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Canopy Composition and Forest Structure Provide Restoration Targets for Low-Order Riparian Ecosystems

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Abstract

Many programs are in place to protect and restore low-order streams and riparian zones. However, information on riparian zone forests is sparse for many biogeographical regions, especially compositional and structural data that would provide useful targets for restoration. This study provides quantitative data on riparian zone composition and forest structure from three physiographic provinces of eastern United States. Data from 219 low-order (first- to fourth-order) forested reaches were arranged by three basal area (BA) categories meant to represent successional categories and variations in forest structure. Detrended correspondence analysis (DCA) was used to illustrate differences among successional categories and physiographic provinces. The DCA ordination separated stands into four physiographic subregions, based on the species composition of late-successional stands. Many early to mid-successional stands (<30 m^2/ha) were similar in composition to late-successional reference stands (BA ≥ 30 m^2/ha) in the same physiographic subregion. In such sites, natural successional processes would likely be sufficient to restore the compositional and structural attributes inherent in late-successional stands if provided long-term protection. Other sites with dissimilar compositions may have been recovering from more intensive types of alterations, such as mechanized land clearing. In such sites, restoration to historic compositions could benefit functionally by planting oaks (*Quercus* spp. L.) and other heavy mast species.

Key words: composition, ordination, riparian, structure, succession.

Introduction

Forested riparian zones are important for maintaining the physical, biological, and chemical integrity of riparian ecosystems and for buffering the impact of nonpoint source pollutants transported to them from adjacent uplands (Peterjohn & Correll 1984; Jacobs & Gilliam 1985; Phillips et al. 1993). This is especially true of late-successional riparian forests because such forests include large canopy trees, snags, downed wood, and a three-dimensional structure that includes understory strata of multiple-aged canopy trees, subcanopy trees, shrubs, and herbaceous plants. Such forests support exceptional invertebrate and vertebrate habitat (Hyatt & Naiman 2001; Wipfli et al. 2007), litter for in-stream biota (Thorp et al. 1985; Wallace et al. 1997), and soils high in organic matter to fuel denitrifying microbes (Lowrance et al. 1984; Groffman et al. 1992; Tesoriero et al. 2004).

Linear dimension is an important spatial characteristic of streams and riparian forests because they interface directly with upland activities where most nonpoint source pollution originates (Brinson 1993; Alexander et al. 2007). Riparian zones of low-order streams, herein defined as first- to fourth-order streams (sensu Strahler 1952), are important to water quality because they comprise about 90% of a stream network's total length (Rheinhardt et al. 1999, 2005). Headwater reaches, herein defined as first- to second-order streams, are particularly important because they comprise two-thirds of most stream networks (Leopold et al. 1964; Freeman et al. 2007). Due to their prevalence in the landscape, riparian zones of low-order streams provide enormous potential for buffering land-disturbing activities in uplands (Spruill 2000).

Riparian ecosystems of headwater reaches (first- to second-order streams) are hydrologically driven by groundwater discharge and so are generally intermittent to perennial, depending on their hydrogeologic and climate setting (Winter 2007). Although most topographic contour maps depict intermittent and perennial streams as blue lines (dashed and solid, respectively, e.g., U.S.

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Geological Survey [USGS] 1:24,000-scale topographic maps), many intermittent streams are missed by these maps. The third- to fourth-order streams tend to be more perennial in nature and so are usually mapped as solid blue lines, even on lower resolution maps (e.g., 1:100,000 scale).

Although some low-order streams in the United States are protected from alteration by federal, state, and local regulations, headwater reaches in many areas are either not regulated or receive minimal regulatory protection. Although many headwater reaches are in poor condition (NRC 2002), there is growing awareness of their potential to maintain and improve water quality. A growing number of government programs are available in the United States for restoring low-order riparian ecosystems, including headwater reaches (NRC 2001; Palmer et al. 2005).

Strategies for restoring low-order reaches vary from intensive approaches that include realigning channels, designing floodplains, and planting trees and other vegetation in riparian zones to more extensive approaches that rely principally on natural successional processes. Examples of extensive approaches include acquiring conservation easements to restrict or eliminate timber harvesting or by purchasing land outright. Because extensive approaches are far less expensive (per unit land area) than more intensive approaches, their main attraction is that they could be applied for the same cost over a larger proportion of a stream network.

