	0.308	2.076	0.065	
Year	0.205	0.284	0.721	0.496	0.023	0.335	0.068	0.947	0.632	0.241	2.618	0.048	*
dNDVI * Location	-3.257	2.848	-1.143	0.283	1.083	3.231	0.335	0.743	-6.503	2.497	-2.604	0.033	*
dNDVI * Year	-2.961	2.571	-1.151	0.289	0.560	3.030	0.185	0.857	-6.475	2.183	-2.966	0.032	*
Location * Year	-0.207	0.327	-0.634	0.548	-0.099	0.390	-0.253	0.805	-0.192	0.276	-0.693	0.520	

	SER_r				SER_a			
Fixed effects	*E*	*SE*	*t*	*P*	*E*	*SE*	*t*	*P*
Random effect: Site	0.250	0.332	0.750	0.467	-0.261	0.680	-0.384	0.706
dNDVI	-0.421	3.007	-0.140	0.891	7.880	6.150	1.281	0.217
Location	-0.075	0.381	-0.195	0.848	0.654	0.773	0.846	0.409
Year	0.028	0.336	0.082	0.936	0.703	0.702	1.001	0.331
dNDVI * Location	1.026	3.233	0.317	0.756	-8.965	6.594	-1.360	0.192
dNDVI * Year	0.490	3.034	0.162	0.874	-7.734	6.334	-1.221	0.239
Location * Year	-0.102	0.391	-0.260	0.800	-0.288	0.837	-0.344	0.735

Statistical significance is denoted by the following: p < 0 '***', p < 0.001 '**', p < 0.01 '*', p < 0.05 '.'

Table 2.2. Effects of fire and urbanization on turnover of understory plant communities in the southern Appalachian region (USA), analyzed with a linear mixed model. Estimate (E), standard error (S), t value, and associated P-values (*P*) for the response variable Shannon's diversity in exurban and natural locations, across a fire severity gradient indicated by dNDVI (delta normalized difference vegetation index).

Fixed effects	*Predictors*	*E*	*S*	*t*	*P*	
Random effect: Site						
Response variable:	dNDVI	-0.780	0.422	-1.848	0.067	
Shannon diversity (^{1}D)	Location	1.032	0.402	2.569	0.011	*
	Year	0.200	0.402	0.497	0.620	
	dNDVI *	-1.032	0.838	-1.232	0.221	
	dNDVI * Year	0.475	0.848	0.560	0.576	
	Location *	-1.101	0.806	-1.366	0.175	

Statistical significance is denoted by the following: p < 0 '***', p < 0.001 '**', p < 0.01 '*', p < 0.05 '.'

FIGURES

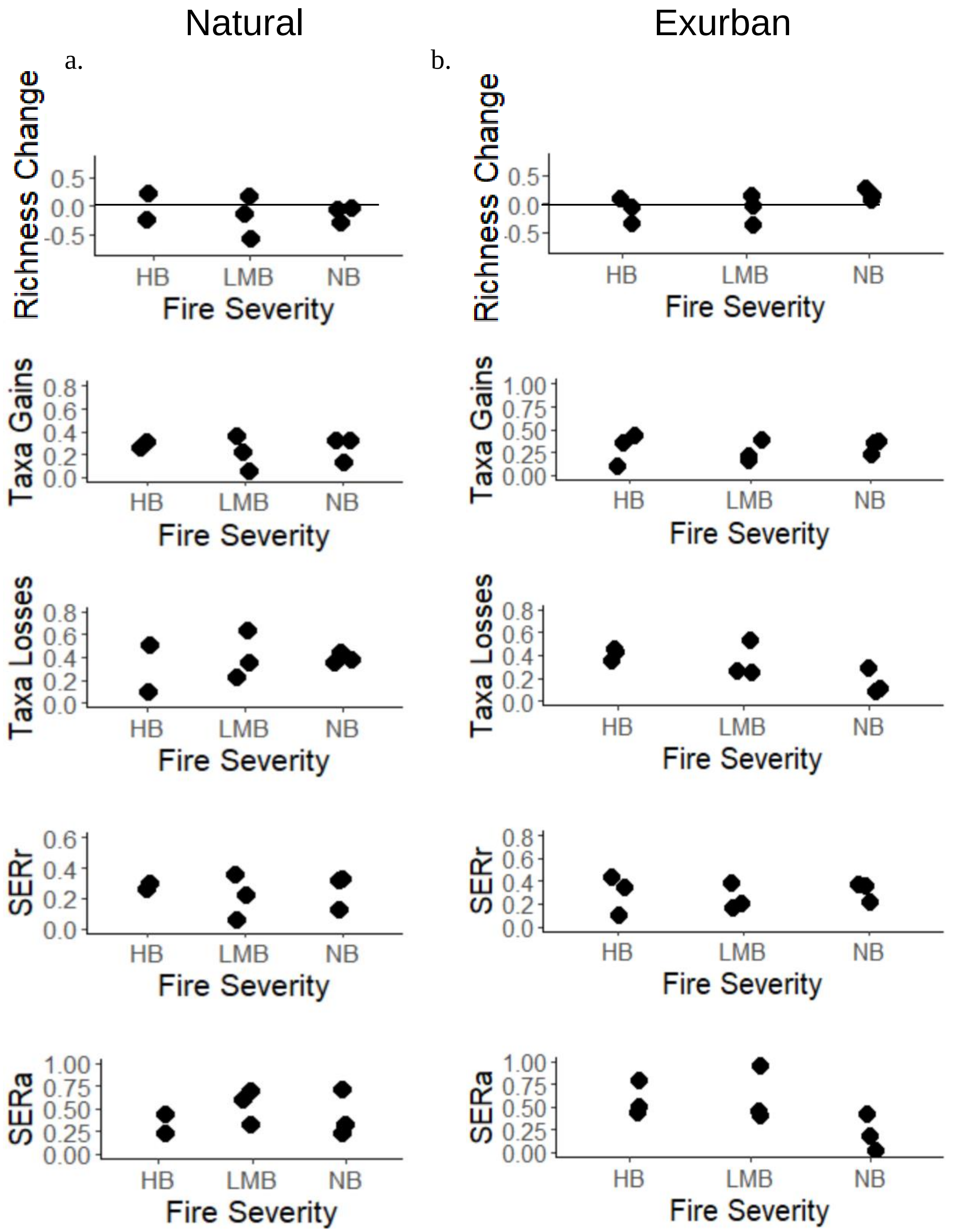

Figure 2.1. Plant community turnover in understory plant communities for the full sampling seasons of 2018 and 2019 in the Great Smoky Mountains National Park and Gatlinburg, Tennessee (USA) after a wildfire. Compositional changes were estimated with five community metrics (richness change, taxa gains, taxa losses, SER_r, and SER_a) at sites in the Great Smoky Mountains National Park (natural, **a**) and in Gatlinburg, Tennessee (exurban, **b**).

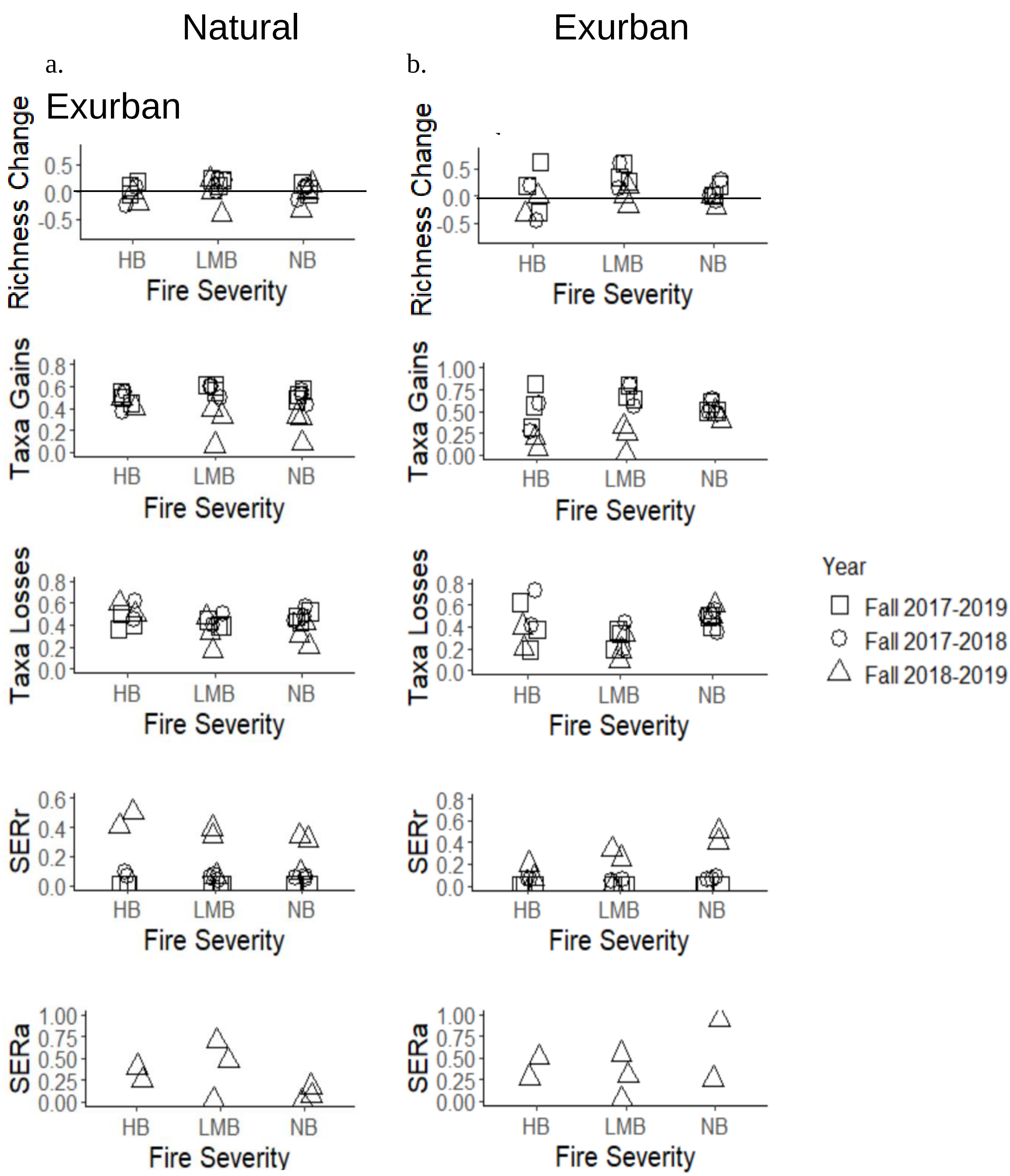

Figure 2.2. Plant community turnover in understory plant communities for the fall sampling seasons of 2017, 2018, and 2019 in the Great Smoky Mountains National Park and Gatlinburg, Tennessee (USA) after a wildfire. Compositional changes were estimated with five community metrics (richness change, taxa gains, taxa losses, SER_r, and SER_a) at sites in the Great Smoky Mountains National Park (natural, **a**) and in Gatlinburg, Tennessee (exurban, **b**).

