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

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Urban Ecosystems

The Influence of Exurban Development Age on Riparian Vegetation

--Manuscript Draft--

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Abstract:	<p>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.</p>	

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

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22 Greenville Zoo and University of North Carolina Highlands Biological Station.

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23 **Abstract**

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

38 **Keywords:** Appalachian, Invasive plants, Stream, *Tsuga canadensis*, Urban

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39 Introduction

40 The United States is experiencing increases in population size and urbanization. Between
41 2000 and 2010 the population of the United States increased by 9.7%, and 83.7% of the
42 population resides in metropolitan areas (Mackun and Wilson 2011). Land use practices are
43 shifting and forests are being converted into residential land (Wear and Bolstad 1998). The
44 majority of development has been low density, suburban land that is decentralized from any
45 urban center, especially in the Southeast (Mcdonald et al. 2010), where population growth was
46 16.6% between 2000 and 2010 (Pollard and Jacobson 2011). Such development is often termed
47 exurbanization. Theobald (2004) highlighted the absence of a single definition for the term;
48 however, exurban areas typically fall somewhere between the urban and rural areas in terms of
49 population density (0.025 – 5 people per ha). Low density developments are projected to increase
50 in future decades (Wear and Bolstad 1998; Theobald 2010) and they are often near highly
51 biodiverse areas (Gagne and Fahrid 2010); both of these factors suggests the developments may
52 pose a serious threat to many species and ecosystems.

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

60 Riparian vegetation is integral in determining both composition and function of stream
61 ecosystems (Warner and Hendrix 1984) and it serves as a buffer zone between upland areas and

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4 62 streams (Hill 1996; Lowrance 1998). Streamside vegetation helps maintain stream temperature,
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6 63 provides woody debris for habitat along and within the stream, and assists in the uptake of NO_3^-
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9 64 from shallow groundwater (Sweeney 1992; Tabacchi et al. 2002). Riparian vegetation also
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11 65 stabilizes banks and provides cover for many species of wildlife. Plants provide detritus material
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14 66 within the stream, creating both a food source and habitat for aquatic organisms (Warner and
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16 67 Hendrix 1984). Urbanization has greatly reduced vegetation at a global scale (McKinney 2002),
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19 68 and riparian forests are particularly sensitive to land use change (Malanson 1993). Urbanization
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21 69 directly alters vegetative community composition and structure through replacement of
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24 70 vegetation by urban infrastructure and fragmentation. Species diversity, tree basal area, and
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26 71 native plant density have been shown to decrease near urban areas (Porter et al. 2001; Moffatt et
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29 72 al. 2004). Loss of canopy cover can increase algal growth, thereby changing low-order stream
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31 73 systems from allochthonous- to autochthonous-based systems (Doi et al. 2007; Hall et al. 2000;
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34 74 and Sobczak et al. 2002). A decrease or a change in detrital inputs may yield lower
35
36 75 macroinvertebrate biomass or altered macroinvertebrate community composition (Sobczak et al.
37
38 76 2002), which can have implications for higher trophic levels (Johnson and Wallace 2005).
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41 77 Furthermore, stream temperatures increase with canopy loss, which alters habitat suitability for
42
43 78 many organisms (Bozinovic et al. 2011). Sediment loading in streams can increase with riparian
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46 79 vegetation loss, and decrease water quality (Osborne and Kovacic 2006).

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48 80 Urbanization causes a shift in vegetative communities and reduces native plant diversity
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51 81 while increasing the number of exotic and invasive species (Burton et al. 2005; Burton et al.
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53 82 2008; King and Buckney 2001; McKinney 2001; McKinney 2002; Warren et al. 2015). A study
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56 83 by Loewenstein and Loewenstein (2005) found significantly more exotic plant species at urban
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58 84 sites along a rural-to-urban gradient in the Piedmont ecoregion of Georgia. Pennington et al.

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85 (2010) identified similar trends in Ohio, but also found an increase in early successional native
86 plant species in urbanized riparian areas. Shifts in vegetation may often be driven by “hydrologic
87 drought” that develops from lowered water tables in urban areas (Groffman et al. 2003). A
88 review by Groffman et al. (2003) identified twice as many upland plant species in urban
89 floodplains relative to non-urbanized floodplains (Brush et al. 1980) in Maryland, and suggested
90 this assemblage shift was the result of altered hydrology.

91 Pennington et al. (2010) argued that previous studies on urbanization and stream response
92 are too broad in scope and need to focus on local-scale variables like riparian vegetation. The
93 authors showed that local vegetative community changed in response to urbanization, and that
94 these local scale changes drove alterations of urban streams and riparian areas. The authors make
95 a final argument that future conservation efforts in the face of urbanization should focus on
96 maintaining wide riparian forests and limiting impervious surface development within riparian
97 areas. Wang et al. (2001) found similar results while studying urban fish populations, noting that
98 impervious surface within the riparian area or within a 1.6–km radius upstream had a stronger
99 influence on fish populations and hydrology than comparable levels of impervious surface that
100 were further away. Allan et al. (1997) found no correlation between local riparian vegetation and
101 landscape scale factors. Other studies have argued that watershed-scale conservation, as opposed
102 to protection of just the riparian zone, is necessary to protect stream organisms (von Behren et al.
103 2013; Sarr and Hibbs 2007; Willson and Dorcas 2003); however, the fact remains that
104 Pennington et al. (2010) suggest an important hypothesis that may apply to some aspects of
105 stream ecosystems. Increased riparian forest buffers may then lead to reduced exotic plant
106 invasions and maintenance of hydrological function in riparian areas, even if they do not protect
107 all stream species from declines. The take away is that both local– and landscape–scale factors

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108 are of importance, but more work needs to be done to assess the relative role that factors at these
109 scales play in shaping riparian vegetation within urban areas.