Although there are a handful of studies describing the forest composition of floodplain vegetation of low-order perennial streams in eastern North America (Monk 1966; Gemborys & Hodgkins 1971; Glascock & Ware 1979; Parsons & Ware 1982; Rheinhardt et al. 1998), forest composition reference data are sparse for riparian zones of intermittent streams and their stream channels in this region (Rheinhardt et al. 2000) as are data from successional stands (Phillips 2002). This lack of data may be due to intermittent streams being perceived by some as being less valuable than perennial streams and thus less regulated. Further, headwater streams (intermittent and perennial) seldom provide habitat for fisheries, and most have low silvicultural potential when contrasted with bottomland hardwood forests on floodplains of large and intermediate-sized rivers (Hodges 1998; Kellison et al. 1998). However, in regions where cropland or pasture covers a large proportion of the land surface, low-order riparian forests often represent habitat quality and complexity not found elsewhere in the landscape (Brinson & Verhoeven 1999).

If protecting and restoring low-order riparian zones that are in early stages of forest succession (extensive restoration approach) are to become widespread, there is a need for more information about the composition of developing riparian forests as they succeed toward maturity. We know that riparian forests gain biomass and become more stratified with age until they reach maturity and that 90% of the aboveground forest biomass consists of trees and tree-derived detritus (Brinson et al. 2006). However, little is known about changes in canopy composition as biomass accumulates throughout succession.

Reference data on differences in composition among sites of various ages (and biomass) could be used to plan lower cost alternatives for riparian restoration that could be applied more widely in the landscape (extensive approaches) and determine where more intensive intervention might be required. Therefore, our objective was to (1) obtain reference data on riparian zone forest structure and composition in low-order riparian ecosystems from three physiographic provinces of the eastern United States and (2) use those data as a basis for outlining strategies for restoring structure and function to low-order riparian zone forests. To do this, stand basal area (BA) (total cross-sectional area of trees) was used as a surrogate for forest biomass, three-dimensional structure, and successional status.

Study Area and Land Use History

All study reaches were located in the Delaware River, Chesapeake Bay, and Albemarle/Pamlico Sound drainage basins (Fig. 1). These basins drain an ecologically diverse area of eastern North America covering 280,479 km^2 across eight states and five physiographic provinces. Sampling was conducted in three of the five physiographic provinces: Coastal Plain, Piedmont, and Ridge & Valley.

Land use history has varied widely among the physiographic provinces. Agricultural areas in the Coastal Plain have been relatively stable over the past 100–200 years, except for more recent changes related to encroaching urbanization and agricultural intensification. Most of the wetter second- to fourth-order riparian forests have been managed for timber, but at a small scale as wood lots, and have been repeatedly harvested over the past 200 years. In contrast, many drier riparian forests on first-order reaches were ditched long ago to maximize arable land or filled and paved when converting them to urban developments.

In the Piedmont, agricultural expansion during the nineteenth century led to widespread soil erosion that carried sediment into streams and floodplains. Many larger floodplains became filled with sediment, but when farming on uplands was abandoned due to loss of fertility from the erosion, forests reclaimed the landscape and widespread erosion ceased. Streams are now downcutting through accumulated sediment to historic riverbeds, which has left river floodplains high and dry (Ruhlman & Nutter 1999). Little is known specifically about how lower order streams and channels were affected. However, headward cutting of low-order streams is now common (R. D. Rheinhardt, personal observations).

In the Ridge & Valley physiographic province, most forests were cleared for farming by 1800. Farming was eventually abandoned on slopes but has continued in

