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The influence of exurban landscapes and local site characteristics on riparian vegetation

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Abstract:

The southern Appalachian Mountains have experienced large population growth and a change in land use in the past 30 years. The majority of development has been low density, suburban land, known as exurban development. The long-term effects of exurbanization on riparian vegetative communities in the southeastern Appalachian Mountains are not well known. We sought to determine if vegetative community composition and structure change as a function of watershed-level variables such as time since neighborhood development or percent impervious surface within the watershed. We also assessed local-scale measures of disturbance such as canopy cover and basal area. Over two years we sampled a total of 27 streams in exurban watersheds ranging in age from four to forty-four years, along with eight forested streams. Watershed-scale variables such as neighborhood age and impervious surface cover did not influence the aspects of riparian vegetation community we measured. Canopy cover, a measure of local habitat disturbance, offered better predictions of vegetation community metrics. Exurban neighborhoods and their landowners may have the potential to manage for riparian vegetation through the use of maintained stream buffer zones along the entire length of the stream.

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Abstract

The southern Appalachian Mountains have experienced large population growth and a change in land use in the past 30 years. The majority of development has been low density, suburban land, known as exurban development. The long-term effects of exurbanization on riparian vegetative communities in the southeastern Appalachian Mountains are not well known. We sought to determine if vegetative community composition and structure change as a function of watershed–level variables such as time since neighborhood development or percent impervious surface within the watershed. We also assessed local–scale measures of disturbance such as canopy cover and basal area. Over two years we sampled a total of 27 streams in exurban watersheds ranging in age from four to forty-four years, along with eight forested streams. Watershed–scale variables such as neighborhood age and impervious surface cover did not influence the aspects of riparian vegetation community we measured. Canopy cover, a measure of local habitat disturbance, offered better predictions of vegetation community metrics. Exurban neighborhoods and their landowners may have the potential to manage for riparian vegetation through the use of maintained stream buffer zones along the entire length of the stream.

Keywords: Appalachian, Invasive plants, Stream, *Tsuga candensis*, Urban

Introduction

The United States is experiencing increases in population size and urbanization. Between 2000 and 2010 the population of the United States increased by 9.7%, and 83.7% of the population resides in metropolitan areas (Mackun and Wilson 2011). Land use practices are shifting and forests are being converted into residential land (Wear and Bolstad 1998). The majority of development has been low density, suburban land that is decentralized from any urban center, especially in the Southeast (Mcdonald et al. 2010), where population growth was 16.6% between 2000 and 2010 (Pollard and Jacobson 2011). Such development is often termed exurbanization. Theobald (2004) highlighted the absence of a single definition for the term; however, exurban areas typically fall somewhere between the urban and rural areas in terms of population density (0.025 – 5 people per ha). Low density developments are projected to increase in future decades (Wear and Bolstad 1998; Theobald 2010) and they are often near highly biodiverse areas (Gagne and Fahrid 2010); both of these factors suggests the developments may pose a serious threat to many species and ecosystems.

Stream systems and their associated riparian zones are especially susceptible to changes following exurbanization. Impervious surfaces associated with buildings and roads alter the rates and movement of water flow such that less percolation of water occurs into the soil, leading to a reduction in base flow, but an increase in flow during rain events (Paul and Meyer 2001). These hydrologic changes not only modify stream and riparian morphology, but can also alter soil moisture (Gold et al. 2001), water table depth, organic matter, root density, and soil pH in adjacent riparian areas (Gift et al. 2010).

Riparian vegetation is integral in determining both composition and function of stream ecosystems (Warner and Hendrix 1984) and it serves as a buffer zone between upland areas and streams (Hill 1996; Lowrance 1998). Streamside vegetation helps maintain stream temperature, provides woody debris for habitat along and within the stream, and assists in the uptake of NO_3^- from shallow groundwater (Sweeney 1992; Tabacchi et al. 2002). Riparian vegetation also stabilizes banks and provides cover for many species of wildlife. Plants provide detritus material within the stream, creating both a food source and habitat for aquatic organisms (Warner and Hendrix 1984). Urbanization has greatly reduced vegetation at a global scale (McKinney 2002), and riparian forests are particularly sensitive to land use change (Malanson 1993). Urbanization directly alters vegetative community composition and structure through replacement of vegetation by urban infrastructure and fragmentation. Species diversity, tree basal area, and native plant density have been shown to decrease near urban areas (Porter et al. 2001; Moffatt et al. 2004). Loss of canopy cover can increase algal growth, thereby changing low-order stream systems from allochtonous- to autochthonous-based systems (Doi et al. 2007; Hall et al. 2000; and Sobczak et al. 2002). A decrease or a change in detrital inputs may yield lower macroinvertebrate biomass or altered macroinvertebrate community composition (Sobczak et al. 2002), which can have implications for higher trophic levels (Johnson and Wallace 2005). Furthermore, stream temperatures increase with canopy loss, which alters habitat suitability for many organisms (Bozinovic et al. 2011). Sediment loading in streams can increase with riparian vegetation loss, and decrease water quality (Osborne and Kovacic 2006).

Urbanization causes a shift in vegetative communities and reduces native plant diversity while increasing the number of exotic and invasive species (Burton et al. 2005; Burton et al. 2008; King and Buckney 2001; McKinney 2001; McKinney 2002; Warren et al. 2015). A study by Loewenstein and Loewenstein (2005) found significantly more exotic plant species at urban sites along a rural-to-urban gradient in the Piedmont ecoregion of Georgia. Pennington et al.

(2010) identified similar trends in Ohio, but also found an increase in early successional native plant species in urbanized riparian areas. Shifts in vegetation may often be driven by “hydrologic drought” that develops from lowered water tables in urban areas (Groffman et al. 2003). A review by Groffman et al. (2003) identified twice as many upland plant species in urban floodplains relative to non-urbanized floodplains (Brush et al. 1980) in Maryland, and suggested this assemblage shift was the result of altered hydrology.

Pennington et al. (2010) argued that previous studies on urbanization and stream response are too broad in scope and need to focus on local-scale variables like riparian vegetation. The authors showed that local vegetative community changed in response to urbanization, and that these local scale changes drove alterations of urban streams and riparian areas. The authors make a final argument that future conservation efforts in the face of urbanization should focus on maintaining wide riparian forests and limiting impervious surface development within riparian areas. Wang et al. (2001) found similar results while studying urban fish populations, noting that impervious surface within the riparian area or within a 1.6–km radius upstream had a stronger influence on fish populations and hydrology than comparable levels of impervious surface that were further away. Allan et al. (1997) found no correlation between local riparian vegetation and landscape scale factors. Other studies have argued that watershed-scale conservation, as opposed to protection of just the riparian zone, is necessary to protect stream organisms (von Behren et al. 2013; Sarr and Hibbs 2007; Willson and Dorcas 2003); however, the fact remains that Pennington et al. (2010) suggest an important hypothesis that may apply to some aspects of stream ecosystems. Increased riparian forest buffers may then lead to reduced exotic plant invasions and maintenance of hydrological function in riparian areas, even if they do not protect all stream species from declines. The take away is that both local– and landscape–scale factors are of importance, but more work needs to be done to assess the relative role that factors at these scales play in shaping riparian vegetation within urban areas.