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

125 While the response of riparian vegetation to timber harvest has been evaluated at various
126 time steps following disturbance, no such knowledge exists for the same communities in the
127 context of exurban housing developments (Pennington et al. 2010). It is unknown if riparian
128 communities surrounded by exurban housing developments will undergo a process of recovery
129 with time toward pre-disturbance conditions, or if they will remain altered in the long-term. To
130 address this data gap we evaluated the influence of impervious surface, neighborhood age, and

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131 other landscape–scale variables on several measures of the riparian plant community. We also
132 evaluated the ability of surrogate measures for local habitat management to predict plant species
133 richness, diversity, and the number of non-native species. We hypothesize that stream riparian
134 zones will exhibit signs of recovery (more similarity to forested sites) in areas with older and
135 less–developed neighborhoods. We also hypothesize that changes in vegetation communities will
136 be influenced partially by local scale variables.

137 **Methods**

138 *Study Area*

139 Our study sites were within the Southern Blue Ridge Ecoregion (Fig. 1), which spans
140 over 3,804,045 ha and covers sections of Georgia, South Carolina, North Carolina, Tennessee,
141 and Virginia. The mountains are between 450 and 2040 m in elevation. There are over 400
142 species of plants and animals endemic to this region, more endemics than any other North
143 American ecoregion (The Nature Conservancy and Southern Appalachian Forest Coalition
144 2000). Parts of the southern Appalachians along the Blue Ridge Escarpment receive the highest
145 level of rainfall in the United States east of the Cascades, and the climate of these mountains
146 ranges from temperate to boreal.

147 *Site Selection*

148 To select focal streams we evaluated 2014 aerial images from the region to identify
149 watersheds with exurban development (i.e., residential development with < 17% impervious
150 surface). Within these watersheds, we used ARCGIS 10.1 (ESRI, Redlands, CA) to overlay a
151 high resolution stream layer from the National Hydrography Dataset and a tax parcel data layer
152 derived from Sevier County, TN and Macon County, NC. From these overlays we identified 80
153 potential locations that were streams in watersheds containing only exurban development (i.e.,

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4 154 only low-intensity residential development). We attempted to contact the property owners along
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6 155 each stream by phone or in person. Once permission was obtained to access the property we
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9 156 traveled to each site in an attempt to standardize stream size and development to the extent
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12 157 possible. Following ground validation we were left with 27 first- or second-order exurban
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14 158 streams across the two counties in Western North Carolina and Eastern Tennessee. We selected
15
16 159 eight additional streams that contained no impervious surface within the watershed. Four of these
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19 160 forested sites were located within the Coweeta Hydrologic Laboratory property in Otto, North
20
21 161 Carolina, and four were within Walker Valley in the Great Smoky Mountain National Park, TN
22
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24 162 (Fig. 1). All forested sites were presumed to have been logged, but the harvest was greater than
25
26 163 75 years ago. We assume that all of the exurban sites were logged around the same time.
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29 164 Reference sites that had never been logged would not be adequate for comparison with our
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31 165 exurban sites.

32
33 166 To calculate the age of development in each exurban watershed, we used tax parcel
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36 167 information. We extracted the age of each individual structure within the study area, and
37
38 168 averaged those ages across all buildings in the watershed. Exurban housing ranged in age from
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41 169 four to forty-two years (mean = 25.99 yrs) across the 27 watersheds with development. We also
42
43 170 calculated impervious surface coverage for each watershed by obtaining 2014 leaf off aerial
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46 171 imagery (0.65 meter resolution) from the counties containing our study areas. Percent forest
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48 172 cover within our watersheds would be nearly the inverse of percent impervious surface, and thus
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51 173 was not used in the study. This was done by hand-delineating polygons around all impervious
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53 174 surfaces and calculating the percent of the watershed they covered. We calculated distance to
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56 175 impervious surface using the “near” tool in ARCGIS 10.1, measuring the distance from stream
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58 176 sample plots to the nearest impervious surface polygon.

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177 *Field Methods*

178 We established a 45–m transect along the length of each stream and established
179 vegetation plots in the summer of 2014, similar to methods used by Surasinghe and Baldwin
180 (2015). Transects were selected by maximizing the amount of exurban development within the
181 watershed by having a study site as far downstream as possible, without including other forms of
182 land use, but were limited by where we could get access to private property. These transects were
183 broken into three five meter sections, each ten meters apart. Along each of the five meter
184 sections, we measured 10 m from the bank of the stream to establish a 50 m² plot (Fig. 2). The
185 plot was measured on the right side of the first section, the left side of the second section, and the
186 right side of the third section. Within each plot we identified all vegetation to species. If an
187 identification could not be made on site, we took photos and identified them later
188 (plants.usda.gov; USDA, NRCS 2003). If a positive ID to species–level could not be made, we
189 identified it to the lowest possible taxonomic level (Family or Genus) and added a unique
190 numeric identifier. We counted all trees within a plot; however we only recorded incidence data
191 for herbaceous and shrubby vegetation. We measured percent canopy cover three times in the
192 middle of the stream using a convex spherical densiometer. We estimated percentage of ground
193 covered by coarse woody debris (CWD), vegetation, and bare ground (defined as rock or soil not
194 covered by vegetation) within each plot to the nearest 5% (Table 1). We considered any fallen
195 limb or tree larger than 10 cm in diameter to be CWD. We recorded basal area (m²/ha) of each
196 section using a 10BAF basal area prism.