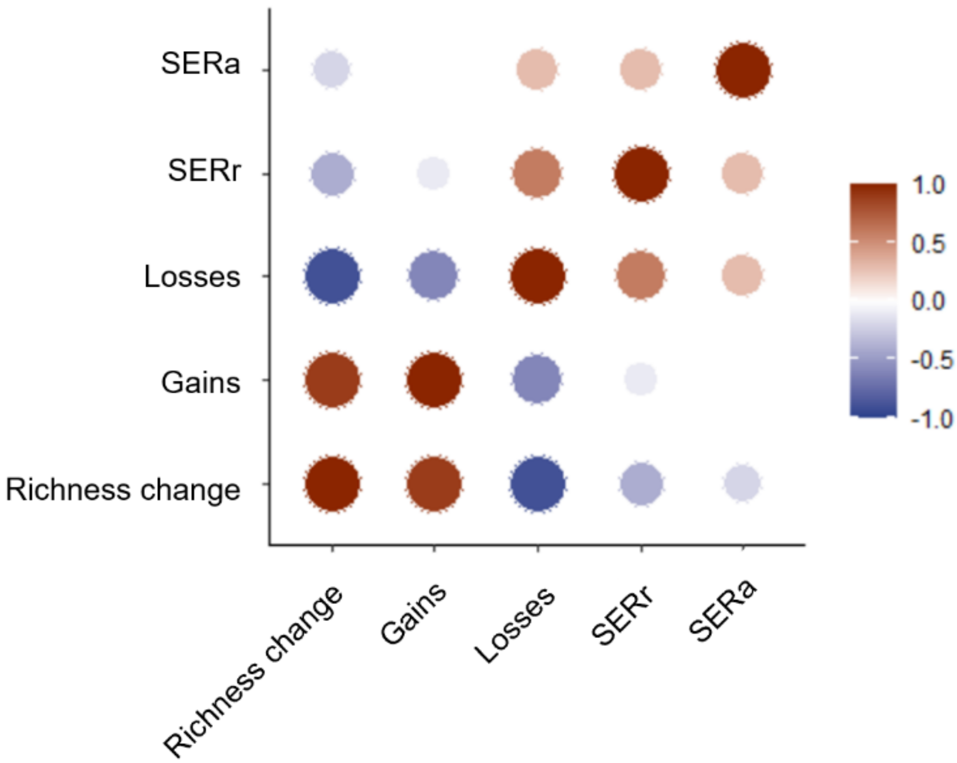

Figure 2.3. Correlation matrix showing relationships between five metrics of community turnover, richness change, taxa gains, taxa losses, SER_a, and SER_r during the full sampling seasons of 2018 and 2019. Negative correlative relationships between variables are in blue whereas positive relationships are in red.

APPENDIX IIA
Supplementary Materials

METHODS

dNBR and dNDVI

The fire severity map was provided by the National Park Service (NPS) in GIS format. The product was generated by U.S. Forest Service Remote Sensing Application Center using delta normalized burn ratio (dNBR) calculated from Landsat satellite images (spectral bands) directly after the fire in December 2016 as:

$$\text{dNBR} = \text{NBR pre-fire} - \text{NBR post-fire}$$

where NBR is the normalized burn ratio:

$$\text{NBR} = \frac{\text{LandsatBand4} - \text{LandsatBand7}}{\text{LandsatBand4} + \text{LandsatBand7}}$$

The dNBR scores are used to differentiate between unburned and burned areas, the latter separated in vegetation fire severity categories. We downloaded the MODIS NDVI from United States Geological Survey (USGS) Land Processes Distributed Active Archive Center with the AppEEARS tool (AppEEARS Team 2020). To calculate dNDVI scores, we subtracted the NDVI average of June, July, and August 2017 (after the fire) from the NDVI average of months June, July, and August 2016 (before the fire). Resulting dNDVI scores were used in addition to burn categories based on dNBR, to quantify fire damage to forest canopy in the first leaf-on season post fire, relative to canopy greenness in the leaf-on season before the fire, in addition to burn categories based on dNBR.

Hill numbers

Quantifying diversity using Hill numbers of orders 1 and 2 provides diversity metrics that vary in terms of their sensitivity to relative taxa abundances. ${}^{1}D$, Shannon diversity, weighs taxa proportional to their relative taxa abundance, and ${}^{2}D$, Simpson diversity, weighs abundant taxa more heavily than in ${}^{1}D$ (Chao et al. 2014). We report ${}^{1}D$ (Shannon diversity) as:

$${}^{1}D = -\sum_{i=1}^{S} p_i \ln p_i$$

where p_i is the proportion of the *i*th taxa (Shannon 1948).

REFERENCES FOR APPENDIX IIA

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Chao, A., C.-H. Chiu, and L. Jost. 2014. Unifying Species Diversity, Phylogenetic Diversity, Functional Diversity, and Related Similarity and Differentiation Measures Through Hill Numbers. Annual Review of Ecology, Evolution, and Systematics 45:297–324.

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TABLES

Table 2.1S. Alpha (^1D and ^2D) and beta (β) diversity across fire severities and locations during the fall sampling periods in 2017, 2018, and 2019.

		Alpha diversity						*Beta diversity*		
		2017		2018		2019		2017	2018	2019
Location	*Fire severity*	^1D	^2D	^1D	^2D	^1D	^2D		β	
Natural	High burn	3.747	3.048	4.951	4.371	4.968	4.356	2.526	1.909	1.833
Natural	High burn	5.329	3.130	7.832	6.950	4.429	3.722			
Natural	High burn	2.832	2.246	5.802	5.070	-	-			
Natural	Low/Medium burn	4.023	2.875	7.214	5.327	5.588	4.899	2.423	2.268	2.230
Natural	Low/Medium burn	9.607	8.385	10.427	6.597	11.897	8.014			
Natural	Low/Medium burn	4.726	3.769	6.799	4.637	10.233	8.923			
Natural	No burn	7.725	6.230	9.279	6.474	6.194	4.979	2.710	2.108	2.294
Natural	No burn	6.321	5.070	7.252	5.839	5.540	3.751			
Natural	No burn	8.817	7.118	3.045	1.816	11.203	8.668			
Exurban	High burn	7.848	2.723	6.921	5.590	-	-	3.586	2.483	2.786
Exurban	High burn	2.839	4.578	1.979	1.399	4.000	4.000			
Exurban	High burn	5.859	3.130	6.000	4.313	6.088	4.165			
Exurban	Low/Medium burn	3.888	4.780	6.314	3.805	-	-	2.438	2.029	2.647
Exurban	Low/Medium burn	5.611	4.571	5.896	3.093	3.683	2.553			
Exurban	Low/Medium burn	5.592	1.800	5.210	3.559	5.051	3.497			
Exurban	No burn	1.890	6.422	8.033	6.359	5.342	3.615	1.857	2.786	2.679
Exurban	No burn	5.380	4.769	3.698	2.815	5.273	4.420			
Exurban	No burn	3.147	2.739	6.422	5.486	7.371	5.268			

Table 2.2S. Alpha (^1D and ^2D) and beta (β) diversity across fire severities and locations during the full sampling periods in 2018 and 2019.

		Alpha diversity				*Beta diversity*	
		2018		2019		2018	2019
Location	*Fire severity*	^1D	^2D	^1D	^2D	β	
Natural	High burn	4.254	4.783	6.081	4.077	6.214	3.000
Natural	High burn	6.406	5.250	4.891	4.967		
Natural	High burn	4.482	5.031	-	-		
Natural	Low/Medium burn	5.898	3.230	6.342	5.044	5.690	3.545
Natural	Low/Medium burn	9.327	5.978	6.037	3.788		
Natural	Low/Medium burn	6.951	6.141	6.980	5.467		
Natural	No burn	8.173	5.242	2.795	5.029	5.114	3.764
Natural	No burn	8.144	5.777	6.988	5.336		
Natural	No burn	6.845	3.756	5.358	6.496		
Exurban	High burn	6.381	3.439	4.822	-	5.961	5.045
Exurban	High burn	2.968	5.763	7.998	5.054		
Exurban	High burn	8.131	3.841	9.367	4.000		
Exurban	Low/Medium burn	5.893	4.855	6.171	-	5.069	4.500
Exurban	Low/Medium burn	4.402	4.937	8.753	3.950		
Exurban	Low/Medium burn	6.144	4.453	5.089	4.624		
Exurban	No burn	6.633	3.585	4.466	6.375	6.545	4.449
Exurban	No burn	4.343	4.341	4.461	4.303		
Exurban	No burn	4.598	4.612	8.038	5.730		

Table 2.3S. Plant community turnover in herbaceous plant communities during **a)** fall seasons 2017 and 2019, **b)** fall 2017 and 2018, **c)** fall 2018 and 2019, and **d)** full seasons 2018 and 2019 in the Great Smoky Mountains National Park and Gatlinburg, Tennessee (USA) after a wildfire. Compositional changes were estimated with five community metrics (richness change, taxa gains, taxa losses, SER_r , and SER_a) at sites in the national park (natural) and in Gatlinburg (exurban). SER_a was not calculated for sampling occurences in 2017. Fire severity was estimated with dNDVI and categorized into no burn (NB), low/medium burn (LMB), or high burn (HB).

a.

Location	*Fire severity*	*Richness change*	*Taxa gains*	*Taxa losses*	SER_r	SER_a
Natural	High burn	0.091	0.545	0.455	0.090	-
Natural	High burn	-0.250	0.375	0.625	0.060	-
Natural	High burn	-	-	-	-	-
Natural	Low/Medium burn	0.000	0.500	0.500	0.070	-
Natural	Low/Medium burn	0.212	0.606	0.394	0.030	-
Natural	Low/Medium burn	0.200	0.600	0.400	0.050	-
Natural	No burn	-0.143	0.429	0.571	0.050	-
Natural	No burn	0.053	0.526	0.474	0.060	-
Natural	No burn	0.111	0.556	0.444	0.040	-
Exurban	High burn	-	-	-	-	-
Exurban	High burn	-0.467	0.267	0.733	0.070	-
Exurban	High burn	0.176	0.588	0.412	0.060	-
Exurban	Low/Medium burn	-	-	-	-	-
Exurban	Low/Medium burn	0.125	0.563	0.438	0.050	-
Exurban	Low/Medium burn	0.600	0.800	0.200	0.060	-
Exurban	No burn	-0.100	0.450	0.550	0.060	-
Exurban	No burn	0.000	0.500	0.500	0.090	-
Exurban	No burn	0.294	0.647	0.353	0.060	-

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b.

Natural	High burn	0.100	0.500	0.400	0.032	-
Natural	High burn	-0.056	0.444	0.500	0.061	-
Natural	High burn	0.182	0.545	0.364	0.035	-
Natural	Low/Medium burn	0.222	0.611	0.389	0.054	-
Natural	Low/Medium burn	0.111	0.556	0.444	0.099	-
Natural	Low/Medium burn	0.143	0.571	0.429	0.051	-
Natural	No burn	0.053	0.526	0.474	0.086	-
Natural	No burn	-0.043	0.478	0.522	0.057	-
Natural	No burn	0.625	0.813	0.188	0.067	-
Exurban	High burn	-0.313	0.313	0.625	0.048	-
Exurban	High burn	0.188	0.563	0.375	0.051	-
Exurban	High burn	0.263	0.632	0.368	0.045	-
Exurban	Low/Medium burn	0.333	0.667	0.333	0.057	-

Table 2.3S continued

Exurban	Low/Medium burn	0.212	0.606	0.394	0.064	-
Exurban	Low/Medium burn	0.600	0.800	0.200	0.029	-
Exurban	No burn	0.000	0.500	0.500	0.067	-
Exurban	No burn	0.000	0.500	0.500	0.051	-
Exurban	No burn	0.200	0.600	0.400	0.048	-

c.