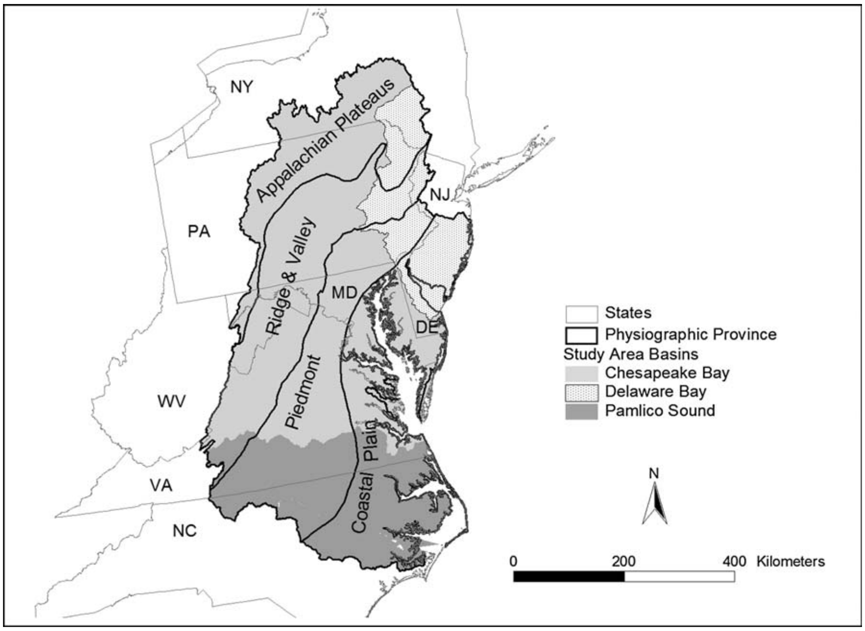

Figure 1. The drainage basins of the Atlantic Slope study area. Sampled stream networks were in three physiographic provinces: Coastal Plain ($n = 8$ stream networks), Piedmont ($n = 6$ stream networks), and Ridge & Valley ($n = 8$ stream networks).

valleys to the present. Farmland abandoned on slopes reverted to forest, but those forests have been repeatedly cut. As is true for the other provinces, no information is available on the land use history specific to low-order riparian zones. However, many headwater reaches in the Ridge & Valley Province arise in mountainous parts of the landscape now mostly covered by forest.

In all three physiographic provinces described above, the major land use changes in the last half-century have been urbanization, suburbanization, and sprawl (Johnson 2001; Torrens 2006). In urban areas, many headwater riparian ecosystems have been converted to underground storm drains or obliterated entirely; those that remain are often highly degraded. The proliferation of impervious surface during urbanization is responsible for major alterations to the remaining headwater streams (Paul & Meyer 2001). In many cases, ephemeral overland flows that once fed the upper reaches of intermittent streams during storm events have been amplified by storm flows that originate from impervious surfaces in other watersheds. These urban conversions have caused increased peak flows because impervious surfaces can neither effectively detain rainfall nor contribute to groundwater recharge. Increased peak flows have led to flashier hydrographs, channel incision, headward cutting of channels, and increased sediment loads during storm run-off. Although these alterations often destabilize stream banks, they do not disrupt succession beyond the near-channel zone. However, incision and flashy hydrographs often reduce the period of soil saturation in the riparian zone, leading to a change in forest composition to species tolerant of drier conditions.

Methods

We selected 22 stream networks to represent the range of land cover and topography for the three major physiographic provinces of the study region (Wardrop et al. 2005). Within each of these networks, we randomly selected 20 stream reaches for sampling. However, an additional set of 20 random locations was identified for sampling in two of the stream networks. Randomization of sampling locations was conducted using a geographic information system (GIS) algorithm available from the Web page of Environmental Systems Research Institute (ESRI) (Eichenlaub; http://arcscripts.esri.com/details.asp?dbid=10296) and adapted by Brooks et al. (2004). The ESRI algorithm uses Avenue script to place random points along line shapefiles (e.g., USGS—National Hydrologic Data streams). The points randomly selected marked the center of 100-m-long × 100-m-wide reaches along which various attributes were measured, including BA of trees (cross-sectional area). Although the target number of sample reaches in each stream network was 20, some networks had fewer due to their small size or to other factors such as difficult or denied access.

Data Collection

In total, 467 reaches were sampled in three physiographic provinces: eight Coastal Plain stream networks, six Piedmont stream networks, and eight Ridge & Valley stream networks. The majority of reaches were sampled by a single two-person field team to help ensure data consistency, but three additional field crews sampled some of the reaches. All crews measured tree BA by species. BA of trees was either calculated from plots (about 10% of reaches) by measuring diameter at breast height (cross-sectional area of stems at 1.5 m above ground) of each tree or using an angle gauge (Bitterlich plotless method). Previous studies have shown that data from stands sampled using fixed plots and plotless methods in eastern North American forests are comparable; plotless methods, however, are more efficient (Grosenbaugh 1952; Shanks 1954; Rice & Penfound 1955; Lindsey et al. 1958; Levy & Walker 1971).