197 *Analysis*

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

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4 200 17% watershed impervious surface) in Microsoft Excel (Redmond, WA). Shannon diversity was
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7 201 estimated for trees because we had counts of individuals for this group, but not for all vegetation
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9 202 types. Using the iNEXT package (Hsieh et al. 2014) in Program R (R Core Team 2013), we
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11 203 created species accumulation curves for both the number of sites sampled and the number of
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14 204 individuals sampled for the forested and the exurban sites. Because of the differences in the
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16 205 number of sites, we used rarefaction to estimate diversity after eight samples for both land cover
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19 206 categories as this was the total number of forested sites. To assess differences in vegetative
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21 207 community composition as a function of neighborhood age and percent impervious surface, we
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24 208 used a canonical correspondence analysis (CCA). This type of ordination analysis is appropriate
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26 209 when the goal is to understand the structure of community data in the context of a specific set of
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29 210 environmental variables (McCune and Grace 2002). We examined all vegetation (using only
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31 211 incidence data) and tree species (using count data) in two separate CCA analyses. We conducted
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34 212 these analyses using only data from sites with development, since neighborhood age was not
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36 213 applicable to fully forested sites. A second CCA of all vegetation was run using only plants that
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38 214 were detected at least 3 times across all sites. We used the vegan package (Oksanen et al. 2015)
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41 215 in Program R (R Core Team 2013) to run the CCAs.

42
43 216 We used multivariate multiple regression to examine the influence of percent impervious
44
45 217 surface, neighborhood age, and distance to impervious surface on a suite of uncorrelated
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48 218 ($R < 0.75$) plant-related response variables. Specifically, we examined the influence of our
49
50 219 selected predictors on basal area, canopy cover, vegetative cover, CWD, Shannon-Wiener
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53 220 diversity (for trees), tree species richness, total plant species richness, exotic species richness,
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55 221 non-woody vegetation species richness, annual and perennial plants, growth form category (forb,
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58 222 forb/subshrub, subshrub, subshrub/vine, subshrub/tree, vine, shrub/tree, graminoid, fern, shrub,
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4 223 forb/vine), and wetland associated plants. Because almost all of our sites have a relatively high
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6 224 proportion of forested area within the watershed, we also wanted to examine the influence of
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9 225 habitat structure within the riparian zone on vegetation. We used basal area, canopy cover, and
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11 226 coarse woody debris to quantify differences in forest structure at the local scale. Sites with higher
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14 227 basal area, canopy cover, and CWD were considered less disturbed or have experience a longer
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16 228 period since a previous disturbance. We again used multivariate multiple regression to test for
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19 229 relationships between local site characteristic predictors and the same response variables used for
20
21 230 landscape-level predictors. A model was also run using only forested sites to test for the
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24 231 influence of local scale variables on assemblage structure in forested communities without
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26 232 exurban influence.

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29 233 We used logistic regression models to examine the influence of hypothesized predictor
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31 234 variables on the presence or absence of selected species. Eastern hemlock (*Tsuga canadensis*) and
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33 235 yellow-poplar (*Liriodendron tulipifera*) were chosen because they each made up more than 10%
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36 236 of all trees identified. We also evaluated great rhododendron (*Rhododendron maximum*) because
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38 237 it was the most common species and indicative of a climax riparian ecosystem in this region
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41 238 (Keever 1953). We evaluated the presence of ericaceous shrubs [great rhododendron, mountain
42
43 239 laurel (*Kalmia latifolia*), and mountain doghobble (*Leucothoe fontanesiana*)] based on their
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46 240 importance in these ecosystems in terms of pH regulation and soil nutrients (Monk et al. 1985).
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48 241 We evaluated red maple (*Acer rubrum*) and species not native to the United States because both
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51 242 are commonly associated with disturbance and human activities (Burton and Samuelson 2008;
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53 243 King and Buckney 2000; Tift and Fajvan 1999).

54 55 244 **Results**

56 57 58 245 *Descriptive characteristics*

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246 There were a total of 36 tree species found across all sites. Mean species richness and
247 Shannon diversity were higher in forested sites relative to exurban sites; however, there was
248 considerable overlap in the range of these measures between site categories (Table 2). Sample-
249 based rarefaction ($n = 8$) revealed no significant difference (95% confidence intervals
250 overlapped) between exurban and forested sites in the accumulation of tree species, based on
251 abundance data (Fig. 3a), however, the shape of the accumulation curve suggest that richness in
252 both categories of sites is not fully represented by our sample. Across all sites, we identified 151
253 species of herbaceous and shrubby plants. Individual-based species accumulation curves for
254 herbaceous plants again showed no significant difference between forested and exurban sites
255 (Fig. 3b). Exotic plants were found at 16 out of 27 exurban sites, and at one of the forested sites.
256 A total of 19 wetland indicator plants were identified across all sites, with an average of 3.4 and
257 2.4 plants per site at forested and exurban sites respectively. Many different growth forms were
258 identified, but the most common growth form across sites in both land cover categories was forb.

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

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269 found at exurban sites and one species at forested sites. The most common exotic species was
270 stilt grass (*Microstegium vimineum*). Red maple and exotic species were present at more than
271 fivefold as many exurban sites as forested sites.