Natural	High burn	0.000	0.500	0.500	0.505	0.402
Natural	High burn	-0.200	0.400	0.600	0.406	0.253
Natural	High burn	-	-	-	-	-
Natural	Low/Medium burn	-0.412	0.059	0.471	0.064	0.023
Natural	Low/Medium burn	0.000	0.333	0.333	0.337	0.478
Natural	Low/Medium burn	0.222	0.389	0.167	0.391	0.700
Natural	No burn	-0.333	0.083	0.417	0.088	0.015
Natural	No burn	0.000	0.310	0.310	0.314	0.077
Natural	No burn	0.133	0.333	0.200	0.335	0.178
Exurban	High burn	-	-	-	-	-
Exurban	High burn	-0.333	0.067	0.400	0.071	0.515
Exurban	High burn	0.000	0.200	0.200	0.202	0.253
Exurban	No burn	-0.182	0.000	0.182	0.002	0.565
Exurban	No burn	0.000	0.333	0.333	0.337	0.009
Exurban	No burn	0.167	0.250	0.083	0.251	0.308
Exurban	Low/Medium burn	-	-	-	-	-
Exurban	Low/Medium burn	-0.200	0.400	0.600	0.406	0.941
Exurban	Low/Medium burn	0.000	0.500	0.500	0.505	0.253

d.

Natural	High burn	0.200	0.300	0.100	0.300	0.431
Natural	High burn	-0.250	0.250	0.500	0.252	0.218
Natural	High burn	-	-	-	-	-
Natural	Low/Medium burn	-0.591	0.045	0.636	0.048	0.601
Natural	Low/Medium burn	0.135	0.351	0.216	0.352	0.316
Natural	Low/Medium burn	-0.130	0.217	0.348	0.219	0.697
Natural	No burn	-0.313	0.125	0.438	0.127	0.224
Natural	No burn	-0.069	0.310	0.379	0.312	0.322
Natural	No burn	-0.026	0.316	0.342	0.317	0.705
Exurban	High burn	-0.350	0.100	0.450	0.102	0.780
Exurban	High burn	0.077	0.423	0.346	0.425	0.489
Exurban	High burn	-0.086	0.343	0.429	0.345	0.427
Exurban	Low/Medium burn	-0.368	0.158	0.526	0.160	0.948
Exurban	Low/Medium burn	-0.050	0.200	0.250	0.201	0.449
Exurban	Low/Medium burn	0.143	0.381	0.238	0.382	0.408
Exurban	No burn	0.143	0.214	0.071	0.215	0.414
Exurban	No burn	0.065	0.355	0.290	0.356	0.180
Exurban	No burn	0.263	0.368	0.105	0.369	0.010

Table 2.4S. The difference in composition and dispersion between fire severities based off a Bray-Curtis dissimilarity matrix in **a)** 2018 and **b)** 2019. Composition difference ranges from 0-1 for the distance between centroids of compared fire severity treatments. Homogeneous communities will return a 0 whereas completely different communities return a value of 1. Dispersion difference is the average distance between a species and the centroid of the fire severity.

a.

Fire severity (1)	*Fire severity (2)*	*Composition difference*	*Dispersion difference*	*Greater dispersion*
High burn	Low/Medium burn	0.430	0.008	Low/Medium burn
High burn	No burn	0.559	0.037	No burn
Low/Medium burn	No burn	0.486	0.029	No burn

b.

High burn	Low/Medium burn	0.379	0.020	Low/Medium burn
High burn	No burn	0.517	0.003	No burn
Low/Medium burn	No burn	0.462	0.016	Low/Medium burn

FIGURES

Figure 2.1S. Conceptual disturbance gradient at the study sites ranging from no disturbance (natural conditions in the GSMNP with no fire damage) to high disturbance (exurban conditions in Gatlinburg, Tennessee with high fire severity).

CHAPTER III:
DESENSITIZED TO DISTURBANCES: UNDERGRADUATE ATTITUDES TOWARD WILDFIRE AND URBANIZATION ARE MOSTLY UNCHANGED AFTER AN INTERVENTION

ABSTRACT

There is strong scientific consensus that human-caused disturbances are altering the landscape and demand immediate intervention. Understanding attitudes towards these disturbances, especially in undergraduates, is important for curriculum development and future mitigation plans. We evaluated the beliefs and intention of undergraduate students to act toward anthropogenic disturbances in three biology major and three non-major's courses. Students were assessed via an online Wildfire and Urbanization Attitude survey (WUAS) prior to and after a randomly assigned video intervention. The intervention that the students received was either a fact-based or emotion-based video in which content was the same, but visuals differed. Students had generally negative beliefs toward wildfire and urbanization disturbances prior to an intervention, after which this relationship grew. Student beliefs and intention to act from pre- to post-intervention were positively correlated indicating that their intention to act increased as their beliefs about the environmental impact of wildfire and urbanization increased. Generally, student beliefs toward anthropogenic disturbances did not differ between major or video type. Respondents wanted to improve the perceived state of the environment, but generally felt a sense of hopelessness in their individual ability to help. This study advances our understanding of undergraduates' attitudes toward anthropogenic disturbances and suggests that carefully planned anthropogenic disturbance curricula could affect students' willingness to take future action.

INTRODUCTION

Human-caused environmental change (i.e., anthropogenic disturbances) has had an impact on the functioning of global ecosystems since the start of the Anthropocene in the 1800s (Cardinale et al., 2012; Goudie 2018). Urban areas have rapidly expanded worldwide, consequently modifying biodiversity and ecosystem health, and ultimately leading to the intersection of wildlands and residential areas, termed the wildland-urban interface (WUI) (Radeloff et al., 2005; Radeloff et al., 2018). In recent years, special attention has been paid to understanding how people feel about climate change, with the majority of research targeting the general public and secondary schools (Aksit et al., 2017). Fewer studies have investigated college students' knowledge, attitudes, and beliefs about climate change (Aksit et al., 2017) and even fewer studies have examined college students' attitudes toward additional anthropogenic disturbances (i.e., human-caused wildfire and urbanization). As human populations expand and biodiversity is threatened, there is a strong need to understand student attitudes toward diverse types of anthropogenic changes.

Given the significant environmental impact of anthropogenic disturbance phenomena, college student beliefs surrounding these events need to be well understood. Students in classrooms today may eventually be in a position to inform land management, urban planners, or policy makers (Ryan 2012) and it is imperative that they do so from an informed perspective. To properly educate students about anthropogenic disturbances, educators need a clearer grasp of student knowledge, concerns, and attitudes toward disturbance events (Wacholtz, Artz, and Chene 2014). Thus, an understanding of extant student attitudes can be used to adjust teaching practices and science curricula to foster science literacy and environmental advocacy (Wacholtz, Artz, and Chene 2014). Our assumption is that students with a greater understanding of anthropogenic disturbances will be more likely as adults to better inform management, landowners, and policymakers on mitigation tactics.

Prior studies have shown that non-STEM majors are likely able to engage with the scientific process; however, they may be less motivated and confident compared to STEM majors (Hebert and Cotner 2019). A study by Cotner et al., (2017) found that non-STEM majors were more likely than biology majors to hold misconceptions about the nature of science, though they were not completely unaware of how science functions and the scientific process. Additionally, non-STEM majors are less likely than biology majors to see science as personally relevant or influential in their lives (Cotner et al., 2017), which may impact attitudes toward particular topics, especially anthropogenic disturbances. For many non-STEM majors, an introductory life science course can be a meaningful opportunity (or potentially the only opportunity) to engage students with science and encourage positive attitudes toward change. Thus, it is important to study whether interventions related to anthropogenic disturbances can shift their perspective on these topics.

Theoretical Model

An early model of environmental behavioral intention proposed that increasing an individual's knowledge about the environment leads to a shift in attitudes and may ultimately lead to changes in behavior (Hungerford and Volk 1990; Yu and Yu 2017). Ajzen's theory of planned behavior demonstrates that an individual's intention to act can be influenced by their attitude associated with the action (Ajzen 1985). In this theory, if the attitude associated with the intended behavior is positive, then there is a greater drive to perform the behavior (i.e., intention to act) (Ajzen 1985; Christensen and Knezek 2015). A 2012 study that measured attitudes toward human-induced climate change found that students who have positive attitudes and beliefs toward increasing climate change effects on the environment are more likely to want to act to reduce its effects (Sinatra et al. 2012; Christensen and Knezek 2015). This empirical work provides support for Ajzen's theory that behaviors are manifestations of the values and attitudes of individuals.

Several empirical and theoretical studies have indicated that emotion can drive an individual's attitude and behaviors toward social topics like climate change (Morris et al., 2019). Previous studies have found that positive emotions have elicited hope and engagement with sustainability issues, whereas negative emotions, such as fear, can provoke more careful processing about potential solutions (Meijnders, Midden, and Wilke, 2001a, 2001b; Ojala 2012; Nabi, Gustafson, and Jensen 2018). The most commonly used approach to science communication regarding sustainability issues, such as climate change, has been the information deficit approach (Dickson 2005). This approach posits that communicating more peer-reviewed scientific evidence to the general public will encourage action and reduce skepticism (Dickson 2005; Morris et al., 2019). However, previous studies have shown that using a fact-based narrative approach to science communication is minimally effective at motivating lasting behavioral change (Whitmarsh et al., 2013; Morris et al., 2019). Rather, it has been suggested that emotions are the key to prompting a public response to social issues; negative emotions, such as worry, drive risk management and can invoke action (Peters and Slovic 2000; Morris et al., 2019). Because existing emotions associated with environmental-related issues are predictive of successive attitudes and behaviors, emotions provoked by environmental issue message styles may play an influential role in associated attitude and behavior change (Nabi, Gustafson, and Jensen 2018).

Using Ajzen's theory of planned behavior (1985), this study identified differences in attitudes toward wildfire and urbanization in undergraduate biology major and non-major students. Attitude in this study was defined as "positive or negative feelings and predispositions" to wildfire and urbanization (Lovelace and Brickman 2013). According to Christensen and Knezek (2015), attitudes toward environmental issues consist of "beliefs, affect, and behavioral intentions that combine to illustrate attitudes toward environmentally related activities or issues". Though this study did not access behavior directly, Ajzen (2002) stated that attitudinal beliefs and intention to act are a predecessor to behavior (Christensen and Knezek 2015). Thus, we measured the constructs of wildfire and urbanization "beliefs" and "intention to act." Beliefs in this study were related to a student's perception of the effect of wildfire or urbanization on the environment. Intention to act was the student's willingness to take action toward environmental concerns related to wildfire and urbanization disturbances. Finally, we explored the impact of a fact-based versus emotion-based intervention on the above-mentioned dependent variables to determine if presentation of material in the classroom can also affect student attitudes. Therefore, we collected data to test three hypotheses: **H1.** Student beliefs and intention to act toward wildfire and urbanization disturbances on the environment will be different from pre- to post-intervention; **H2.** Biology major attitudes toward environmental disturbances will be significantly different compared to non-biology majors; and **H3.** Type of intervention (fact-based or emotion-based videos) will impact students' beliefs and intention to act toward disturbances.

Scientific knowledge can often be personally relevant, and the lack of science understanding can affect policy decisions, personal choices, and general decision making (Cotner et al., 2017). Results from this study can be used to inform anthropogenic disturbance curricula in the classroom, provide valuable insight to policy makers on the concerns of their constituents, and assess student perceptions and understanding of global change phenomena beyond climate change. This study will further test the link between student understanding of biological processes and their beliefs and intention to act specific to anthropogenic disturbances.

METHODS

Participants and Recruitment

Before beginning recruitment, this study was approved by the University of Tennessee-Knoxville Institutional Review Board (IRB-20-06152-XP). This study focused on students in majors and non-majors biology course sections (n = 3 biology majors course; n = 3 non-majors course) at a large four-year research institution in the southeastern United States in spring 2021. The majors course was a freshman introductory biology course with approximately 550 students enrolled across the three sections; the non-majors course was a general education course with approximately 700 students enrolled across the three sections. Students invited to participate in this study were those who registered for the selected biology classes and whose instructors agreed to send the study information to their students. Any student in the identified courses who agreed to the consent information and took the surveys had their data included in the study, with the exception of those who were under 18. Those under 18 could answer the questions, but their answers were not included in the data set. Students were incentivized to complete the surveys and watch the video as part of the course by the instructors offering three extra credit points upon completion. If students wanted the opportunity to receive extra credit but did not want to participate in the study, a separate assignment was given to earn credit. Students in these biology courses were mostly freshman students, over the age of 18, with varied backgrounds, genders, and ethnicities.