Riparian vegetation response to exurban development may be similar to areas of timber management (a common land use in Southern Appalachia) because both land uses entail the removal of large quantities of forest cover. The life history traits of herbaceous understory plants vary, and as a result so does their recovery following timber harvest. Duffy and Meier (2003) compared herbaceous understory of old growth forests to secondary forests ranging in 45 to 87 years since clear-cutting. They found that neither cover nor species richness increased with age in these secondary forests. The authors argue that 87 years is insufficient time for understories to recover and that these species will never recover to primary forest states due to climatic differences today relative to when the old growth forests were established and landscape level changes like habitat fragmentation that prevent dispersal of seed from some species. Duffy and Meier (2003) also argue that a near complete recovery to pre-disturbance conditions will not occur until large trees have had time to grow, and then fall. This slow recovery with time may be dependent on amount and proximity of propagules, and it has been argued that recovery can actually occur over time and that Duffy and Meier failed to fairly represent pre disturbance conditions in their chronosequence study (Johnson et al. 1993).

While the response of riparian vegetation to timber harvest has been evaluated at various time steps following disturbance, no such knowledge exists for the same communities in the context of exurban housing developments (Pennington et al. 2010). It is unknown if riparian communities surrounded by exurban housing developments will undergo a process of recovery with time toward pre-disturbance conditions, or if they will remain altered in the long-term. To address this data gap we evaluated the influence of impervious surface, neighborhood age, and other landscape–scale variables on several measures of the riparian plant community. We also evaluated the ability of surrogate measures for local habitat management to predict plant species richness, diversity, and the number of non-native species. We hypothesize that stream riparian zones will exhibit signs of recovery (more similarity to forested sites) in areas with older and less–developed neighborhoods. We also hypothesize that changes in vegetation communities will be influenced partially by local scale variables.

Methods

Study Area

Our study sites were within the Southern Blue Ridge Ecoregion (Fig. 1), which spans over 3,804,045 ha and covers sections of Georgia, South Carolina, North Carolina, Tennessee, and Virginia. The mountains are between 450 and 2040 m in elevation. There are over 400 species of plants and animals endemic to this region, more endemics than any other North American ecoregion (The Nature Conservancy and Southern Appalachian Forest Coalition 2000). Parts of the southern Appalachians along the Blue Ridge Escarpment receive the highest level of rainfall in the United States east of the Cascades, and the climate of these mountains ranges from temperate to boreal.

Site Selection

To select focal streams we evaluated 2014 aerial images from the region to identify watersheds with exurban development (i.e., residential development with < 17% impervious surface). Within these watersheds, we used ARCGIS 10.1 (ESRI, Redlands, CA) to overlay a high resolution stream layer from the National Hydrography Dataset and a tax parcel data layer derived from Sevier County, TN and Macon County, NC. From these overlays we identified 80 potential locations that were streams in watersheds containing only exurban development (i.e., only low-intensity residential development). We attempted to contact the property owners along each stream by phone or in person. Once permission was obtained to access the property we traveled to each site in an attempt to standardize stream size and development to the extent possible. Following ground validation we were left with 27 first– or second–order exurban streams across the two counties in Western North Carolina and Eastern Tennessee. We selected eight additional streams that contained no impervious surface within the watershed. Four of these forested sites were located within the Coweeta Hydrologic Laboratory property in Otto, North Carolina, and four were within Walker Valley in the Great Smoky Mountain National Park, TN (Fig. 1). All forested sites were presumed to have been logged, but the harvest was greater than 75 years ago. We assume that all of the exurban sites were logged around the same time. Reference sites that had never been logged would not be adequate for comparison with our exurban sites.

To calculate the age of development in each exurban watershed, we used tax parcel information. We extracted the age of each individual structure within the study area, and averaged those ages across all buildings in the watershed. Exurban housing ranged in age from four to forty-two years (mean = 25.99 yrs) across the 27 watersheds with development. We also calculated impervious surface coverage for each watershed by obtaining 2014 leaf off aerial imagery (0.65 meter resolution) from the counties containing our study areas. Percent forest cover within our watersheds would be nearly the inverse of percent impervious surface, and thus was not used in the study. This was done by hand-delineating polygons around all impervious surfaces and calculating the percent of the watershed they covered. We calculated distance to impervious surface using the “near” tool in ARCGIS 10.1, measuring the distance from stream sample plots to the nearest impervious surface polygon.

Field Methods

We established a 45–m transect along the length of each stream and established vegetation plots in the summer of 2014, similar to methods used by Surasinghe and Baldwin (2015). Transects were selected by maximizing the amount of exurban development within the watershed by having a study site as far downstream as possible, without including other forms of land use, but were limited by where we could get access to private property. These transects were broken into three five meter sections, each ten meters apart. Along each of the five meter sections, we measured 10 m from the bank of the stream to establish a 50 m^2 plot (Fig. 2). The plot was measured on the right side of the first section, the left side of the second section, and the right side of the third section. Within each plot we identified all vegetation to species. If an identification could not be made on site, we took photos and identified them later (plants.usda.gov; USDA, NRCS 2003). If a positive ID to species–level could not be made, we identified it to the lowest possible taxonomic level (Family or Genus) and added a unique numeric identifier. We counted all trees within a plot; however we only recorded incidence data for herbaceous and shrubby vegetation. We measured percent canopy cover three times in the middle of the stream using a convex spherical densiometer. We estimated percentage of ground covered by coarse woody debris (CWD), vegetation, and bare ground (defined as rock or soil not covered by vegetation) within each plot to the nearest 5% (Table 1). We considered any fallen limb or tree larger than 10 cm in diameter to be CWD. We recorded basal area (m^2/ha) of each section using a 10BAF basal area prism.

Analysis

We evaluated both species richness of all vegetation and Shannon diversity of tree species between forested sites (no impervious surfaces in the watershed) and exurban sites (1–

17% watershed impervious surface) in Microsoft Excel (Redmond, WA). Shannon diversity was estimated for trees because we had counts of individuals for this group, but not for all vegetation types. Using the iNEXT package (Hsieh et al. 2014) in Program R (R Core Team 2013), we created species accumulation curves for both the number of sites sampled and the number of individuals sampled for the forested and the exurban sites. Because of the differences in the number of sites, we used rarefication to estimate diversity after eight samples for both land cover categories as this was the total number of forested sites. To assess differences in vegetative community composition as a function of neighborhood age and percent impervious surface, we used a canonical correspondence analysis (CCA). This type of ordination analysis is appropriate when the goal is to understand the structure of community data in the context of a specific set of environmental variables (McCune and Grace 2002). We examined all vegetation (using only incidence data) and tree species (using count data) in two separate CCA analyses. We conducted these analyses using only data from sites with development, since neighborhood age was not applicable to fully forested sites. A second CCA of all vegetation was run using only plants that were detected at least 3 times across all sites. We used the vegan package (Oksanen et al. 2015) in Program R (R Core Team 2013) to run the CCAs.