272 *Vegetation community response to urbanization*

273 In a CCA using only tree abundance data, 5% and 4% of variance was explained by age
274 and impervious surface, respectively. When incidence data were used for a CCA with all plants,
275 4.3% and 4% of the variance was explained by age and impervious surface respectively (Fig. 4).
276 A second CCA using plants detected within at least 3 plots provided showed similar results for
277 age and impervious surface, 4.3% and 3.9% respectively.

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

289 Predictors of presence varied widely across target species. Presence of red maple and
290 yellow-poplar were not significantly related to any of the selected predictors ($P > 0.05$ for all
291 logistic regressions). Higher basal area increased the probability of eastern hemlock ($P = 0.02$),

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292 great rhododendron ($P = 0.03$), and other ericaceous shrub ($P = 0.01$) presence, and decreased
293 the likelihood that exotic species would be present ($P = 0.02$). Areas of higher canopy cover
294 increased the likelihood of great rhododendron [($P = 0.02$ (all sites) and $P = 0.03$ (exurban sites))]
295 and other ericaceous shrub presence ($P < 0.01$) and decreased the likelihood that exotics were
296 present ($P = 0.04$ across all sites). For every five percent increase in canopy cover there was a
297 four percent decrease in the likelihood of exotic species presence, and an increase in the percent
298 likelihood of great rhododendron presence by ~ 6% at all sites and 7% at exurban sites.
299 Neighborhood age did increase likelihood of great rhododendron presence ($P = 0.04$ across
300 exurban sites) and the presence of other ericaceous shrubs ($P < 0.01$). For every five-year
301 increase in neighborhood age there was a 6.1% increase in the likelihood of great rhododendron
302 presence, which at least for this one species, is a result consistent with recovery toward more
303 forested conditions.

304 **Discussion**

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

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315 keep them from succumbing to hemlock woolly adelgid infection. Dead and dying hemlocks in
316 an exurban setting are also more likely to be removed since they pose a safety hazard.

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

329 Pennington et al. (2010) argued for the importance of local scale predictor variables, and
330 our results support their findings. Reduced canopy cover predictably led to an increase in the
331 amount of ground cover by understory vegetation, however, exotic species were often prominent
332 members of the understory community. For example, an exurban site in East TN with little
333 canopy cover had riparian plots that were 100% covered by herbaceous vegetation, in the form of
334 kudzu (*Pueraria lobata*). This observation is likely due to increased light availability (Parendes
335 and Jones 2001, Setterfield et al. 2005, Vidra and Shear 2008, Warren et al. 2015). Sites with
336 lower canopy cover also contained more species of annual plants Taken together, these trends
337 could indicate the maturation of a forest from having an abundance of ruderal, annual, non-

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338 woody plants, to a more stable community of perennial, woody vegetation. Future studies might
339 consider examining the abundance herbaceous species, as we only collected incidence data.
340 Increased canopy cover is often characteristic of more mature forests; however, our results
341 suggest this variable does not necessarily increase as neighborhoods age, perhaps due to local
342 land use practices in that neighborhood.

343 Our results show that canopy cover was positively correlated with Shannon diversity of
344 trees. This result was not simply a function of increased tree abundance, because basal area did
345 not correlate with Shannon diversity. Higher levels of diversity promote increased primary
346 productivity of plant communities (Nijis and Roy 2003; Wilsey and Potvin 2000) and in the
347 Southern Appalachians overall diversity relates positively with canopy cover and primary
348 productivity (Belote et al. 2011; Elliot et al. 1998) as these ecosystems are some of the most
349 biodiverse in the world (Elliot et al. 1998; Hodkinson 2010). Increasing riparian ecosystem
350 primary production, and consequently the detrital inputs, is very important for southern
351 Appalachian headwater stream ecosystems; they have detritus based food webs that are
352 composed primarily of foliage from nearby trees (Hall et al. 2000). Reduced canopy cover
353 reduces detritus input (Wallace et al. 1997) and decreases food chain length (Jenkins et al. 1992).
354 Changes in detrital food base are linked to forest cover along the entire length of the stream, not
355 the immediately present forest cover at the site, and can occur from minimal forest cover loss
356 (England and Rosemond 2004). For example, if Chinese privet (*Ligustrum sinense*) becomes
357 abundant in a riparian area because of a disturbance like urbanization it can alter the form of
358 detritus that enters the stream. Privet detritus decomposes at a faster rate and can alter nutrient
359 cycling and decomposition in riparian areas and within the stream. Chinese privet is found to
360 decompose at a faster rate than native tree leaves (Mitchell et al. 2011). Similar results were

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361 found by Fargen et al. (2015) in a study on Amur honeysuckle (*Lonicera mackii*); an invasive
362 plant within the same genus of one of our most common exotic plants, Japanese honeysuckle.
363 The authors found that the leaves of *L. mackii* decomposed two weeks faster and had fewer
364 macroinvertebrates than the native sugar maple (*Acer sacharum*). Likewise, Swam et al. (2008)
365 found that litter from the the exotic, invasive tree of heaven (*Ailanthus altissima*) also broke
366 down more quickly than that of native plants. The authors noted that the presence of native plant
367 leaf litter could help “armor” and slow the decomposition of the non-native tree of heaven.