Survey Design

Students were asked to complete a pre-intervention online survey about wildfire and urbanization disturbances (hereafter the Wildfire and Urbanization Attitude Survey [WUAS]). The survey consisted of a total of 35 questions, as follows: 8 Likert-scale questions on wildfire beliefs, one-Likert scale question about wildfire intention to act, seven Likert-scale questions on urbanization beliefs, one Likert-scale question about urbanization intention to act, six Likert-scale questions related to general environmental issues to measure intention to act, three open-ended questions asking about wildfire, urbanization, and general environmental disturbances (i.e., why do you feel this way about wildfire?), and seven demographic questions (i.e., gender, race, hometown, first-generation college student status, etc.) (see supplementary materials Appendix IIIA for the full WUAS). The WUAS included 15 questions modified from an existing climate attitude survey from Christensen and Knezek (2015) for both belief and intention to act constructs. Likert-scale questions from the Christensen and Knezek (2015) climate attitude survey belief constructs were modified to include the words “wildfire” or “urbanization” in place of “global climate change”, but no modification was made related to the questions surrounding the intention to act construct. Questions were reworded slightly if direct word replacement was not feasible. Though multiple climate attitude surveys exist, the one created by Christensen and Knezek (2015) was the most relevant for adaption to wildfire and urbanization attitude questions for undergraduate students. Other questions added to the Christensen and Knezek (2015) items were the open-ended questions and the demographic questions.

Intervention

After students took the pre-intervention WUAS, the “classroom” intervention occurred via an asynchronous online lecture (i.e., voiceover videos) that contained descriptive information on general anthropogenic disturbances, wildfire, and urbanization, as well as location-specific disturbance information in areas of interest (e.g., urbanization and wildfires in Gatlinburg, TN). The asynchronous format standardized any confounding variables associated with how the researcher taught in person (i.e., researcher attitude, pedagogical approaches, etc.). These videos were sent to students via the instructor the week after taking the pre-intervention survey.

The delivery of the intervention was randomized so that the students in each class either received a “fact-based” video or an “emotion-based” video (hereafter “video type”). Though the script and presenter (M.H.H.) of both videos were the same, the visuals on the fact-based video were similar to something that students would receive in a science class (e.g., charts, maps, infographics, etc.) whereas the emotion-based video had visuals similar to something that students would see on the news or social media (e.g., pictures of charred landscapes, animals wandering in an urban landscape, etc.). Videos were piloted prior to this study in a separate introductory biology course to determine if they differentially impacted student emotions (UTK IRB-21-06293-XM).

The intervention and post-intervention survey were distributed to the students one week after taking the pre-intervention survey. This post-intervention survey assessed changes in beliefs associated with wildfire, urbanization, and general environmental issues as well as changes in motivation to act from the intervention.

Data Preparation

Pre-intervention data were assessed and analyzed to identify baseline comparisons between majors and non-majors. Prior to assessment, students under the age of 18 ($n = 1$) were removed from the study, in addition to duplicate responses or incomplete responses. Likert-scale survey responses were summed across the wildfire and urbanization beliefs and intention to act constructs (Appendix IIIA: WUAS). Pre- and post-intervention responses were then matched to understand differences between majors and non-majors, changes in attitude (beliefs and intention to act) in response to intervention, and attitude differences between video type. Responses were matched from the e-mail address of the respondents that was required upon starting the survey. Matched pre- and post-intervention data were additionally filtered to ensure that students watched the intervention video prior to beginning the post-intervention WUAS. Only students who completed the post-intervention survey for over 540 seconds were used in the analysis ($n = 196$). This post-intervention time requirement was set in place because both videos (i.e., fact-based or emotion-based) were slightly over nine minutes long, thus ensuring that students were watching the full intervention video prior to completing the survey.

Reliability and Validity

Reliability and validity are important features of instrument measurement. Reliability is related to the consistency of the instrument when it is given to the same individuals more than once (Arjoon, Xu, and Lewis 2013). Validity is the extent that the instrument measures what it is intended to measure (Arjoon, Xu, and Lewis 2013). Cronbach's alpha was calculated as a measure of internal consistency and reliability for the entire survey, as well as for the individual constructs (Cronbach 1951; Taber 2018). Guidelines provided by Kline 1999 for Cronbach's alpha were used to assess the reliability of the WUAS (i.e., coefficient above 0.7 is acceptable). The validity of the constructs of the WUAS (i.e., wildfire and urbanization beliefs and intention to act) was assessed via confirmatory factor analysis (Appendix IIIA: Table 3.1S; Figure 3.1S) to verify three constructs (wildfire and urbanization beliefs and intentions) indicated by Christensen and Knezek (2015). Items on the WUAS that were negatively phrased (i.e., "We cannot do anything to stop wildfires.") were reverse scored for ease of comparison to the positively phrased items (see items 20, 21, and 22 on Appendix IIIA: WUAS). The validity of the criteria of the WUAS were assessed using Pearson correlations for the pre- and post-intervention survey responses.

Quantitative Analyses

The number of participants, means, standard deviation, and standard error were calculated for questions that form the constructs in the pre- and post-intervention surveys. We fitted generalized linear models (GLMs) that assessed differences in fire and urbanization beliefs and intention to act both pre- and post-intervention. The fixed effect variables we used were: pre- and post-survey results, video type, major type, and their pairwise interactions. The response variables of the GLM (wildfire and urbanization beliefs, and intention to act) were modeled as having Poisson errors to account for sampling twice within each classroom. Models using the Poisson distribution were assessed for over-dispersion.

Data analysis and instrument validation for this study are based on previous studies by Christensen and Knezek (2015) and Sinatra et al., (2012). All exploratory analyses, reported statistics, and graphical representations were performed using the packages: "corrplot", "EFAtools", "ggplot2", "ggpubr", "glmer", "GPArotation", "lavaan", "ltm", and "psych" in RStudio v. 4.0.3.

Qualitative Analyses

Inductive coding of the open-ended responses of the WUAS was performed in Microsoft Excel by two trained coders (M.M.H. and M.W.), who first went through the pre-intervention responses (n = 1,788 responses to three open-ended questions) and post-intervention responses (n = 1,092 responses to three open-ended questions) to inductively develop themes and codes. A code defined here is "a word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute" (Saldana 2016). Using inductive coding helps to capture the experience of the participants instead of forcing participants' words to fit into preconceived ideas (Rowan 1981). After a preliminary review of the responses, coders (M.M.H. and M.W.) worked together to create a codebook, which included themes, codes (and sub-codes [Appendix IIIA: Codebook]). Coders then independently assigned codes to each response, after which coders examined each response together and agreed on final codes. Multiple codes could be assigned to each response. At the completion of coding all responses, patterns were analyzed for the pre-intervention responses and matched post-intervention responses. Themes emerged which were then compared with the quantitative findings.

RESULTS

Pilot Study

A pilot study of the videos was conducted before the full study to confirm that the videos were receiving a response from the students. The pilot study revealed that the majority of students in the fact-based group (56.3%) rated the video as a 4-5 (on a scale of 1= no emotion, 5= strong emotions), whereas 65.5% of the emotion-based group rated the video as a 4-5. A larger proportion of students rated the video lower on the emotion scale in the fact-based group (43.7%) compared to the emotion-based group (34.5%).

Respondent Demographics

There were 596 initial respondents to the pre-intervention WUAS. The respondents of this survey were predominately Caucasian (84%) with 456 students identifying as women, 133 identifying as men, 3 identifying as non-binary, and 4 students choosing not to disclose. Of the respondents, 190 students were in the biology majors class, whereas 286 were in the non-majors class. The remaining 120 students either did not disclose the course they were taking or chose multiple courses. There were 135 students that identified as being first-generation students (neither parent nor guardian who the student has lived with has a bachelor’s degree) whereas 456 students did not identify as being first generation or did not disclose.

There were 196 matched respondents who took both the pre- and post-intervention WUAS and met the time requirement for the post-intervention survey. This population was predominately Caucasian (87%), with 154 respondents identifying as women, 40 students identifying as men, and the remaining students choosing to not disclose. Of these respondents, 95 were biology majors whereas 70 were considered non-majors. The remaining 31 students did not disclose the course they were taking and therefore were not included in analyses. There were 141 students who identified as being first-generation students whereas 41 students stated they were not first-generation students (Appendix IIA: Table 3.2S).

Survey Reliability and Descriptive Statistics

Cronbach’s alpha for the entire pre-intervention and post-intervention WUAS was 0.89. Cronbach’s alpha for the pre-intervention wildfire and urbanization beliefs constructs were 0.85 and 0.79 respectively, whereas intention to act was 0.75. Cronbach’s alpha for the post-intervention wildfire and urbanization beliefs construct were 0.88 and 0.85 respectively, while intention to act was 0.79. This is higher than the standard of 0.70 which indicates good survey reliability (Kline 1999).

A Kaiser-Meyer-Olkin criterion test (KMO) was performed before conducting the factor analysis. A KMO test determines the suitability of the data set for factor analysis. Our KMO value was 0.904; a value above 0.5 is considered acceptable for conducting a factor analysis (Kaiser and Rice 1970). A confirmatory factor analysis was performed on the 22 individual Likert-scale questions on the pre-intervention WUAS, using the 596 pre-intervention responses. This analysis indicated that two constructs (wildfire beliefs and urbanization beliefs) and a third construct (intention to act) were well represented by survey items after eliminating three items from the survey (items 9, 15, and 17; Appendix IIIA: Figure 3.1S). Items 20-22 that originally had negative factor loadings were reverse scored so that the items could be compared to positively phrased items on the WUAS. Gains in wildfire and urbanization beliefs are defined as a respondents’ increased perception that wildfire and urbanization disturbances have an impact on the environment. A gain in intention to act means that the respondent's likelihood of taking some type of action to protect the environment was increased.

Correlative relationships were found between beliefs and intention to act on several occasions. Pre-intervention wildfire beliefs and pre-intervention intention to act were positively correlated with a moderate sized relationship ($R = 0.416$). Post-intervention wildfire beliefs and intention to act had a large positive relationship ($R = 0.706$). Pre-intervention urban beliefs and intention to act had a moderately positive relationship ($R = 0.379$) that grew post-intervention ($R = 0.475$) (Appendix III: Figure 3.1). These positive correlation coefficients indicate that intention to act increases as student beliefs toward the effects of wildfire and urbanization on the environment increase from pre- to post-intervention.

Additionally, significant positive relationships were found between wildfire and urban beliefs both pre- and post-intervention. Pre-intervention urban beliefs were correlated with pre-intervention wildfire beliefs ($R = 0.403$). Similarly, this relationship grew post-intervention ($R = 0.527$). This indicates that student beliefs toward one type of disturbance positively impacts their beliefs toward the other disturbance, with this relationship growing post-intervention (Appendix III: Figure 3.1). Finally, pre-intervention intention to act had a small correlative relationship with post-intervention intention to act ($R = 0.175$).

The number of participants, means, standard deviations, and standard errors for the wildfire and urbanization beliefs and intention to act constructs on the pre- and post-intervention WUAS are presented in Table 3.1 & 3.2. In the pre-intervention WUAS, non-major students most agreed with item 1 "I believe our climate is changing," and least strongly agreed with item 21 "It is a waste of time to work to solve environmental problems." Majors students most strongly agreed with item 18 "I can do my part to make the world a better place," whereas they also least agreed with item 21. From the post-intervention WUAS, non-major respondents most strongly agreed with item 4 "I believe that there is evidence of an increase in global wildfire occurrence," and least strongly with item 20 "I think most of the concerns about environmental problems have been exaggerated." Majors students most strongly agreed with item 6 "Wildfires will impact our environment in the next 10 years," and also least strongly agreed with item 20 (Appendix IIIA: WUAS).