We used multivariate multiple regression to examine the influence of percent impervious surface, neighborhood age, and distance to impervious surface on a suite of uncorrelated ($R<0.75$) plant-related response variables. Specifically, we examined the influence of our selected predictors on basal area, canopy cover, vegetative cover, CWD, Shannon-Wiener diversity (for trees), tree species richness, total plant species richness, exotic species richness, non-woody vegetation species richness, annual and perennial plants, growth form category (forb, forb/subshrub, subshrub, subshrub/vine, subshrub/tree, vine, shrub/tree, graminoid, fern, shrub, forb/vine), and wetland associated plants. Because almost all of our sites have a relatively high proportion of forested area within the watershed, we also wanted to examine the influence of habitat structure within the riparian zone on vegetation. We used basal area, canopy cover, and coarse woody debris to quantify differences in forest structure at the local scale. Sites with higher basal area, canopy cover, and CWD were considered less disturbed or have experience a longer period since a previous disturbance. We again used multivariate multiple regression to test for relationships between local site characteristic predictors and the same response variables used for landscape-level predictors. A model was also run using only forested sites to test for the influence of local scale variables on assemblage structure in forested communities without exurban influence.

We used logistic regression models to examine the influence of hypothesized predictor variables on the presence or absence of selected species. Eastern hemlock (*Tsuga candensis*) and yellow-poplar (*Liriodendron tulipifera*) were chosen because they each made up more than 10% of all trees identified. We also evaluated great rhododendron (*Rhododendron maximum*) because it was the most common species and indicative of a climax riparian ecosystem in this region (Keever 1953). We evaluated the presence of ericaceous shrubs [great rhododendron, mountain laurel (*Kalmia latifolia*), and mountain doghobble (*Leucothoe fontanesiana*)] based on their importance in these ecosystems in terms of pH regulation and soil nutrients (Monk et al. 1985). We evaluated red maple (*Acer rubrum*) and species not native to the United States because both are commonly associated with disturbance and human activities (Burton and Samuelson 2008; King and Buckney 2000; Tift and Fajvan 1999).

Results

Descriptive characteristics

There were a total of 36 tree species found across all sites. Mean species richness and Shannon diversity were higher in forested sites relative to exurban sites; however, there was considerable overlap in the range of these measures between site categories (Table 2). Sample-based rarefaction (n = 8) revealed no significant difference (95% confidence intervals overlapped) between exurban and forested sites in the accumulation of tree species, based on abundance data (Fig. 3a), however, the shape of the accumulation curve suggest that richness in both categories of sites is not fully represented by our sample. Across all sites, we identified 151 species of herbaceous and shrubby plants. Individual-based species accumulation curves for herbaceous plants again showed no significant difference between forested and exurban sites (Fig. 3b). Exotic plants were found at 16 out of 27 exurban sites, and at one of the forested sites. A total of 19 wetland indicator plants were identified across all sites, with an average of 3.4 and 2.4 plants per site at forested and exurban sites respectively. Many different growth forms were identified, but the most common growth form across sites in both land cover categories was forb.

The most common tree (i.e. found at the greatest number of sites) was the yellow-poplar, occurring at 22 sites (5 of 8 forested sites and 17 of 27 exurban sites). The most frequently counted tree across all sites was the eastern hemlock, occurring at 22 sites (7 of 8 forested sites and 14 of 27 exurban sites). It is of note that of the 67 hemlocks identified, 45 were dead, presumably from the hemlock woolly adelgid (*Adelges tsugae*). In sites where eastern hemlock stems (live and/or dead) were present, it was nearly 2.5 times more abundant in forested sites relative to exurban ones (5.1 vs. 2.1 stems per site; $F = 13.32$, $P = 0.0016$). However, there was no difference in live hemlock stem counts between forested and exurban sites (1.3 vs. 0.9 stems per site).The most frequently counted living tree was the yellow-poplar. The most common mid or understory plant across all sites was great rhododendron. A total of 19 exotic species were found at exurban sites and one species at forested sites. The most common exotic species was stilt grass (*Microstegium vimineum*). Red maple and exotic species were present at more than fivefold as many exurban sites as forested sites.

Vegetation community response to urbanization

In a CCA using only tree abundance data, 5% and 4% of variance was explained by age and impervious surface, respectively. When incidence data were used for a CCA with all plants, 4.3% and 4% of the variance was explained by age and impervious surface respectively (Fig. 4). A second CCA using plants detected within at least 3 plots provided showed similar results for age and impervious surface, 4.3% and 3.9% respectively.

Multivariate multiple regression revealed no significant relationships between neighborhood age, impervious surface, or distance from impervious surface and most of our vegetation community response variables. Impervious surface did positively influence the number of exotic species ($R^2 = 0.09$, $P < 0.05$). Multivariate multiple regression using canopy cover and basal area (local environmental variables) as predictor variables showed that canopy cover was a significant predictor for at least some of the response variables. Because canopy cover was the only significant local site predictor, linear regressions were used to evaluate bivariate relationships with response variables. Canopy cover negatively influenced herbaceous cover ($R^2 = 0.38$, $P < 0.001$),the number of exotic species ($R^2 = 0.33$, $P < 0.001$), and the amount of annual plants ($R^2 = 0.14$, $P = 0.02$), while having a positive influence on Shannon diversity of trees ($R^2 = 0.26$, $P < 0.001$).

Predictors of presence varied widely across target species. Presence of red maple and yellow-poplar were not significantly related to any of the selected predictors ($P > 0.05$ for all logistic regressions). Higher basal area increased the probability of eastern hemlock ($P = 0.02$), great rhododendron ($P = 0.03$), and other ericaceous shrub ($P = 0.01$) presence, and decreased the likelihood that exotic species would be present ($P = 0.02$). Areas of higher canopy cover increased the likelihood of great rhododendron [($P = 0.02$ (all sites) and $P = 0.03$ (exurban sites)] and other ericaceous shrub presence ($P < 0.01$) and decreased the likelihood that exotics were present ($P = 0.04$ across all sites). For every five percent increase in canopy cover there was a four percent decrease in the likelihood of exotic species presence, and an increase in the percent likelihood of great rhododendron presence by ~ 6% at all sites and 7% at exurban sites. Neighborhood age did increase likelihood of great rhododendron presence ($P = 0.04$ across exurban sites) and the presence of other ericaceous shrubs ($P < 0.01$). For every five-year increase in neighborhood age there was a 6.1% increase in the likelihood of great rhododendron presence, which at least for this one species, is a result consistent with recovery toward more forested conditions.