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

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

387 *Conclusion*

388 Our work suggests that riparian vegetative composition in watersheds containing exurban
389 developments is not primarily driven by the amount of impervious surface (at ranges from 1 –
390 17%) or the age of the exurban development. Instead, local site variables such as canopy cover
391 and basal area provided the best predictors of exotic species and other vegetative characteristics.
392 These local-scale measures can be influenced by riparian management practices. In Macon and
393 Jackson County, North Carolina there are ordinances requiring 30 foot buffer zones along
394 streams, but from our observations exurban developments allow impervious surface closer to the
395 stream. During construction of a neighborhood, basal area and canopy cover can be reduced from
396 clear-cutting, or land owners may clear vegetation after acquiring the property, then continue to
397 clear through mowing or trimming over time. Furthermore, once the property is privately owned
398 there is little enforcement of buffer regulations. On multiple occasions we met land owners with
399 concerns about the neighbors removing trees along the stream bank, or observed it ourselves.
400 The absence of a correlation between basal area and CWD could also mean that landowners are
401 removing snags and fallen trees. Much of the southern Appalachians is privately owned, and
402 there is a fast-growing wildland-urban interface (Macie and Hermansen 2002). This means that
403 cooperation with private land owners is integral to maintaining the biodiversity and function of
404 these ecosystems. Future studies that assess the minimum forest buffer width required to
405 maintain vegetative communities similar to forested sites would provide land owners and
406 neighborhoods more specific target objectives for sustainable management of riparian habitats.

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

Variable	All Sites		Urban Sites	
	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)

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

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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)

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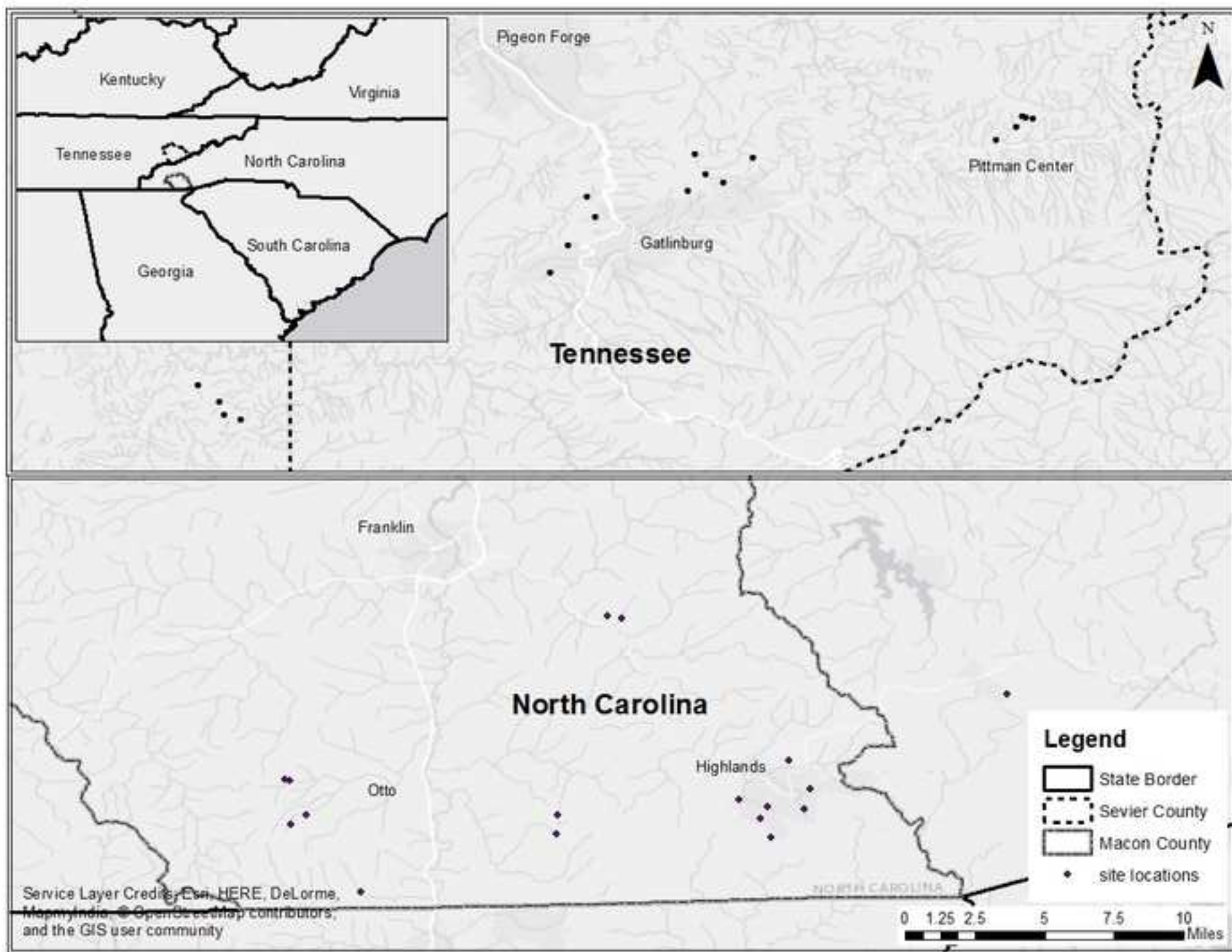
583 **Figure legends**