Quantitative Results

To address H1 that student beliefs and intention to act toward wildfire and urbanization disturbances will be different from pre- to post-intervention, GLM tests were performed (Appendix III: Table 3.3). Student beliefs toward urbanization were significantly different from pre- to post-intervention, whereas wildfire beliefs and intention to act were insignificant, thus partially confirming H1.

H2 posits that biology major attitudes toward environmental disturbances will be significantly different compared to non-biology majors. GLM tests showed that there were no significant differences between majors and non-majors beliefs toward wildfire ($P = 0.852$), urbanization ($P = 0.918$), or intention to act ($P = 0.591$) from pre- to post-intervention (Appendix III: Table 3.3; Figure 3.2). Mean values for the wildfire and urbanization belief construct as well as the intention to act construct increased for both majors and non-majors post-intervention (Appendix III: Table 3.1; Table 3.2). Biology major attitudes toward environmental disturbances were not significantly different compared to non-majors, thus rejecting H2.

Our final hypothesis (H3) was that type of intervention (fact-based or emotion-based videos) will impact students' beliefs and intention to act toward disturbances. GLM tests found that there were no significant differences between the fact-based and emotion-based videos regarding student beliefs toward wildfire ($P = 0.732$), urbanization ($P = 0.774$), or intention to act ($P = 0.847$) after the intervention (Appendix III: Table 3.3; Figure 3.3). Biology majors that watched the emotion video had the lowest mean values across all constructs; however, there were no significant differences across video type (Appendix III: Table 3.2), thus rejecting H3.

Qualitative Results

To understand the reasoning behind student answers to the Likert-scale questions, we asked open-ended questions "why do you feel this way about wildfire, urbanization, or environmental issues?" (n = 3). Codes used surrounding the open-ended questions included: personal experience/relationships, viewpoint (+/-/0), feelings (+/-), level of impact (+/-), responsibility, method of action, method of information, knowledge level, causality, opinions (+/-/0), validity of topic (+/-), othering, and doom. For a full representative list of codes and their related themes, see supplementary materials Appendix IIIA: Codebook.

Three codes (level of impact, viewpoint, and method of action) were the primary focus throughout the review of the qualitative results due to their repetition used across major and video type. Level of impact is related to how the respondent perceives the disturbances' effect on self, the environment, others, or the future. From one respondent:

> "Wildfires are **impacting** our animal populations.
> Wildfires keep growing and they could eventually
> **harm** [our planet] as a whole."

Viewpoint is how the respondent perceives the environment generally or the disturbance itself. For example:

> "The environment is extremely **important**…"

Finally, method of action is how the respondent believes the environmental issue should (or should not be) dealt with and if (or what) action should be taken. From one respondent:

> "I want to be able to make a difference
> because it is important [to me], but it is
> hard to feel big when knowing what I
> can do would make little difference."

Prior to the intervention, 25% of all students recognized that were was some level of impact from wildfires on the future, the environment, themselves, others etc., whereas 40% of students recognized an impact from urbanization, and 11% on general environmental disturbances. After the intervention, 26% of all students recognized that there was some level of impact from wildfires in addition to 28% from urbanization. Only 9% of students recognized that there was an impact from general environmental disturbance.

Level of impact was 65% more frequent throughout majors than non-majors prior to the intervention. Post-intervention, level of impact increased to 70% more frequent throughout the majors compared to the non-majors. Method of action was 36% more frequent throughout majors compared to non-majors pre-intervention, whereas this value increased to 67% post-intervention. Finally, viewpoint toward disturbances were 53% more likely in majors compared to non-majors pre-intervention, whereas this value slightly decreased to 51% post-intervention.

Level of impact was 43% more frequent in the emotion-based video type compared to the fact-based video type. Method of action was 36% more frequent in emotion-based videos than the fact-based videos. Finally, viewpoint was 54% more frequent in emotion-based videos compared to the fact-based videos. Additional representative answers surrounding the three commonly used codes (level of impact, viewpoint, and method of action) are in Appendix III: Table 3.4.

Overall, the frequency of all codes used from pre- to post-intervention stayed relatively consistent across all respondents, mainly about the idea of students caring about the environment, having a personal experience with some type of environmental impact, and feeling like action should be taken to preserve the integrity of the environment. Students had a relatively negative attitude about the idea of anthropogenic disturbances and felt like something should be done to prevent future harm.

After the intervention, a code "doom" was added to the environmental issues codebook, meaning that students felt hopeless in their efforts to make an impact on the environment. This was due to student responses surrounding the idea that although they wanted to help, they felt that "there was nothing they could do." The frequency of this code was minimal; however, the majority of students coded under "doom" were in the emotion-based video group, while there were no differences between majors and non-majors. As one student said:

> "I think there is so many problems that we can try and fix but there are other things that are **out of our control**."

This idea that students wanted to help, but generally felt "helpless" or that one person "could not make a change" was repeated throughout the open-ended responses, though there were positive correlations between beliefs and intention to act prior to and after the intervention. This idea was further emphasized through the "responsibility" code, where students believe that someone should be taking responsibility for environmental problems. This code was 63% more frequent for majors compared to non-majors. Post-intervention, 56% more students in the emotion video group compared to the fact-based group thought similarly.

DISCUSSION

In our study, we analyzed the differences between biology majors and non-majors' attitudes (i.e., beliefs and intention to act) toward wildfire and urbanization disturbances before and after watching two types of videos meant to influence those attitudes. We hypothesized that: **H1.** Student beliefs and intention to act toward wildfire and urbanization disturbances will be different from pre- to post-intervention; **H2.** Biology major attitudes toward environmental disturbances will be significantly different compared to non-biology majors; and **H3.** Type of intervention (fact-based or emotion-based videos) will impact students' beliefs and intention to act toward disturbances. Overall, we found that: (i) student beliefs and intentions pre-intervention were significant and positively correlated, with the relationship growing post-intervention (Appendix III: Figure 3.1); (ii) student beliefs toward urbanization disturbances were significantly different from pre- to post-intervention WUAS, but wildfire beliefs and intention to act were not significantly different (Appendix III: Table 3.3); (iii) student beliefs toward wildfire and urbanization disturbances and intention to act generally did not differ between biology majors and non-majors (Appendix III: Table 3.3; Figure 3.2); and (iv) the type of intervention students received did not significantly impact student beliefs and intention to act (Appendix III: Table 3.3; Figure 3.3). Students had general negative attitudes and beliefs toward wildfire and urbanization prior to the intervention and this relationship grew after the intervention.

The theory of planned behavior (Ajzen 1980) indicates there is reason to believe a relationship might exist between beliefs and intentions. Three of the five constructs that form the theory of planned behavior are particularly relevant to this study (Ajzen 2005):

1. Attitudes – Positive or negative interest in a particular topic and/or situation.
2. Perceived power - Perceived presence of factors that may facilitate or impede performance of a behavior.
3. Perceived behavioral control – A person's perception of the difficulty associated with performing the behavior of interest.

This study found a significant positive relationship between pre- and post-intervention belief categories compared to intention to act, suggesting that as student beliefs that wildfire and urbanization are harmful to the environment increased, intention to act also increased. Though beliefs that urbanization is harmful to the environment increased post-intervention, there were no significant differences in respondent intention to act or wildfire beliefs after the intervention (Appendix III: Table 3.3).

The theory of planned behavior has previously suggested that perceived behavioral control and power can determine motivation to act, and a loss of control or sense of helplessness can potentially demotivate future action (Geiger et al., 2021). The theme that students felt little control over environmental issues and could not make an individual difference was common after exposure to the intervention videos. Respondents felt that something needs to be done, thus the significant positive relationship between beliefs and intention to act, but often thought their individual efforts did not matter. For example:

"I believe there are problems, but I think that there is **only so much one person can do**."

Associated helplessness could be due to construct 2 and 3 in the theory of planned behavior, indicating that students feel little individual power and control over the current environmental situation. However, this study found a positive relationship in beliefs and intention to act, indicating a sense of urgency among respondents that suggests collective action is necessary.

Despite previous views that emotion can deter environmental action, positive (or negative) emotional reactions and perceptions can foster beneficial behavior toward environmental threats (Geiger et al., 2021). Studies have shown that emotions can have an effect on environmental-related behaviors, where negative emotions toward environmental issues can lead to pro-environmental behaviors (Leviston and Walker 2012; Wang et al., 2018). van Zomeren, Postmes, and Spears (2008) argues that a personal feeling of hopelessness and helplessness is not demotivating, but rather can motivate collective action to solve environmental issues (Fritsche et al., 2017; Geiger et al., 2021). As stated by a respondent:

> "I feel like **everyone** can do their small part in helping out the environment. **One person** may not be able to make a change, but a million could…"

Science education has a responsibility to empower students to make informed decisions. A non-majors course may be the only college course where a student is exposed to biology, therefore the needs and priorities of non-majors students may be fundamentally different from the needs of majors students (Cotner et al., 2017). Both major and non-major students remained relatively consistent in their intention to act post-intervention (Appendix III: Figure 3.2). Non-STEM majors are more likely to view science as a static process, and generally tend to be less confident being surrounded by science than majors (Cotner et al., 2017). Introduction to new information in this scenario may have increased both major and non-major beliefs in anthropogenic disturbance issues due to knowledge gain (Cotner et al., 2017). However, intention to act was maintained from pre- to post-intervention possibly due to perceived loss and negative narratives associated with the intervention videos (Hall 2013). Because the emotion-based videos were modeled from something a student may see on social media, the news, etc., this may have fueled problem identification with these anthropogenic issues, rather than solution identification which can be associated with individual feelings of hopelessness (Hall 2013). A study by Hall (2013) suggests that the current narrative of "doom and gloom" usually associated with climate change fosters despair and resistance to change, whereas positive outlooks and hope are crucial for action. The intervention likely reinforced the "doom and gloom" perception and lack of opportunity to make individual change due to graphic imagery (in the emotion videos) and negative tone (in both videos), which may explain why there was not a significant relationship in wildfire beliefs and intention to act from pre- to post-intervention (Appendix III: Table 3.3; Figure 3.3). Though it is impossible to deny that change is needed and the future may seem bleak at times, inspiring small individual action in the classroom could be beneficial for anthropogenic disturbance curricula and thus initiating change on a broader scale.

Anthropogenic disturbance issues are important and need to be addressed, and this study may provide some insight into the correct way to introduce material in the classroom. Previous studies have suggested that the general public has a "finite pool of worry" about social/environmental issues that can often cause "compassion fatigue" (Bloodhart, Swim, and Dicicco 2019). The constant media exposure and bombardment of negative narratives associated with environmental issues can result in a decrease in empathy or eventual desensitization to the topic (Bloodhart, Swim, and Dicicco 2019). Consistent use of negative emotional messages surrounding anthropogenic disturbance may subsequently diminish the driving emotions needed to take future mitigative action.

As educators design curricula for specific courses, we must keep in mind that some students may only be exposed to science on a few occasions. A message of hope and encouragement may be the more appropriate path to initiate future action, whereas risk-association and fear creates a grim and hopeless narrative among students who may not regularly be exposed to science.