Three plots (or Bitterlich points) were placed in each stand to represent the proportion of various cover types present in the riparian zone. If the entire riparian zone was of one cover type, one plot was placed at the center point and one point on each side of the stream, one upstream and one downstream (randomly chosen). All plots and Bitterlich points occurred within a defined section of reach: Bitterlich points were placed at least 30–35 m apart to prevent overlap but still remained within the 1-ha site being sampled.

Data Analysis

Relative BA was calculated for each tree species within a stand. Because one study objective was to determine compositional differences in relation to successional status, total stand BA was partitioned into three classes (roughly equivalent to age, biomass, and three-dimensional structure): BA < 20 m^2/ha (early successional), $20 \leq$ BA < 30 m^2/ha (mid successional), and BA ≥ 30 m^2/ha (late successional). Although BA is positively related with biomass (Brinson et al. 2006), it is not a perfect surrogate for age, successional class, or structure. However, the three categories do provide a rough approximation by which to sort reaches by successional status. In using these successional categories, some dense, early successional stands might have been more mid successional in character and some dense, mid-successional stands may have been more late successional in character, but most stands with BA < 20 m^2/ha and BA > 30 m^2/ha probably represented early and late-successional stands, respectively.

Only low-order (first- to fourth-order) sites with at least two points or plots of the same successional class were used in subsequent data analyses to maintain a reasonable number of Bitterlich tallies for points (or sample area for fixed-area plots). Therefore, compositional data (BA by species) for all stands were represented by two or three points (or fixed-area plots) averaged together. Data on physiographic province, successional class, and latitude were compared with composition data and BA categories using the detrended correspondence analysis (DCA) algorithm in PC-ORD (McCune & Mefford 1999).

Results

Reaches of low-order streams and their riparian forests varied widely in age and degree of human alteration. Of 467 reaches sampled, 13 reaches had no trees. Of the 454 forested or partially forested sites, 225 met our criteria of having at least two of the three points or plots belonging to the same successional class. Six of these sites were fifth order or higher and so were deleted from further analysis. Of the remaining 219 sites, there were 109 Coastal Plain reaches, 48 Piedmont reaches, and 62 Ridge & Valley reaches. Ninety-two of these 219 reaches were classified as late successional (BA ≥ 30 m^2/ha), 45 were mid successional ($20 \leq$ BA < 30 m^2/ha), and 82 were early successional (BA < 20 m^2/ha). However, only 34 of the 92 reaches were late successional in all three points (or plots).

A DCA ordination of the study reaches (Fig. 2), based on species composition, showed a strong relationship with latitude from right to left (cutoff for joint plot arrow based on least squares regression: $r^2 = 0.525$). Stands could be separated into four distinct physiographic subregions (color coded), defined by the ordination position of late-successional stands: northern Ridge & Valley (located north of Virginia), Piedmont, Coastal Plain south of Delaware River estuary, and New Jersey Coastal Plain (located north of Delaware River estuary). Enclosures (solid and dashed) drawn on the ordination diagram delineate sites by these subregions. The enclosures separated Coastal Plain (right) and northern Ridge & Valley stands (left) in the lower half of the ordination. The southern Ridge & Valley sites had no late-successional stands on which to base an enclosure, but the early and late-successional stands, located at the top center of the ordination, separated from the northern Ridge & Valley stands. In contrast, Piedmont stands, delineated by the dashed enclosure in center of ordination, overlapped both the southern Coastal Plain and the northern Ridge & Valley stands. New Jersey Coastal Plain sites (not delimited by its own enclosure) tended to be more compositionally similar to Piedmont stands than with the other Coastal Plain stands because all its late-successional stands occurred within the enclosure delineated for Piedmont stands.

Many early and mid-successional stands occurred outside the enclosures delineating late-successional stands. Of all early and mid-successional stands, 21% ($n = 12$) of southern Coastal plain stands, 50% ($n = 14$) of Piedmont stands, and 61% ($n = 14$) of northern Ridge & Valley stands occurred outside the enclosures for the subregional type based on late-successional reference stands. Because the enclosures delineate the compositional variation of late-successional stands, the enclosures represent targets for restoration for each of the four identified physiographic subregions.