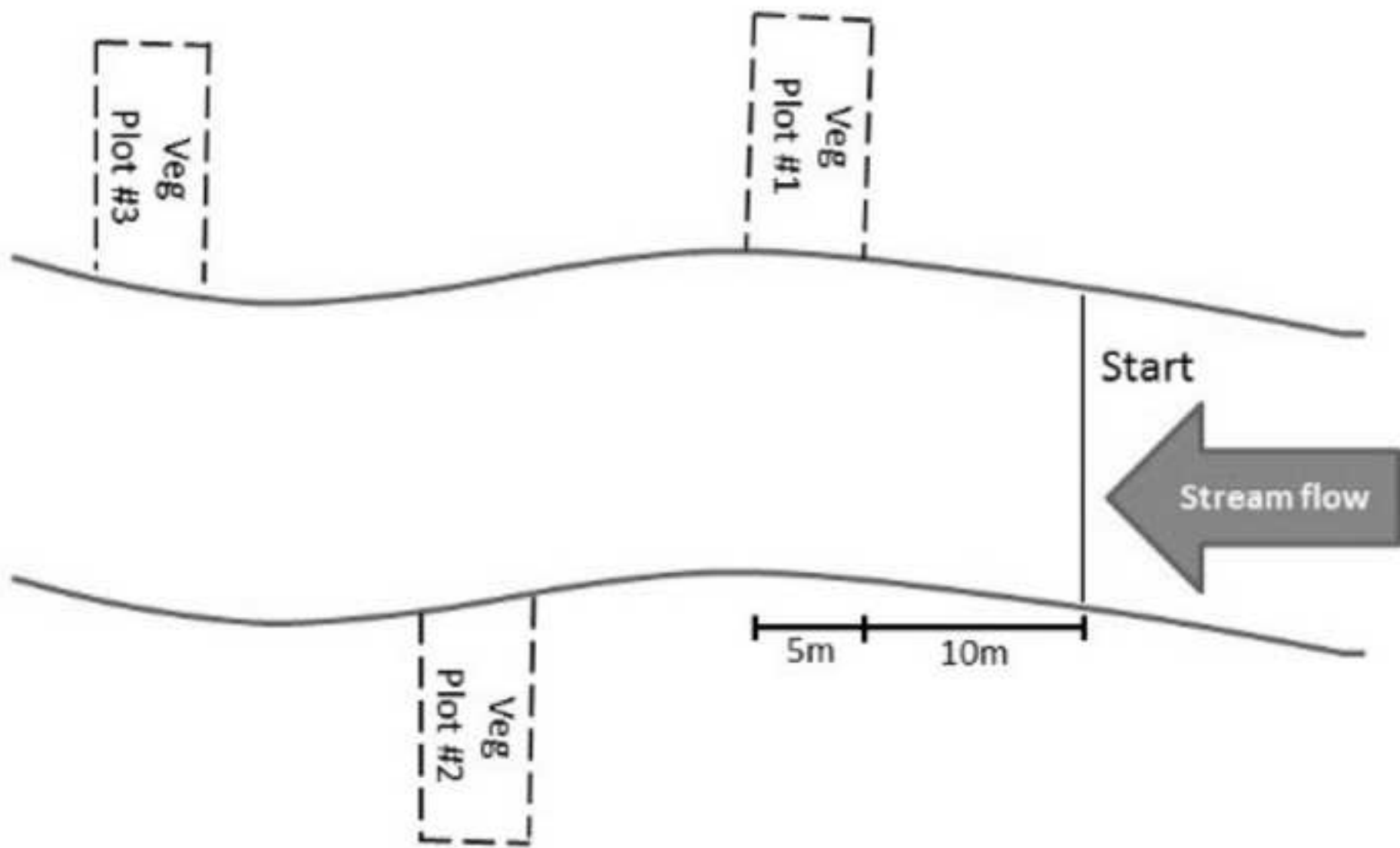
584 **Figure 1.** The 35 riparian vegetation sample plots were located in or near Sevier County,
585 Tennessee (dashed) and Macon County, North Carolina (solid).