Limitations

The researchers recognize that lasting attitude change after one lecture and/or exposure to information is unlikely; however, the outcomes obtained from this study can be used by future researchers to assess general class attitude surrounding wildfire and urbanization disturbances. A future study using the WUAS could be implemented throughout a course to be used longitudinally to measure lasting change rather than change over a short period of time (i.e., two weeks). Secondly, there were limitations associated with the demographics of students in these courses. The majority of students in our study identified as Caucasian women which can underrepresent views of all the students in these courses. Thirdly, though the assignment of video type was randomized per each individual, there was a greater percentage of students that watched the emotion-based video compared to the fact-based video when matching pre- and post-intervention data, which can impact the power of the GLM. Finally, 120 respondents in the pre-intervention survey selected both the majors and non-majors courses as classes they were taking. While this is likely not the case and was most likely user error (some of the same instructors taught both the majors and non-majors courses), these students had to be eliminated from the study so that there was a clear distinction between who was in the majors class and who was in the non-majors class.

Conclusions and Future Directions

As human populations continue to grow and expand geographically, anthropogenic disturbance events will likely become more frequent and intense. Studies have been conducted to understand undergraduate students' knowledge, perceptions, feelings, and attitudes toward climate change, yet minimal research exists on undergraduate understandings of disturbances outside of human-caused climate change. With almost constant exposure to anthropogenic disturbance events on social media, news platforms, and throughout daily life, it is imperative to understand existing undergraduate student attitudes toward these events. A deeper understanding of these attitudes will allow educators to adjust curricula to increase scientific literacy and knowledge that may promote future pro-environmental action. Comparisons made in this study between students from biology majors and non-majors and different video groups can determine if these variables have an effect on students' attitude toward a certain anthropogenic disturbance and how we as educators can better structure curriculum to support a positive atmosphere that promotes action.

Future studies using the WUAS could be implemented in multiple classrooms and courses across the U.S. Regional attitude differences among undergraduates could further refine anthropogenic disturbance curricula based on locality, socio-cultural environmental factors, and personal and/or political values. Additionally, it would be beneficial to further explore differences or similarities in gender and first-generation status in response to the WUAS. It has generally been reported that women express greater emotional environmental concern than men, but little has been done to test this empirically (Arnocky and Stroink 2010). To the researcher's knowledge, no studies have been conducted to assess environmental attitudes associated with first-generation status. Though previous studies have shown that emotional response can affect task engagement in the classroom, which can alter the way students act and experience the world in the future (Goldman et al., 2021). Furthermore, a longitudinal study that would implement the WUAS throughout a semester-long global change ecology course or introductory biology course (for majors and/or non-majors) could help to gain a greater understanding of student attitude change through time.

An introductory biology course may present an opportunity for educators to represent science in an empowering way where students are aware of the issues surrounding anthropogenic disturbances but also feel capable of initiating change. The intervention videos in this study seemed to promote individual feelings of hopelessness and "doom", even though relationships between beliefs and intention to act increased from pre- to post-intervention. Future iterations of these videos could provide more positive messages that encourage action and motive change, regardless of whether a student is a biology major or non-major. Designing anthropogenic disturbance curricula for a student population that has varied knowledge, perceptions, and skills can be complicated. However, as science educators, developing courses and lessons that optimize our students' knowledge, skills, and confidence can result in positive attitudes that can initiate action toward change.

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APPENDIX III

TABLES

Table 3.1. Descriptive statistics for all 22 Likert-scale questions on the pre-intervention wildfire and urbanization attitude change survey (WUAS) for majors and non-majors. Questions were grouped into the constructs of 1) wildfire beliefs, 2) urbanization beliefs, and 3) intention to act. Analyses were completed on the group of students that completed both the pre- and post-intervention survey with the time requirement of 540 seconds.

	n	*Mean*	*Standard deviation*	*Standard error*
Wildfire beliefs				
Majors	95	34.04	3.713	0.381
Non-majors	69	33.81	5.042	0.607
Urban beliefs				
Majors	95	26.79	3.031	0.311
Non-majors	69	27.19	3.901	0.470
Intention to act				
Majors	95	19.92	3.465	0.355
Non-majors	69	20.93	3.002	0.361

Table 3.2. Descriptive statistics for all 22 Likert-scale questions on the post-intervention wildfire and urbanization attitude change survey (WUAS) for majors and non-majors and intervention video type. Questions were grouped into the constructs of 1) wildfire beliefs, 2) urbanization beliefs, and 3) intention to act. Analyses were done on the group of students that completed both the pre- and post-intervention survey with the time requirement of 540 seconds.

	n	*Mean*	*Standard deviation*	*Standard error*
Wildfire beliefs				
Majors (emotion video)	80	35.28	4.100	0.458
Non-majors (emotion video)	50	36.06	3.672	0.519
Majors (fact video)	15	36.20	3.529	0.911
Non-majors (fact video)	19	34.00	5.033	1.155
Urban beliefs				
Majors (emotion video)	80	32.94	3.846	0.430
Non-majors (emotion video)	50	33.18	3.462	0.490
Majors (fact video)	15	32.53	3.226	0.833
Non-majors (fact video)	19	32.74	4.227	0.970
Intention to act				
Majors (emotion video)	80	20.55	3.126	0.349
Non-majors (emotion video)	50	21.46	2.873	0.406
Majors (fact video)	15	21.60	2.261	0.584
Non-majors (fact video)	19	21.05	3.082	0.707

Table 3.3. Effects of major type and video type on pre- and post-intervention fire and urban beliefs, and intention to act analyzed with a generalized linear model (GLM). Associated estimates (E) standard error (SE), z value, and P-values (*P*) are reported for the predictor variables pre- and post-intervention, major type (biology major and non-biology major), video type (fact-based or emotion-based), and their interactions.

	Fire beliefs				*Urban beliefs*				*Intention to act*			
Predictor variables	*E*	*SE*	*z*	*P*	*E*	*SE*	*z*	*P*	*E*	*SE*	*z*	*P*
Intercept	3.563	0.018	193.353	2×10^{-16} ***	3.234	0.022	148.226	2×10^{-16} ***	2.980	0.025	120.820	2×10^{-16} ***
Pre and Post Survey	-0.037	0.026	-1.443	0.149	-0.096	0.031	-3.117	0.002 **	0.005	0.034	0.149	0.882
Video Type	0.019	0.041	0.473	0.636	0.001	0.049	0.017	0.987	0.011	0.054	0.205	0.838
Major Type	0.019	0.029	0.675	0.500	0.016	0.034	0.466	0.641	0.028	0.038	0.749	0.454
Video Type * Major Type	-0.052	0.046	-1.148	0.251	-0.010	0.054	-0.177	0.860	0.035	0.060	0.582	0.561
Survey * Major Type	-0.007	0.038	-0.187	0.852	0.004	0.046	0.102	0.918	0.027	0.050	0.537	0.591
Survey * Video Type	-0.016	0.047	-0.342	0.732	-0.016	0.056	-0.287	0.774	-0.012	0.061	-0.193	0.847

Statistical significance is denoted by the following: p < 0 ‘***’, p < 0.001 ‘**’, p < 0.01 ‘*’, p < 0.05 ‘.’

Table 3.4. Common responses and supporting quotes to the open-ended question "why do you feel the way you to toward [fire, urbanization, and general environmental issues]?" on the pre-intervention survey.

Primary response code	*Explanation*	*Supporting Quote*
"Level of impact" (+/-/0)	How the respondent perceives the disturbance's effect (+/-/0) on self, the environment, others, or the future.	"I know that in the past few years wildfires have increase dramatically. I believe [wildfires] can hurt our future and our environment if nothing is done to prevent them." (-) "Urbanization is without a doubt happening. We're getting closer and closer to megacities and the environmental impacts are extreme." (-) "Environmental problems will change our world and if future generations do not have nature and things to look out on like we do, life will be different." (-)
"Viewpoint" (+/-/0)	How the respondent perceives the disturbance itself (+/-/0).	"Wildfires in my opinion are a direct link to global warming. Wildfires can cause people displacement from their homes and I feel if there is something we can do to prevent this we should." (-) "I don't know of any reason that urbanization will negatively affect the environment." (0) "Knowing about environmental problems is important, doing something about them is even more important. I do feel like there's little I can do as one college student." (-)
"Method of action"	How the respondent perceives the environmental issue should (or should not be) dealt with.	"I believe people are not taking this issue very seriously, which causes the preparation put into solving this issue to be severely limited." "I feel that urbanization is increasing but I'm not sure how to stop it." "I do not think that one person can change the environment. I feel as though if an actual difference is to be made, that it will require cities and not just a few people."

FIGURES

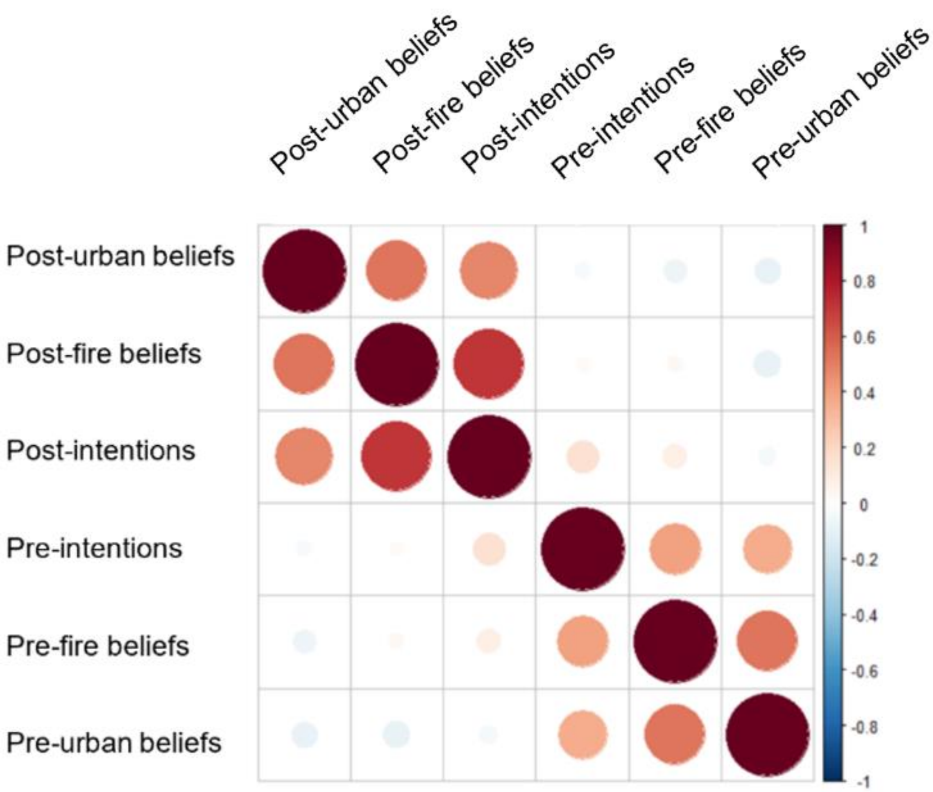

Figure 3.1. Correlation matrix showing relationships between pre- and post-intervention beliefs and intention to action toward wildfire and urbanization disturbances. Negative correlative relationships between variables are in blue, whereas positive relationships are in red.