Discussion

When forested and exurban sites were considered categorically, there were no differences between the estimated richness or diversity values for trees or understory vegetation. The mean accumulation curve generated from exurban areas is slightly higher than that from forested streams, which is most likely due to the lower number of individuals sampled in any one forested plot. Trees from forested plots tended to be larger and thus more distantly spaced (on average basal area was 50% higher in forested riparian plots). The decline of eastern hemlocks appears to be occurring at a faster rate in forested sites. This pattern could be a function of density dependence, as hemlock woolly adelgids typically disperse short distances (McClure 1990) and hemlock stems were less abundant in exurban sites. Human intervention may also play a role. Many homeowners and homeowner's associations treat hemlocks with systemic pesticides to keep them from succumbing to hemlock woolly adelgid infection. Dead and dying hemlocks in an exurban setting are also more likely to be removed since they pose a safety hazard.

Further evaluation of exurban sites focused on the continuous variation within this category as a function of neighborhood age and impervious surface. CCA results suggest that neither age nor the amount of impervious surface (across the range of values we evaluated) structure vegetation communities. Linear regression analyses further revealed all watershed–scale variables to be poor predictors of the selected measures of community response other than a slightly positive relationship between the amount of impervious surface and the number of exotic species. An increase in invasive species in watersheds with more impervious surface could occur from increased transport of seeds from vehicular traffic, more exotic planting due to the presence of more land owners, or increased canopy gaps allowing for the proliferation of many disturbance dependent exotics. Other studies have noted a negative relationship between impervious surface and tree species richness (Burton et al. 2008, Moffatt et al. 2004, and Porter et al. 2001); however, our data show no evidence to support that relationship.

Pennington et al. (2010) argued for the importance of local scale predictor variables, and our results support their findings. Reduced canopy cover predictably led to an increase in the amount of ground cover by understory vegetation, however, exotic species were often prominent members of the understory community. For example, an exurban site in East TN with little canopy cover had riparian plots that were 100% covered by herbaceous vegetation, in the form of kudzu (*Pueraria lobata*). This observation is likely due to increased light availability (Parendes and Jones 2001, Setterfield et al. 2005, Vidra and Shear 2008, Warren et al. 2015). Sites with lower canopy cover also contained more species of annual plants Taken together, these trends could indicate the maturation of a forest from having an abundance of ruderal, annual, non-woody plants, to a more stable community of perennial, woody vegetation. Future studies might consider examining the abundance herbaceous species, as we only collected incidence data. Increased canopy cover is often characteristic of more mature forests; however, our results suggest this variable does not necessarily increase as neighborhoods age, perhaps due to local land use practices in that neighborhood.

Our results show that canopy cover was positively correlated with Shannon diversity of trees. This result was not simply a function of increased tree abundance, because basal area did not correlate with Shannon diversity. Higher levels of diversity promote increased primary productivity of plant communities (Nijis and Roy 2003; Wilsey and Potvin 2000) and in the Southern Appalachians overall diversity relates positively with canopy cover and primary productivity (Belote et al. 2011; Elliot et al. 1998) as these ecosystems are some of the most biodiverse in the world (Elliot et al. 1998; Hodkinson 2010). Increasing riparian ecosystem primary production, and consequently the detrital inputs, is very important for southern Appalachian headwater stream ecosystems; they have detritus based food webs that are composed primarily of foliage from nearby trees (Hall et al. 2000). Reduced canopy cover reduces detritus input (Wallace et al. 1997) and decreases food chain length (Jenkins et al. 1992). Changes in detrital food base are linked to forest cover along the entire length of the stream, not the immediately present forest cover at the site, and can occur from minimal forest cover loss (England and Rosemond 2004). For example, if Chinese privet (*Ligustrum sinense*) becomes abundant in a riparian area because of a disturbance like urbanization it can alter the form of detritus that enters the stream. Privet detritus decomposes at a faster rate and can alter nutrient cycling and decomposition in riparian areas and within the stream. Chinese privet is found to decompose at a faster rate than native tree leaves (Mitchell et al. 2011). Similar results were found by Fargen et al. (2015) in a study on Amur honeysuckle (*Lonicera mackii*); an invasive plant within the same genus of one of our most common exotic plants, Japanese honeysuckle. The authors found that the leaves of *L. mackii* decomposed two weeks faster and had fewer macroinvertebrates than the native sugar maple (*Acer sacharum*). Likewise, Swam et al. (2008) found that litter from the the exotic, invasive tree of heaven (*Ailanthus altissima*) also broke down more quickly than that of native plants. The authors noted that the presence of native plant leaf litter could help "armor" and slow the decomposition of the non-native tree of heaven.

Predictors of individual species presence or absence varied considerably among species. Exotic plants were almost entirely found in exurban neighborhoods, but the probability of finding exotics within exurban neighborhoods was not linked to any of our watershed–scale variables. Eastern hemlock and great rhododendron were associated with increasing basal area, and likely represent species indicative of intact riparian zones. The likelihood of other ericaceous shrubs also increased with increasing forested riparian area. These species are an integral component of southern Appalachian stream ecosystems and have influences on ecosystems characteristics like soil pH, leaf litter depth, and nutrient retention (Monk et al. 1985). Exotic invasion has been linked directly to local vegetative structure in terms of the amount of canopy cover (Vidra and Shear 2008). Stream buffers to development provide increased basal area and canopy cover, which may encourage the persistence of native and climax community species during and after development of an exurban neighborhood. While higher basal area was associated with a higher probability of hemlock presence, it is unclear which drives which. Eastern hemlock is a shade tolerant tree, and therefore persistence likely increases in areas with high basal area, but a large number of hemlocks obviously contribute to high basal area. In reality a positive feedback loop likely exists between intact forests and hemlock recruitment

(Kobe et al. 1995), at least before the introduction of hemlock wooly adelgid (*Adelges tsugae*) that decimated Eastern hemlock populations and as a result modified soil moisture and detritus quality (USDA Forest Service 2005).

Conclusion

Our work suggests that riparian vegetative composition in watersheds containing exurban developments is not primarily driven by the amount of impervious surface (at ranges from 1 – 17%) or the age of the exurban development. Instead, local site variables such as canopy cover and basal area provided the best predictors of exotic species and other vegetative characteristics. These local-scale measures can be influenced by riparian management practices. In Macon and Jackson County, North Carolina there are ordinances requiring 30 foot buffer zones along streams, but from our observations exurban developments allow impervious surface closer to the stream. During construction of a neighborhood, basal area and canopy cover can be reduced from clear-cutting, or land owners may clear vegetation after acquiring the property, then continue to clear through mowing or trimming over time. Furthermore, once the property is privately owned there is little enforcement of buffer regulations. On multiple occasions we met land owners with concerns about the neighbors removing trees along the stream bank, or observed it ourselves. The absence of a correlation between basal area and CWD could also mean that landowners are removing snags and fallen trees. Much of the southern Appalachians is privately owned, and there is a fast-growing wildland-urban interface (Macie and Hermansen 2002). This means that cooperation with private land owners is integral to maintaining the biodiversity and function of these ecosystems. Future studies that assess the minimum forest buffer width required to maintain vegetative communities similar to forested sites would provide land owners and neighborhoods more specific target objectives for sustainable management of riparian habitats.