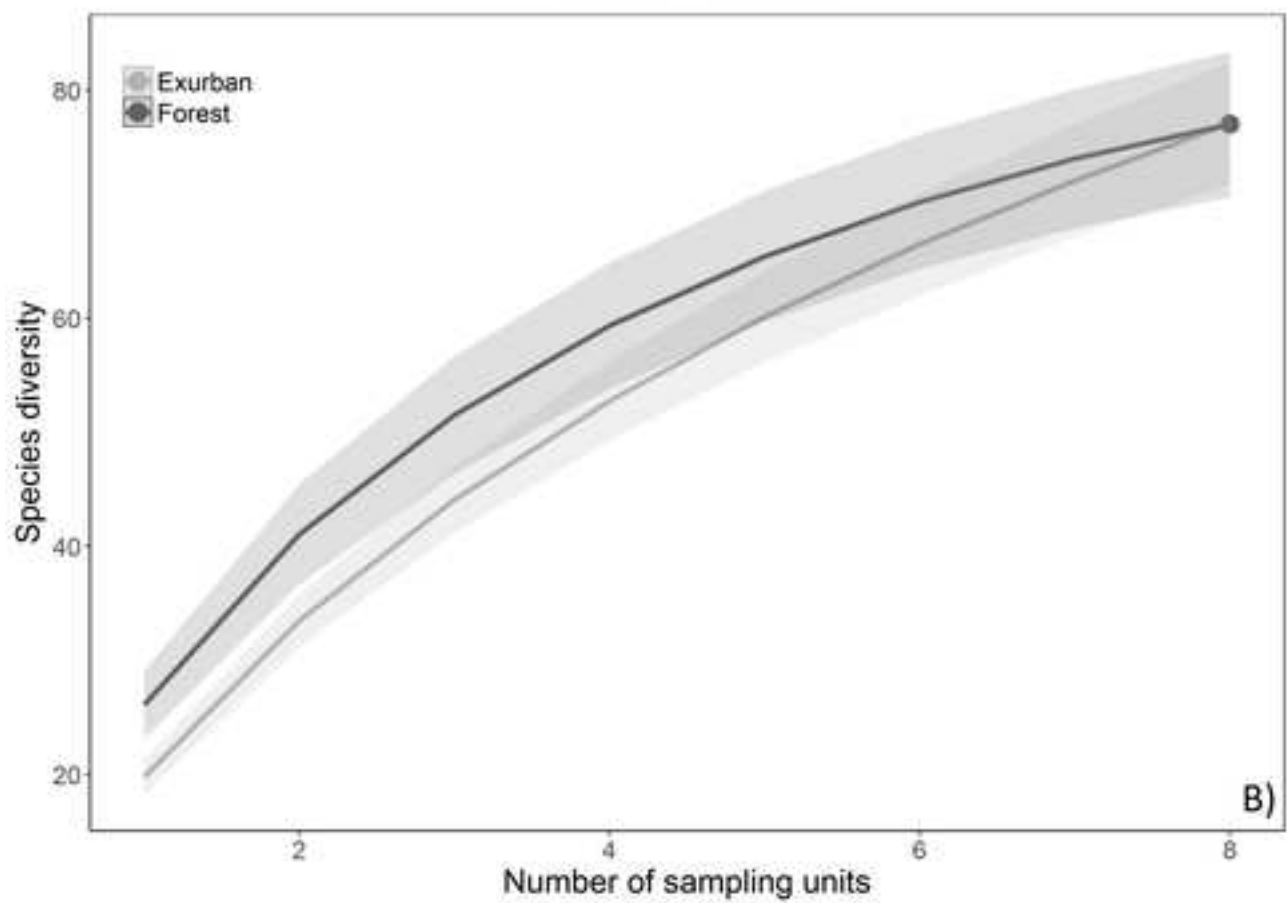
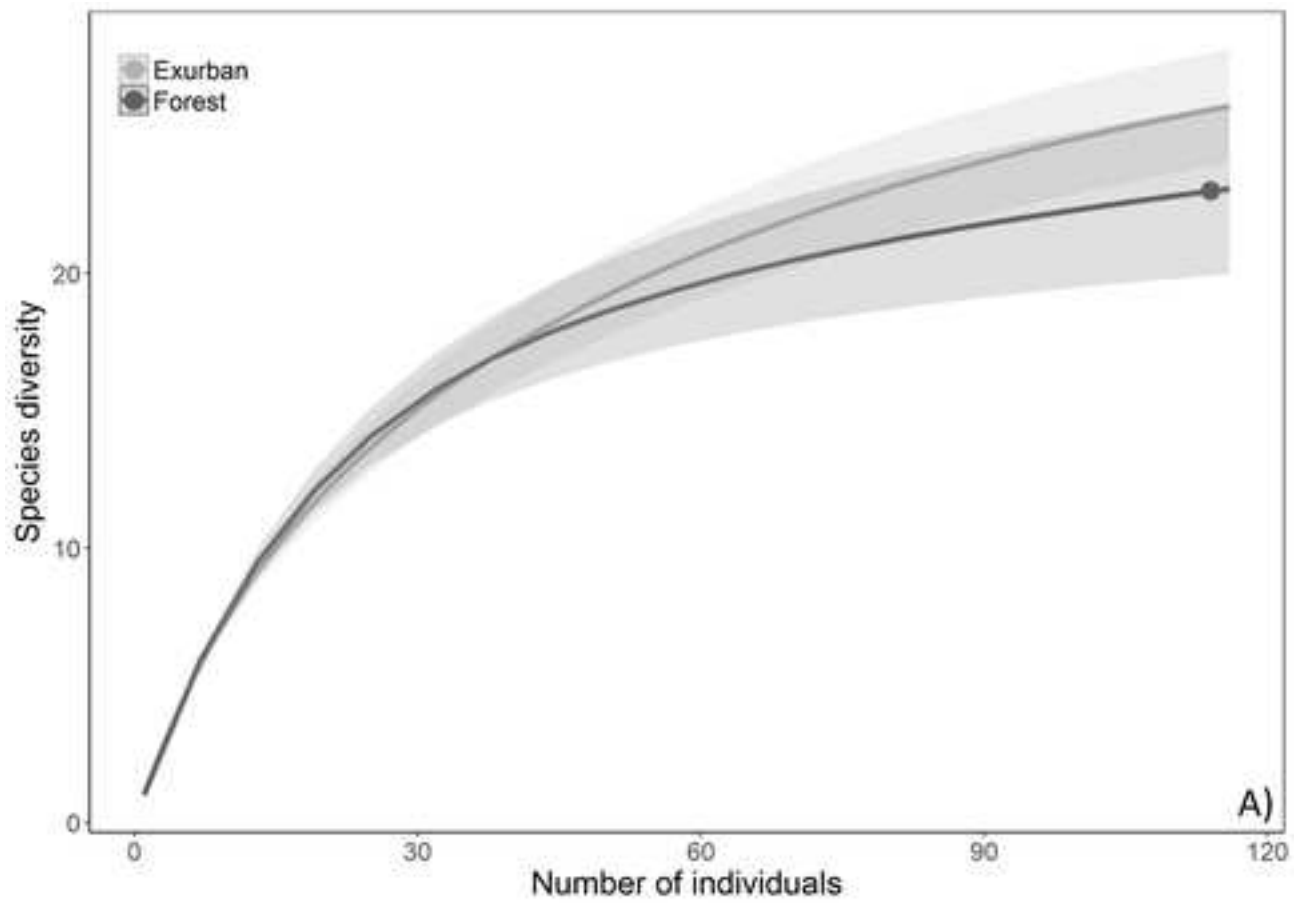
586 **Figure 2.** A graphic of the sample transect and vegetation plots for each of the 35 field sites used
587 to sample riparian vegetation in western Tennessee and eastern North Carolina.