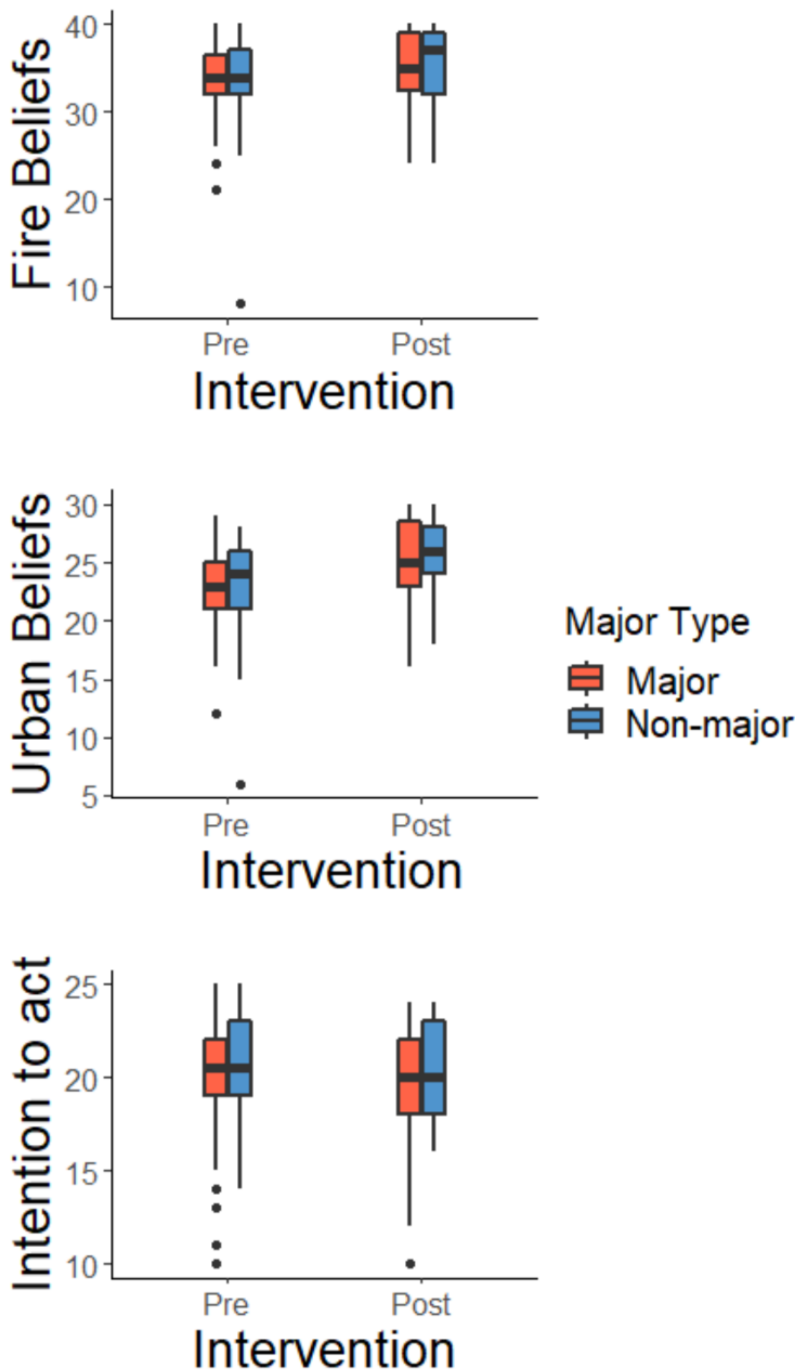

Figure 3.2. Student beliefs and intention to act toward wildfire, urbanization, and general environmental issues on pre- and post-intervention surveys based on major type (non-biology or biology major).

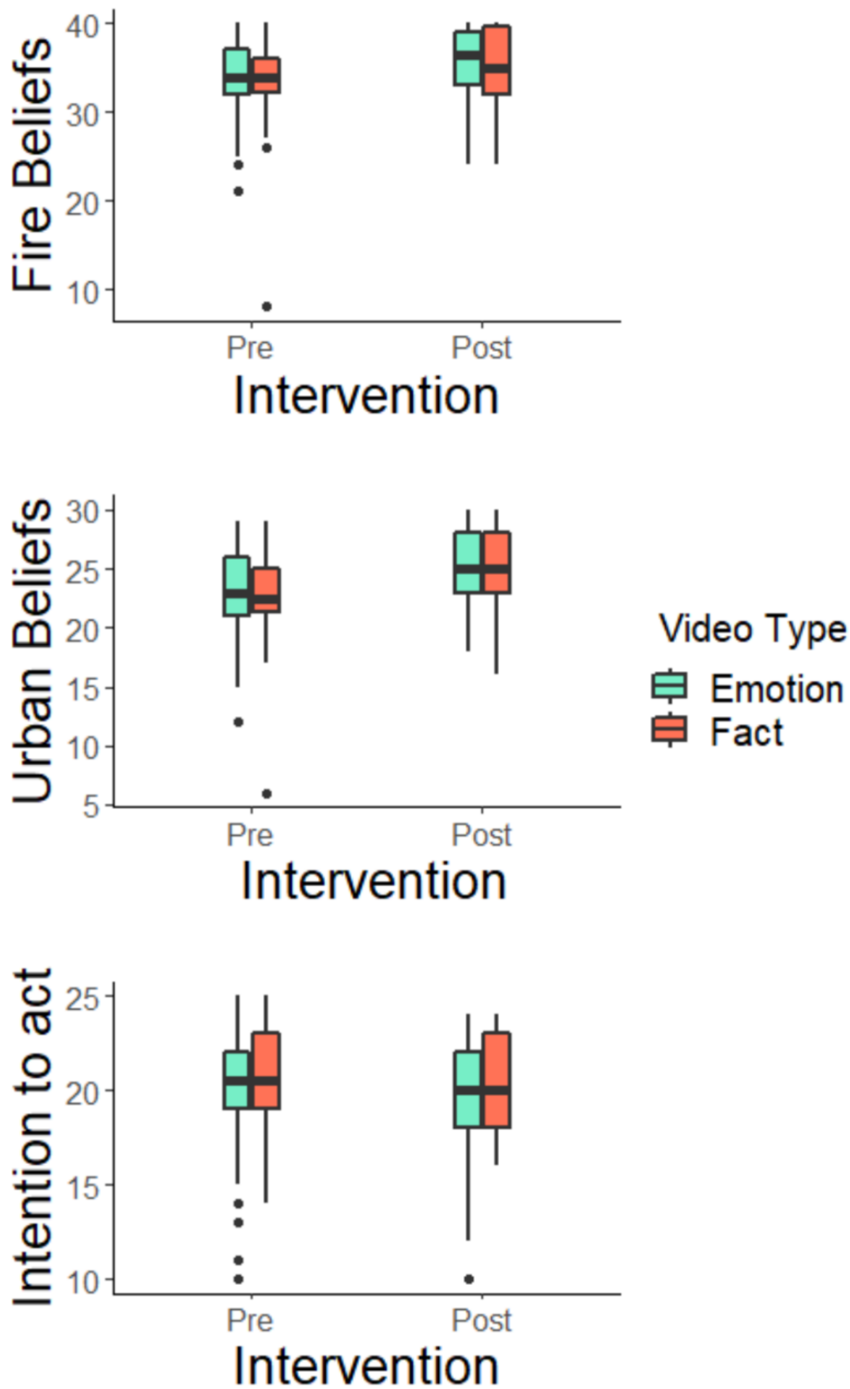

Figure 3.3. Student beliefs and intention to act toward wildfire, urbanization, and general environmental issues on pre- and post-intervention surveys based on video type (fact-based or emotion-based).

APPENDIX IIIA

Supplementary Materials

WUAS- Pre- and Post-Intervention Wildfire and Urbanization Attitude Survey 2020-2021

Are you age 18 or above?
What is your name?
What month were your born? (*only for intervention and post-survey*)
What class(es) are you currently enrolled? Check your class(es).

Wildfire Section

Please respond to the following statements on a 5-point scale where 1 = strongly disagree and 5 = strongly agree.

1) I believe our climate is changing.
2) I believe that wildfire frequency is increasing.
3) I am concerned about wildfires.
4) I believe that there is evidence of an increase in global wildfire occurrence.
5) Wildfires will impact future generations.
6) Wildfires will impact our environment in the next 10 years.
7) The actions of individuals can make a positive difference to reduce wildfires.
8) Wildfires have a negative effect on our lives.

Wildfire beliefs

9) We cannot do anything to stop wildfires.

Intention to act

(Open-ended question)

Why do you feel the way you do about wildfires?
Have you ever been personally impacted by a wildfire?

Urbanization Section

Urbanization is the process in which there is an increase in the number of people living and working in a city or metropolitan area (National Geographic).

Please respond to the following statements on a 5-point scale where 1 = strongly disagree and 5 = strongly agree.

10) I believe that urbanization is occurring.
11) I am concerned about urbanization.
12) I believe that there is evidence of an increase in global urbanization.
13) Urbanization will impact future generations.
14) Urbanization will impact our environment in the next 10 years.
15) The actions of individuals can reduce the impacts of urbanization.
16) Urbanization has a negative effect on our lives.

Urbanization beliefs

17) We cannot do anything to stop urbanization.

Intention to act

(Open-ended question)
Why do you feel the way you do about urbanization?
Do you live in an urbanized area?

General Environmental Questions
Please respond to the following statements on a 5-point scale where 1 = strongly disagree and 5 = strongly agree.
18) I can do my part to make the world a better place for future generations.
19) Knowing about environmental problems and issues is important to me.
20) I think most of the concerns about environmental problems have been exaggerated.
21) It is a waste of time to work to solve environmental problems.
22) There is not much I can do that will help solve environmental problems.

Intention to act

(Open-ended question)
Why do you feel this way about environmental problems?

Demographic Questions
What is your gender or gender identity?
What is your age?
What is your ethnicity?
What is the zip code of your hometown?
What year are you in school?
What is your current or intended major?
Are you a first-generation college student? (*neither parent or guardian who you have lived with has a bachelor's degree*)

Codebook

Wildfire
Why do you feel the way you do?

Code	Description
Personal experience/relationships	Someone they know was involved with a fire
	They were involved with a fire
	Not affected/impacted by a wildfire
	Have not experienced a wildfire
Viewpoint of wildfires (-)	It's scary
	It's sad
	It's dangerous
	It's overwhelming
	Related to climate change
Viewpoint of wildfires (+/0)	It's not a big deal/important/problematic
	It's beneficial
	It's detrimental
	It's unavoidable
	I'm neutral
Feelings (+/-)	Care about the [earth, people, animals, etc]
	I do not care
Level of impact (+/-)	On future
	On self
	On others
	On environment
Level of responsibility	Government issue
	Corporate issue
	Combined responsibility
	Personal responsibility
	No one’s responsibility
Method of action	They're human-caused [therefore need to do something]
	Need to work together
	Preventable
	I can't change anything on my own
Method of information on wildfires	Media influence
	Research
	Education
	Intervention videos

	Other
Knowledge level	Unsure
	Not knowledgeable
Causality	Wildfires are increasing
	Wildfires are caused by climate change
	Wildfires are a natural occurrence

Codebook continued

Urbanization
Why do you feel the way you do?

Code	Description
Personal experience/relationships	Someone they know lives in a city They live in a city Not affected/impacted by urbanization Never seen urbanization
Viewpoint of urbanization (-)	It's inevitable It's stressful It's concerning It's harmful Urbanization is related to climate change
Viewpoint of urbanization (+)	It's inevitable It's not a big deal/important/problematic It's beneficial It's essential It's impactful It's inconsequential It's necessary
Viewpoint of urbanization (0)	I recognize urbanization is happening It's inevitable I'm neutral
Feelings (+/-)	Care about the [earth, people, animals, etc] I do not care
Level of impact (+/-)	On future [economic impact, population growth] On self [opportunities, lifestyle changes, conflicts] On others [gentrification, disease, overcrowding] On environment [habitat loss, pollution] Urbanization is causing climate change
Level of responsibility	Government issue Corporate issue Combined responsibility [we need to work together]

	Personal responsibility No one's responsibility
Method of action	Need to work together Preventable I can't change anything on my own
Method of information on urbanization	Media influence Research Education Intervention videos Other
Knowledge level	Unsure Not knowledgeable
Opinions (+/-)	I have an opinion about urbanization I don't have an opinion about urbanization

Codebook continued

Environmental
Why do you feel the way you do?