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Table 1. Mean (and range) of environmental variables for each site, classified for all sites (n = 35) and only urban sites (n = 27) within the Blue Ridge Mountain region of North Carolina and Tennessee. Values for neighborhood age, impervious surface, and distance to impervious surface are not shown for the all sites columns as reference sites did not have values for these variables.

	All Sites		Urban Sites	
Variable	**Mean**	**Range**	**Mean**	**Range**
Neighborhood Age (years)	N/A	N/A	25.99	(4-42.4)
% Impervious Surface	N/A	N/A	8.31	(0.8-17.7)
Distance to Road (meters)	N/A	N/A	54.30	(1.89-419.3)
Basal Area (m^2/ha)	21.69	(5.35-78.82)	19.11	(5.35-78.82)
% Canopy Cover	89.34	(57.4-96.5)	88.14	(57.4-96.5)
% Vegetation Cover	50.74	(15-96.7)	51.89	(15-96.7)
% Coarse Woody Debris Cover	7.70	(0-28.3)	5.74	(0-25)

Table 2. Mean (and range) of Shannon index and species richness values for riparian vegetation community data collected from forested (n = 8) and exurban (n = 27) sites within the Blue Ridge Mountain region of North Carolina and Tennessee, U.S.A.

Parameter	Forested sites	Exurban sites
Shannon Index	1.73 (1.43 – 2.19)	1.32 (0 – 2.13)
Species Richness	7.4 (5 – 11)	4.6 (0 – 10)

Figure legends

Figure 1. The 35 riparian vegetation sample plots were located in or near Sevier County, Tennessee (dashed) and Macon County, North Carolina (solid).

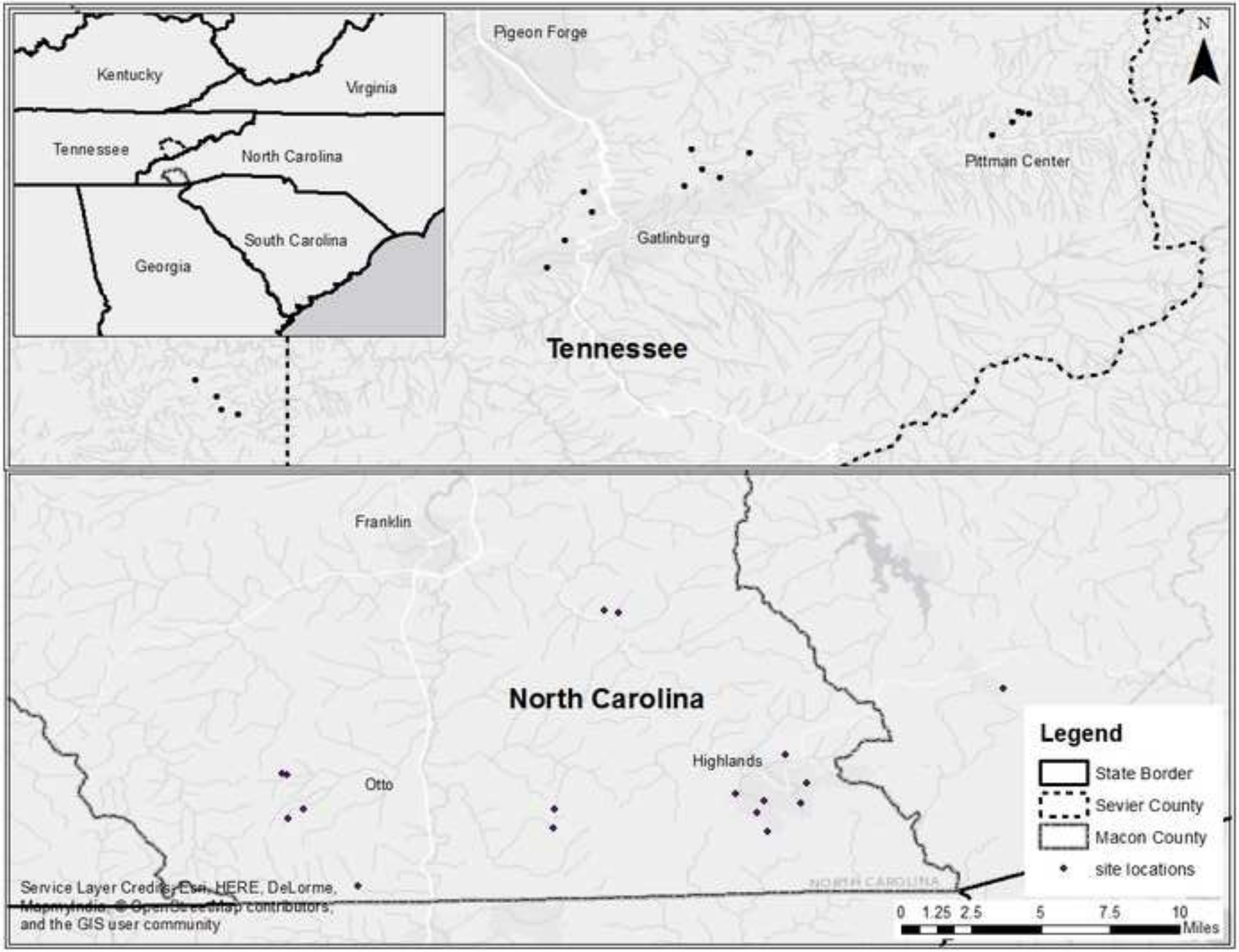
Figure 2. A graphic of the sample transect and vegetation plots for each of the 35 field sites used to sample riparian vegetation in western Tennessee and eastern North Carolina.

Figure 3. Species accumulation curves for (a) abundance data on trees and (b) incidence data on plants for exurban and forested sites for riparian vegetation community data within the Blue Ridge Mountain region of North Carolina and Tennessee, U.S.A.

Figure 4. Canonical Correspondence Analysis (CCA) for (a) abundance data on trees and (b) incidence data on plants for exurban and forested sites for riparian vegetation community data within the Blue Ridge Mountain region of North Carolina and Tennessee, U.S.A.