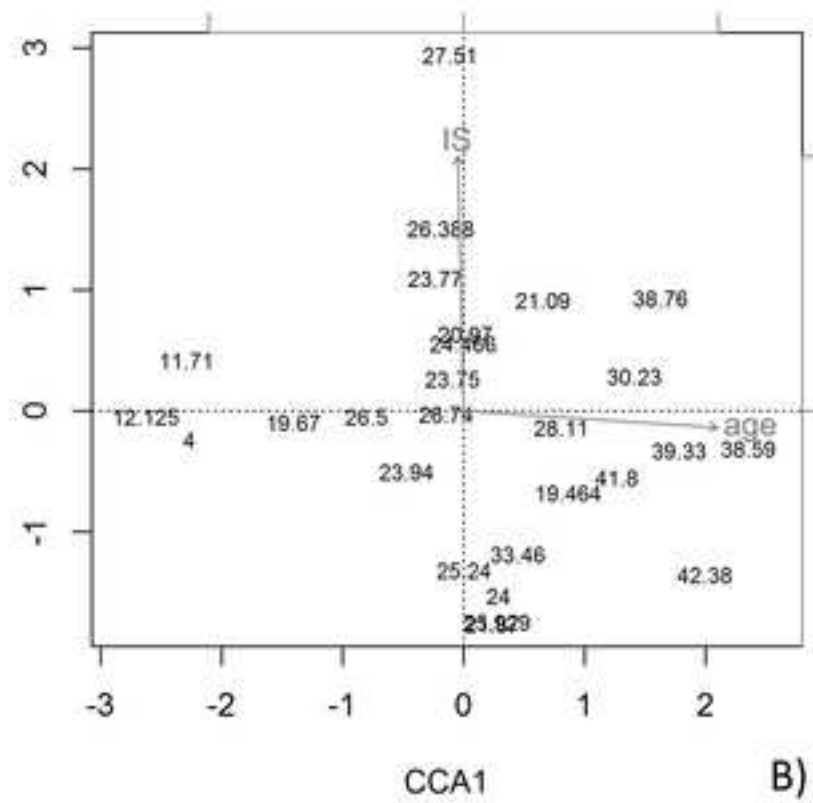
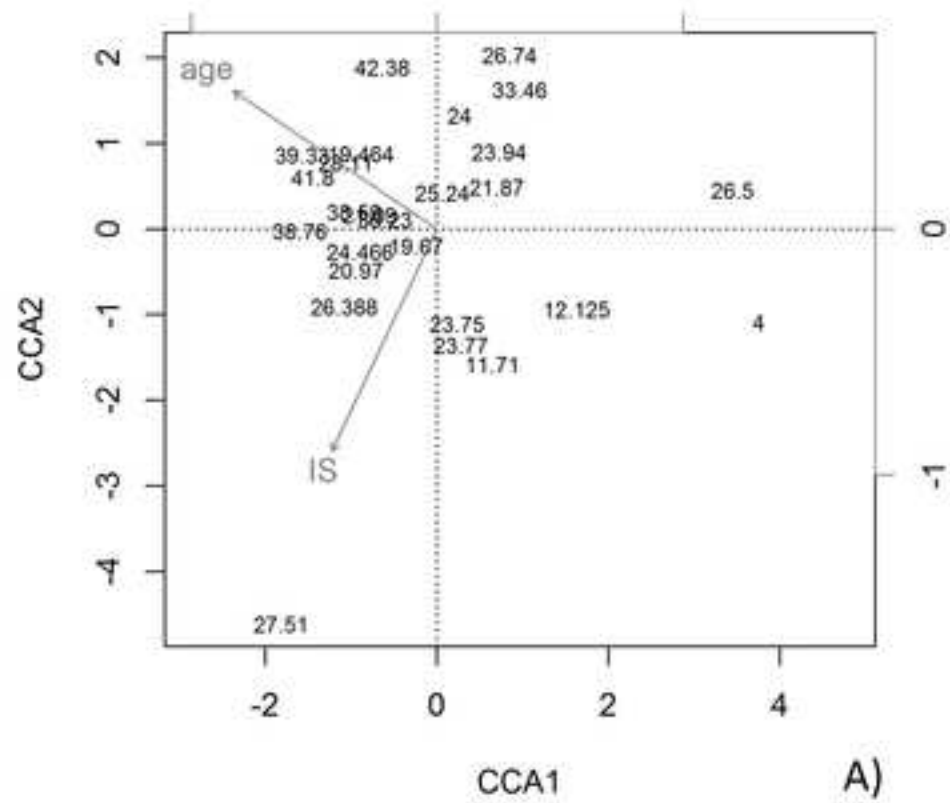
588 **Figure 3.** Species accumulation curves for (a) abundance data on trees and (b) incidence data on
589 plants for exurban and forested sites for riparian vegetation community data within the Blue
590 Ridge Mountain region of North Carolina and Tennessee, U.S.A.

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









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. 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).

Lines 148-163: 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.”**

Lines 166-175: 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.”