Code	Description
Personal experience/relationships	Someone they know is impacted by environmental issues
	They are impacted by environmental issues
	Not affected/impacted by environmental issues
	Never recognized environmental issues
Viewpoint of environmental issues (-)	It's inevitable
	It's concerning
	It's sad
	Related to climate change
Viewpoint of environmental issues (+)	It's inevitable
	It's not a big deal/important/problematic
	It's essential/necessary
Viewpoint of environmental issues (0)	It's important
	I recognize environmental change/problems is happening
	It's inevitable
	I'm neutral
	"We only have one Earth"
Feelings (+/-)	Care about the [earth, people, animals, etc]
	I do not care
Level of impact (+/-)	On future
	On self
	On others
	Globally
Level of responsibility	Government issue
	Corporate issue
	Combined responsibility [we need to work together]
	Personal responsibility
	No one's responsibility
Method of action	They're human-caused [therefore need to do something]
	Need to work together
	Preventable
	I can't change anything on my own

Method of information on environmental issues	Media influence Research Education Intervention videos Other
Validity of topic (+/-)	Some of level invalidity to the topic (-) Some truth to the topic (+) Unsure of true information Politics are involved
Knowledge level	Unsure Not knowledgeable
Othering (placing the blame elsewhere)	People don't care People should be more aware People ignore information
Opinions (+/-)	I have an opinion about environmental issues I don't have an opinion about environmental issues
Doom	There's a lot wrong but I can't do anything about it Climate change is inevitable ("climate doom")
Causality	Environmental crises are increasing Climate change is a problem

TABLES

Table 3.1S. Factor loadings for three factors emerging from the 22-item survey. Two factors are related to beliefs (wildfire and urbanization) and the final factor is related to the intention to act. Items 20, 21, and 22 were reverse scored for consistency. Items 9, 15, and 17 were removed from the analysis.

Item	*Wildfire beliefs*	*Urban beliefs*	*Intention to act*
Item 1	0.660		
Item 2	0.715		
Item 3	0.736		
Item 4	0.807		
Item 5	0.770		
Item 6	0.777		
Item 7	0.519		
Item 8	0.508		
Item 10		0.703	
Item 11		0.575	
Item 12		0.758	
Item 13		0.852	
Item 14		0.817	
Item 16		0.456	
Item 18			0.610
Item 19			0.708
Item 20			0.617
Item 21			0.659
Item 22			0.588

Table 3.2S. Demographics of the respondents broken down by biology major and non-major from the 196 participants in the matched data set.

	Biology	*Non-biology major*
% Male/Female	27/73	14/86
Average age	19.85	19.83
Ethnicity		
% African American	0.05%	0.03%
% American Indian	0.02%	0%
% Asian	0.13%	0%
% Caucasian	75%	91%
% Latino/Latina	0.05%	0.05%
% First generation	78%	100%

FIGURES

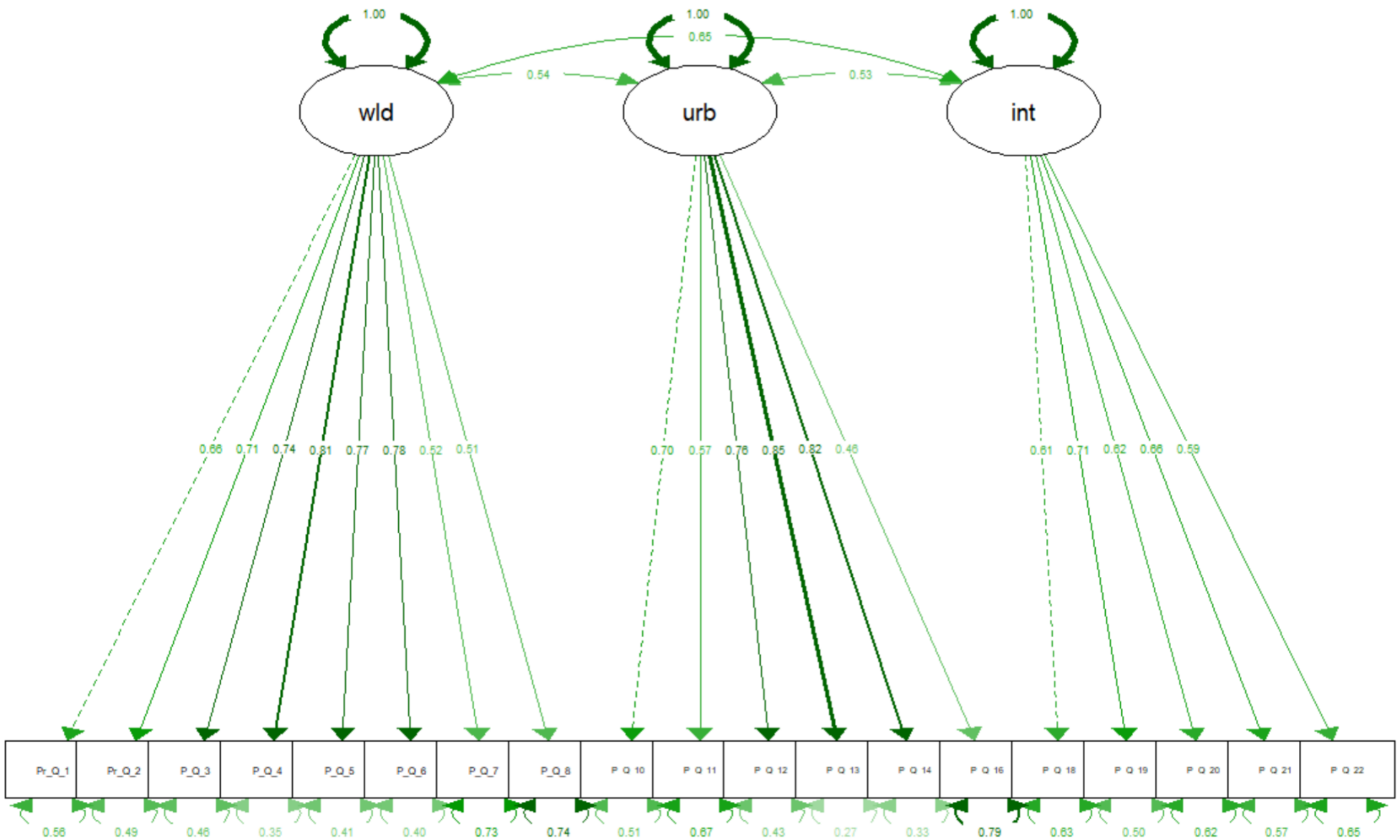

Figure 3.1S. Path diagram for the 22-items on the WUAS with the three represented constructs. Items 9, 15, and 17 removed.

CONCLUSION

Disturbance ecology is a well-developed field; however, minimal focus has been given to interactive anthropogenic disturbances and how people feel toward these disturbances. Anthropogenic disturbance interactions are becoming increasingly important to study because they affect the probability of occurrence of future disturbances and alter ecosystem resistance and resilience. Not only is this important for understanding forest dynamics, but also how people feel toward these disturbances. In my dissertation, I provide evidence that: 1) compounding disturbances (i.e., wildfire and urbanization) surrounding the Chimney Tops 2 case study are affecting composition of understory plant communities; and 2) undergraduate beliefs and intention to act toward anthropogenic disturbances differ after a classroom intervention.

In the first two chapters of this dissertation, I found that: 1) compounded disturbances increased plant abundance and richness, but not diversity; 2) variation in plant composition was explained by fire severity; 3) sites with strongest compounded disturbances (i.e., high burn/exurban locations) had lower abundance and lower plant richness than sites with the least disturbance (i.e., no burn natural locations), and; 4) turnover in understory plant communities in the GSMNP and Gatlinburg were not exacerbated by wildfire; however, areas of compounded disturbances are experiencing seasonal increases in β-diversity, suggesting that environmental filtering is occurring to favor disturbance-adapted plant taxa. Plant species at exurban sites may be subjected to additional environmental filtering from the natural pool of species (i.e., GSMNP) and therefore may be inherently more disturbance-adapted and resilient following a subsequent pulse disturbance event (i.e., fire).

The last chapter of my dissertation found that: 1) student beliefs and intentions from pre- to post-intervention were positively correlated; 2) student beliefs toward urbanization were significantly different from the pre- to post-intervention WUAS, but wildfire beliefs and intention to act were not; and 3) student beliefs and intention to act toward anthropogenic disturbances generally did not differ between major or video types. Students had general negative perceptions and beliefs toward wildfire and urbanization effects on the environment and this relationship grew after exposure to the intervention videos.

This dissertation contributed to advancing our understanding of effects of individual and compounded disturbance occurrences (wildfire and urbanization) on understory plant communities in southeastern U.S. Prior to this research, emphasis on compounded disturbances was disproportionately focused on logging and wind events. As the WUI grows, it is important to recognize that human population expansion brings additional disturbance effects. The results of this dissertation research indicate that chronic disturbance (i.e., urbanization) can positively impact plant communities by increasing their resilience to future acute disturbance events.

As anthropogenic disturbance occurrences become more frequent and receive more media coverage, it is important to understand people's knowledge, perceptions, feelings, and attitudes toward these disturbances. A deeper understanding of these attitudes will allow educators to adjust curricula to increase scientific literacy and knowledge that may promote participation in the public discourse. Comparisons made in this study have shown that exposure to certain information can make a student more likely to want to act to combat future environmental issues.

Future Directions

Future longitudinal studies on interactive and compounded disturbances are needed for a deeper understanding of complex compositional changes in plant communities that may have prolonged consequences for overall forest dynamics, and bottom-up effects on species that rely on these plant communities. Understanding the complex species interactions that occur under anthropogenic disturbances regimes is important as human populations expand, and further perturbations occur on the landscape. In my future research program, I plan to continue studying the effect of interactive anthropogenic disturbances to develop understanding how regional (i.e., southern Appalachia) understory plant communities are changing in response to growing WUI areas. This can be done by examining historical plant communities across the region and comparing to current forest dynamics.

Finally, I aim to implement use of the WUAS in multiple majors and non-majors classrooms and courses across the U.S. in my future research program. This would indicate if there were regional attitude differences toward these disturbances, thus further refining anthropogenic disturbance curricula. Implementation and refinement of this survey would allow for additional studies that aim to understand STEM identity and misconceptions across disciplines, attitude toward anthropogenic disturbances, and intention to act on mitigation efforts through time.

VITA

Mali grew up in Pittsburgh, Pennsylvania where she fell in love with nature and the outdoors as a young child. Prior to joining Dr. Mona Papes' lab for her Ph.D. in 2017, Mali graduated from Penn State University where she received her bachelor's degree in biology with a minor in statistics. Since joining the graduate program at the University of Tennessee, Mali has received several awards, including the Alexander Hollaender Graduate Fellowship, the Biology Teaching Award for Outstanding Instructional Achievement by a Graduate Student, the Breedlove, Dennis Award for Botanical Experiences, Hesler 2018 Herbarium Student Award, and 2018 ORE Summer Graduate Research Assistantship. She has accumulated over $22,000 in grant money to explore her research ideas as well as local and regional attention by focusing on human-caused disturbances and their effects within the southeastern wildland-urban interface. She is presently one of the coordinators of the EEB undergraduate mentoring program, where she has mentored several undergraduates over the course of her career. Mali is also a as well being a scholar-certified Center for the Integration of Research Teaching and Learning (CIRTL) scientific teaching fellow. Upon graduation, Mali will be starting a tenure-track assistant professor of biology position with Tennessee Wesleyan University where she'll be teaching ecology-focused courses and mentoring undergraduate-led research.