Table 1 summarizes species composition based on the mean relative BA for all late-successional stands, arranged by physiographic subregion. In other words, each column represents the mean composition of stands within the three enclosures. There were 109 species in all late-successional stands: 43 species in the southern Coastal Plain stands, 21 species in New Jersey Coastal Plain stands, 30 species in Piedmont stands, and 26 species in northern Ridge &

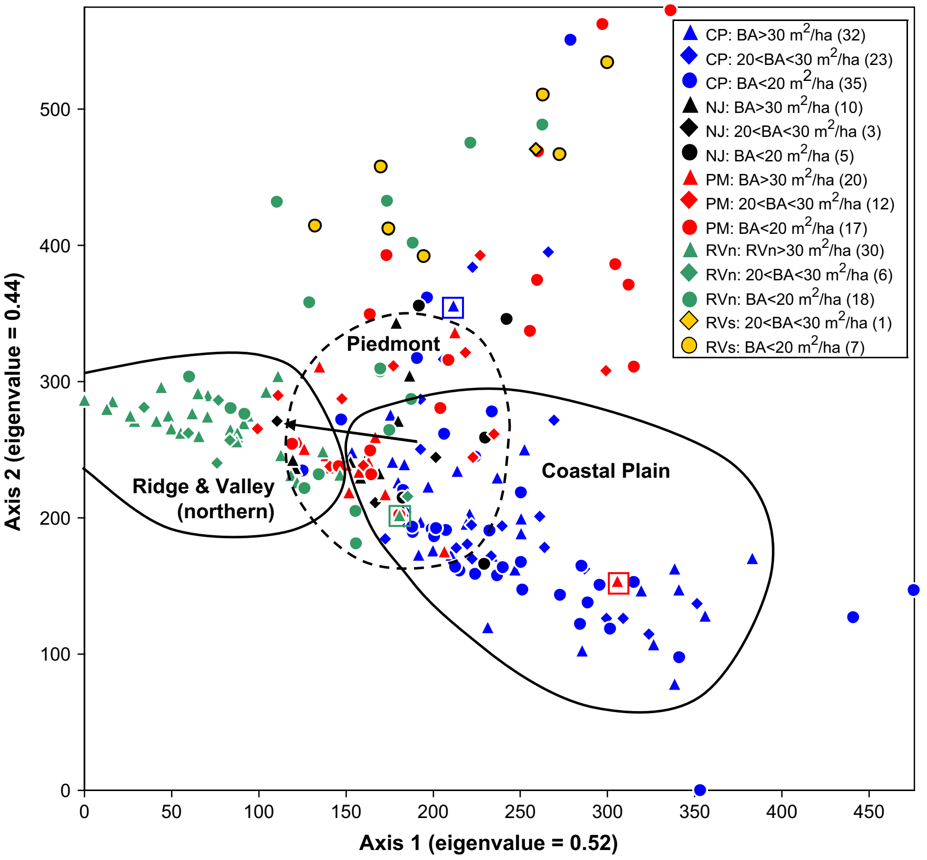

Figure 2. DCA ordination of all riparian stands, arranged by successional category based on BA (symbols) and physiographic subregion (color). Enclosures delimit distributions of late-successional stands (total BA $\geq$ 30 m^2/ha) with respect to physiographic region. New Jersey Coastal Plain stands (black) are within the Piedmont enclosure. CP, Coastal Plain south of Delaware estuary, NJ, New Jersey Coastal Plain, PM, Piedmont, RVn, Ridge & Valley (northern, i.e., north of Virginia), and RVs, Ridge & Valley (southern, i.e., south of Maryland). Parentheses in legend are number of sites sampled in each successional category.

Valley stands. None of the southern Ridge & Valley stands were late successional, and so it is not certain how closely the early and mid-successional stands might be related compositionally to Ridge & Valley late-successional stands.

Red maple (*Acer rubrum* L.) and Tulip poplar (*Liriodendron tulipifera* L.) were dominant or codominant canopy species in the riparian zone of many stands in all physiographic subregions. Sweetgum (*Liquidambar styraciflua* L.) codominated southern Coastal Plain stands, Red oak (*Quercus rubra* L.) codominated Piedmont stands, and Hemlock (*Tsuga canadensis* (L.) Carr.) codominated northern Ridge & Valley stands. A few species occurred in all physiographic subregions and occasionally codominated stands (Table 1): White oak (*Q. alba* L.), Green ash (*Fraxinus pennsylvanica* Marsh.), and Blackgum (*Nyssa sylvatica* Marsh.).