Figure1

Click here to download Figure Figure1.jpg



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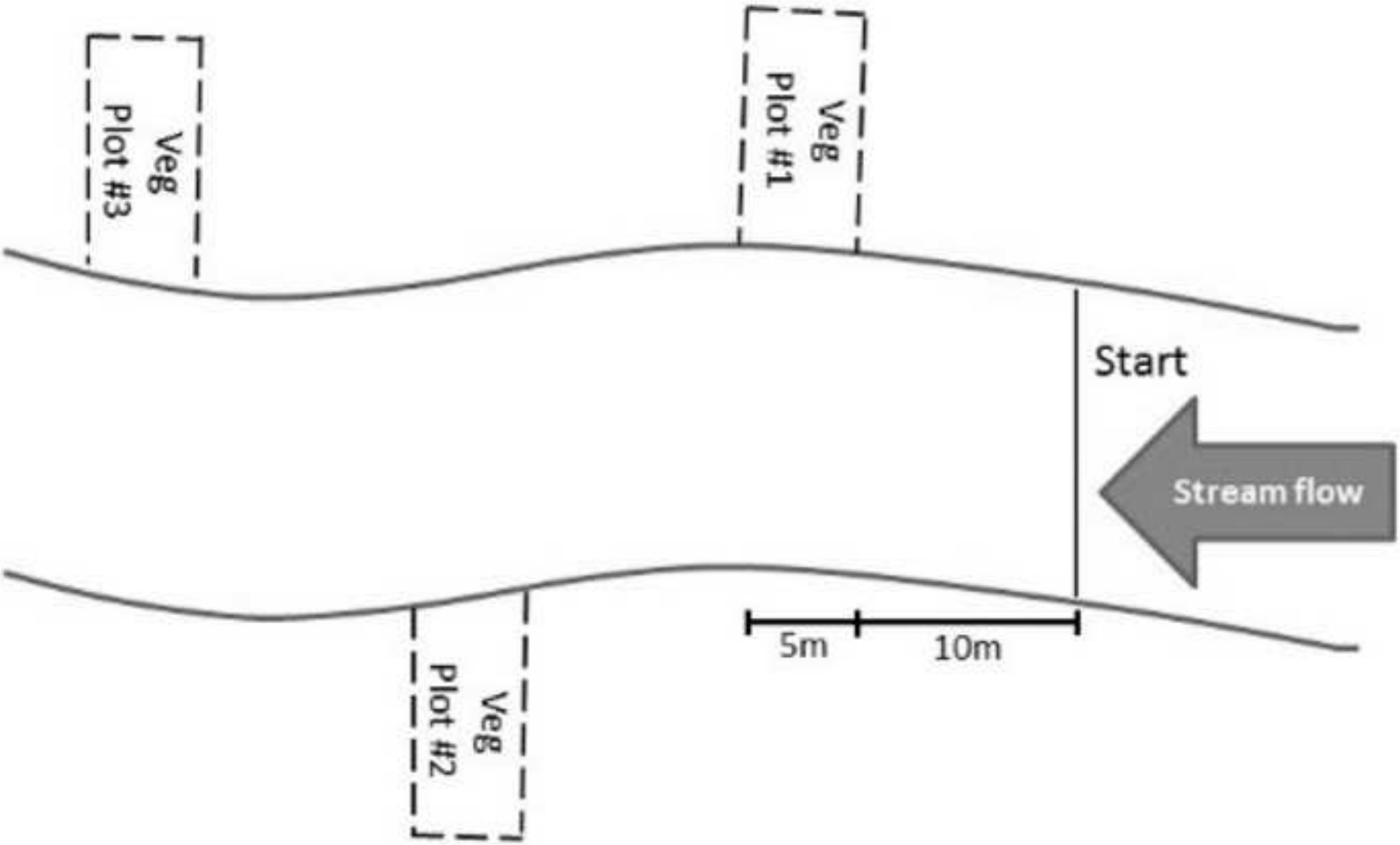

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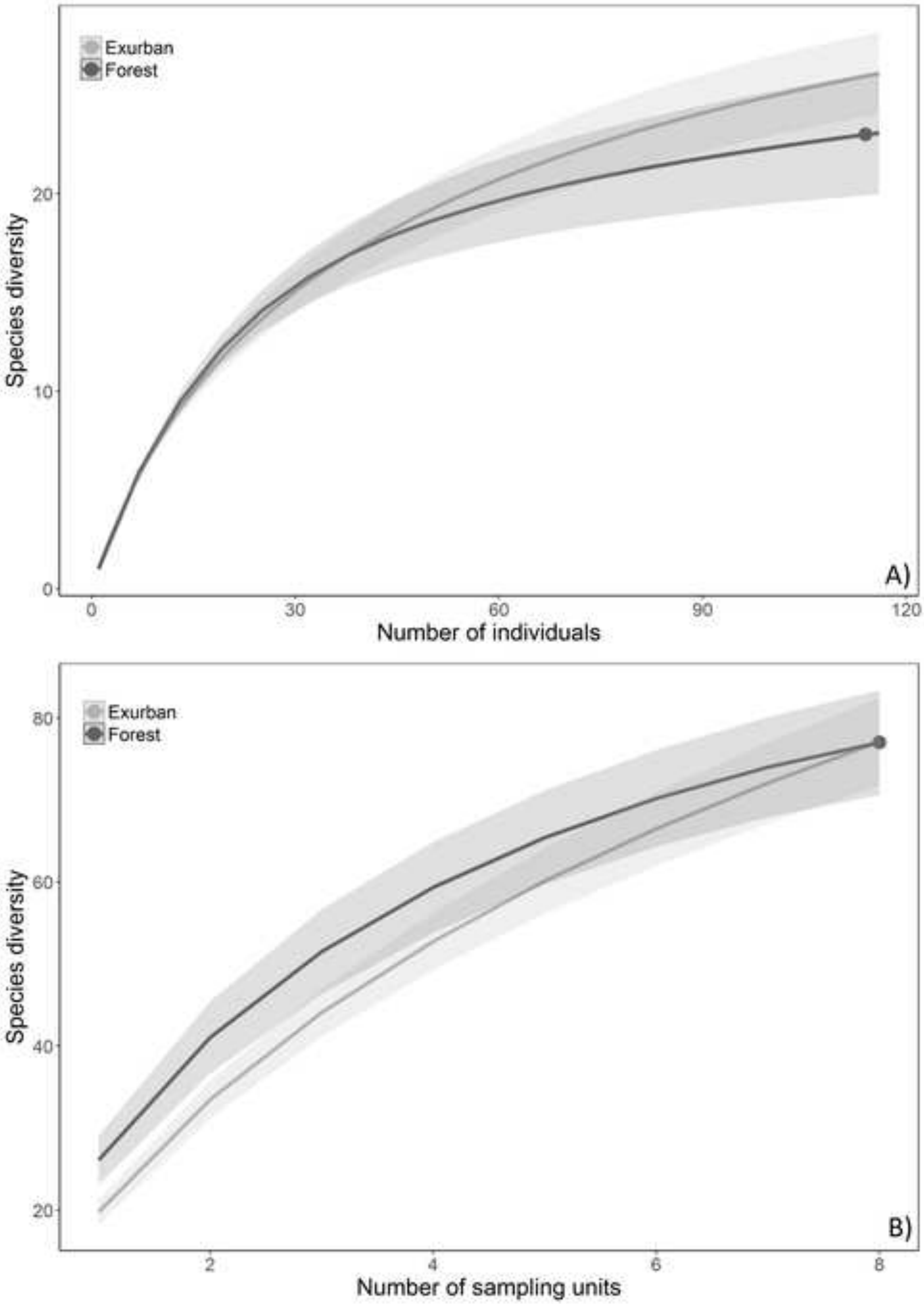

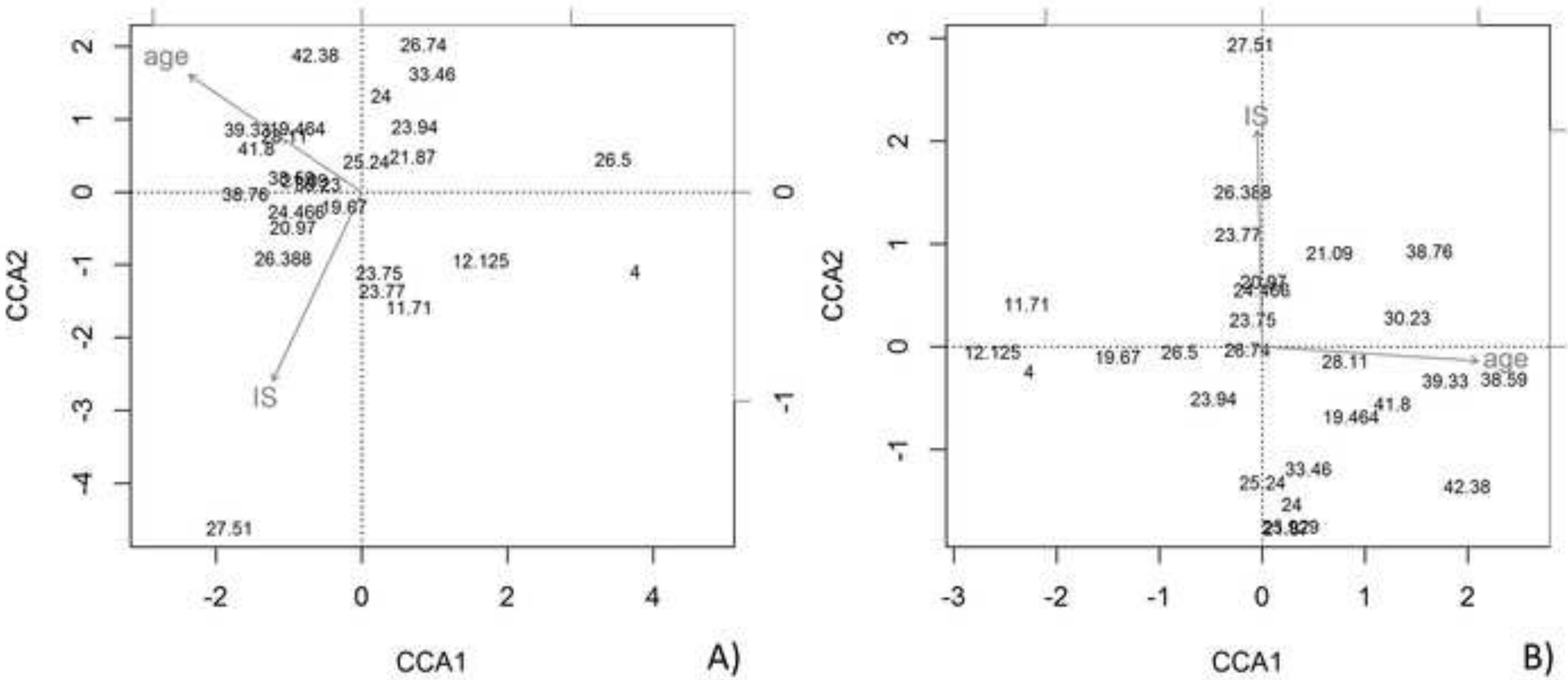
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The reviewers' comments appear below (regular text) along with our responses to their suggestions and edits (bold text). Line numbers represent position in the revised draft.

Summary

The goal of this study was to evaluate the relationship between exurban development and riparian vegetation structure, as well as evaluate the relative importance of local vs. landscape features. Vegetation was measured in plots adjacent to 27 streams in watersheds with exurban development and 8 streams in watersheds with no development. Results showed no relationship with vegetation diversity and neighborhood age and vegetation metrics. Non-native cover and tree diversity was correlated with site-scale canopy cover. While there is some useful information here, I don't think the data and discussions presented are sufficient to address the impacts of exurban development or to evaluate the impact of landscape vs. local features. It is unclear from the existing description if the site selection methods are sufficient to address the stated question. The description of results is incomplete and the figures presented are not helpful for demonstrating key findings. Further analysis, considering other vegetation metrics and other types of land cover may yield interesting results.

Title

This title describes only one aspect of land use considered, leaving out the key finding of the role of local-scale canopy cover.

We have changed the title to more accurately represent our experimental design and analysis.

Introduction

There is some good information here about the impact of development on streams and riparian areas, but it does not provide the specific information necessary to understand the study that was performed. A definition and discussion of exurban development is needed. It is unclear from the information provided in what ways this type of development differs from suburban or timber management. Are there thresholds in imperviousness or density to be considered one type of development or another? Testing the impact of local vs. landscape features is a major aspect of this study, but there is only one study cited that addresses these issues. Hypotheses should be presented in this section and follow logically from the literature review.

Lines 45-47: What are imperviousness thresholds for rural, exurban, and suburban categories? This is a crucial piece of information for the reader.

Lines 46 – 48: We have edited the text to better highlight our message here, which is that the term exurban is loosely defined in the literature, but generally means areas that are neither intensely developed nor undeveloped. The revised portion now reads: "Such development is often termed exurbanization. Theobald (2004) highlighted the absence of a single definition for this term; however, exurban areas typically fall somewhere between the urban and rural areas in terms of population density (0.025 – 5 people per ha)."

Lines 55 and 59: Urban riparian soils are described as having reduced soil moisture in 55-56, but being more hydric in 59. Please clarify. **In an effort to shorten the manuscript we've removed this text, which presented a tangential issue.**

Lines 91-109: This section needs to be greatly expanded. Only one study on local factors is cited. The following could be considered:

Added several other studies and expounded upon these ideas. Our study focuses on response to disturbance by urbanization and articles cited are associated with this issue specifically.

Baker, M.E. and M.J. Wiley. 2009. Multiscale control of flooding and riparian forest composition in lower Michigan, U.S.A. Ecology 90:145-159.

Sarr, D.A. and D.E. Hibbs. 2007. Woody riparian plant distributions in western Oregon, USA: Comparing landscape and local scale factors. Plant Ecology 190:291-311.

von Behren, C., A. Dietrich, and J.A. Yeakley. 2013. Riparian vegetation assemblages and associated landscape factors across and urbanizing metropolitan area. EcoScience 20:373-382.

Line 96: Wording is very confusing here. **Reworded to emphasize that local scale factors influence these streams in the Pennington study, and that these local changes are caused by urbanization. "The authors showed that local vegetative community changed in response to urbanization, and that these local scale changes drove alterations of urban streams and riparian areas"**

Lines 107-109: Couldn't both local and landscape features be important? **Absolutely. I've made that more clear towards the end of the paragraph. "The take away is that both local– and landscape–scale factors are of importance, but more work needs to be done to assess the relative role that factors at these scales play in shaping riparian vegetation within urban areas"**

Line 133: No hypotheses are stated! **Hypothesis stated at the conclusion of the Introduction**

Methods

More information is needed here to clearly explain what was done in this study. It is not clear what criteria were used to select sites. Without more information here it is unclear if the methods properly address the stated question. Map (Figure 1) is not referenced in description of study sites. In inset map at the state level for context would make this fig much more useful.

Inset map is now referenced in the study site description (Line 139) and has been updated to be more clear (Fig. 1).

Lines148-163: How was exurban development identified? Was total imperviousness or density of structures, any other metric used? **Exurban developments were identified in that they were**

in areas around Gatlinburg, TN and Highlands, NC, which is primarily vacation and resort towns. All streams are within subdivisions containing mountainside housing with no other forms of development. Exurbanization by definition isn't a strict amount of impervious surface, but it just a moderately populated residential area somewhere between rural and suburban, that is location away from urban centers and cities and is usually associated vacation or retirement housing.

Line 153: What made a spot a potential location? **Added that they were "fishless streams in watersheds containing only exurban development (i.e., only low-intensity residential development)"**

Line 159: These 8 streams had no impervious cover within the delineated watershed? Or some other area? **"We selected eight additional streams that contained no impervious surface within the watershed"**

Line 162: Based on your lit review, logging over 75 years ago may not be sufficient for forest sites to be considered reference sites (lines 119-120). Need rationale for their use. **Added "All forested sites were presumed to have been logged, but the harvest was greater than 75 years ago. We assume that all of the exurban sites were logged around the same time. Reference sites that had never been logged would not be adequate for comparison with our exurban sites."**

Lines166-175: Were other landscape metrics, like canopy cover, agriculture, or open water measured? **We selected watersheds without agriculture or open water. %forest (or canopy cover) at landscape scale was directly the inverse of what impervious surface was. "Percent forest cover within our watersheds would be nearly the inverse of percent impervious surface, and thus was not used in the study."**

Line 178: Why 45m? **Methods were largely drawn from those of Thilina Surasinghe and are cited appropriately.**

Lines 181: How was exurban development maximized? **"by having a study site as far downstream as possible"**

Figure 2: The veg plots are shown to extend into the stream. This is confusing. **Removed lines that indicated there were veg. plots in the stream.**

Line 188: Need to reference sources used for species identification. **(Referenced the USDA webpage)**

Line 219: What about other vegetation categories that might be relevant, like wetland indicator status, sun/shade tolerance, ruderal species? Categories other than richness and diversity may be more meaningful response variables. **Added additional variables you now mention in paragraph 2 under "analysis"**

Line 198: This is the first time a level of imperviousness is mentioned. This should be stated much earlier. Also, there should be some citation to justify use of this level of imperviousness. **We now invoke impervious surface as part of our description under "Site selection." In the introduction we describe broadly how exurbanization is defined as low-intensity residential development. All impervious surface values were < 17%... NLCD considers low intensity development to be 20-49% impervious surface. Ours are below this threshold in the "Developed, open space" category. https://www.mrlc.gov/nlcd06_leg.php**

Were differences in canopy cover in forested and developed sites looked at? **Yes, canopy cover was measured at each stream.**

Results

This section is incomplete. An indication of imperviousness, canopy cover, and other land cover across sites is needed. Figures in this section are not very helpful for showing meaningful results. Perhaps a CCA map showing the lack of relevance of measured landscape variables, along with a figure showing the relevance of canopy cover.

Lines 246-248: Somewhere in here should include the range of canopy cover and basal area across sites. Also, what did the distribution of imperviousness across sites look like? Were most sites closer to 1%, 17%, evenly distributed within that range?

We created a table that shows a column of environmental variables, mean (range). Table 1 is referenced in the methods section.

Line 283: Canopy cover was a significant predictor, but how much did it vary from site to site? Were some sites completely open? Was there a developed-forested difference in canopy cover? **Table 1 was created to show variation across sites in environmental variables**

Lines 258-261: What about diversity or richness of understory vegetation in relation to canopy cover?

Our results in the paper show only significant results

#Methods and Results were rerun. We were able to supplement the analysis by identifying more plant species and further classifying them into groups that could be analyzed.

Discussion

There is some discussion of the importance of local vs. landscape features, but results are not really framed in the broader context of this topic. As in the introduction, more studies on the importance of local vs. landscape features should be referenced here. The lack of detail on site selection methods and patterns of canopy cover and imperviousness across sites make it difficult to justify conclusions presented in this section. A discussion of findings of this study compared with studies of suburban and urban development would also be useful. Is this level of development perhaps below a threshold for measurable changes?

Line 328: I don’t think described results adequately support this statement. Did you have a real gradient of ages and imperviousness of sites?

We have added a caveat that this result pertains to “the range of values we evaluated…”

Line 296: How do your data suggest this?

“however, our data shows no evidence to support that relationship”

Lines 329-342: Much more canopy description is needed. Was lower canopy cover due to encroaching development?

All we can do at this point is speculate within reason that it has to do with local land management. We initially evaluated canopy cover response to landscape variables, but did not find strong trends. Land owner activities like mowing and tree felling have more influence over canopy cover at the stream. Our canopy cover values are for the canopy cover directly adjacent to the stream, using a densitometer device.

Line 340: What about light increasing in mature forests due to tree-fall gaps?

We’ve softened the language to acknowledge that increased canopy cover is not always characteristic of mature forests

Lines 345-367: Productivity overall increases with canopy cover, but understory density and diversity decrease. How are these important for food webs?

Added that southern Appalachian riparian areas are some of the most diverse in the world, and can be more diverse when left undisturbed. Also discussed how changes in canopy cover and the type of detritus can influence nutrient cycling and in stream habitat.

Lines 390-398: More discussion of disturbance immediately adjacent to the stream would be helpful. You measured distance to imperviousness, but was there deforestation or other disturbance other than the addition of impervious surface that could be important? Were unimproved included in your imperviousness calculations? If not, might they be important? Other types of land cover?

Canopy cover and basal area are direct reflections of local management practices. It was not possible to quantify or qualify all land use changes for all sites, and be able to compare them adequately. Riparian areas could be manicured lawn, mowed, paved, clearcut, an actual building, or multiple other forms of management practice. We felt that canopy cover and basal area were great ways to quantify and qualify the various forms of land use and riparian management into a metric that could be compared across sites. “…land owners may clear vegetation after acquiring the property, then continue to clear through mowing or trimming over time. Furthermore, once the property is privately owned there is little enforcement of buffer regulations. On multiple occasions we met land owners with concerns about the neighbors removing trees along the stream bank, or observed it ourselves.”