There were three late-successional stands that occurred outside their enclosures (outliers). This meant that these outlier stands were compositionally dissimilar to the other late-successional stands of their subregion. The outliers, marked with a box, belonged to southern Coastal Plain, Piedmont, and northern Ridge & Valley stands (one each). The southern Coastal Plain outlier was dominated (95% BA) by Tulip poplar, which is a common successional but long-lived species in all provinces of the study area. The Piedmont outlier was dominated by Red maple and Loblolly pine (*Pinus taeda* L.), both of which are common in southern Coastal Plain reaches. The northern Ridge & Valley outlier was dominated (100%) by Red maple, which made it compositionally align more closely with Coastal Plain reaches.

Although 13 oak species (*Quercus* spp. L.) occurred in the study area, most of these species comprised a small proportion of BA, except for Northern red oak in the northern Ridge & Valley subregion. Oak species included both upland and wetland species. However, most oak species occurred in the southern Coastal Plain subregion ($n = 9$).

Discussion

Land use in the mid-Atlantic region of eastern North America has varied over time and space, but little is known about land use changes along riparian zones of low-order streams in particular. Although ecological

Table 1. Mean relative BA of tree species in unaltered, late-successional stands (total BA $\geq$ 30 m^2/ha), arranged by physiographic subregion.

	Southern Coastal Plain	*New Jersey Coastal Plain*	*Piedmont*	*Northern Ridge & Valley*
No. of sites	32	10	20	30
Mean BA (m^2/ha)	43.5	37.1	38.5	43.5
Acer rubrum L.	22.6	35.1	17.5	20.1
Liriodendron tulipifera L.	11.9	23.9	45.3	10.3
Liquidambar styraciflua L.	17.3	0.5	2.3	—
Tsuga canadensis (L.) Carr.	—	—	—	22.0
Quercus rubra L.	1.9	8.9	4.8	10.8
Pinus strobus L.	—	—	—	8.7
Q. alba L.	3.7	0.8	6.4	6.5
Fraxinus pennsylvanica Marsh.	4.4	7.5	2.6	5.0
P. taeda L.	6.5	—	1.5	—
Nyssa biflora Walt.	4.9	—	—	—
N. sylvatica Marsh.	2.1	3.0	3.9	1.1
Q. velutina Lam.	—	3.5	0.6	—
Other *Quercus* spp.	4.7	0.3	2.7	2.5
Total BA of all other spp.	20.0	16.4	12.5	13.0
No. of other *Quercus* spp.	8	1	4	2
Total no. of tree spp.	44	21	30	26

Southern Coastal Plain refers to stands located south of the Delaware River estuary, whereas New Jersey Coastal Plain refers to stands north of the Delaware estuary. Listed species are those that were one of the top six species with highest mean relative BA within any type, except for the merged *Quercus* spp. category.

functions of riparian ecosystems have been affected by land use in their drainage basins, land use near streams often differs from the surrounding land, particularly in agricultural and urban lands. In such areas, riparian zones provide an oasis of natural forest cover. However, these oases are often directly affected by alterations, such as channelization and timber harvesting, and indirectly affected by pollution from stormwater run-off and invasion of exotic species. Because all such alterations are detrimental to water quality (chemical, physical, and biological), there is a need to understand both the condition of riparian zones and how best to restore them.

Restoring forest structure and composition is only one component of riparian ecosystem restoration. A myriad of factors may influence a successional site's composition at maturity, including intensity of prior land use, susceptibility to invasion by exotic species, seed bank composition, distance from neighboring riparian forests, and the potential of tree species in neighboring forests to disperse seeds to restoration sites. Some species such as Tulip poplar, Red maple, Sweetgum, Tupelo gums (*Nyssa* spp. L.), hickories (*Carya* spp. Nutt.), and oaks can sprout new growth from cut stumps, thus helping insure a return to precut composition. Thus, periodic cutting is a relatively low-intensity alteration, in that forests are likely to return to precut composition and structure with time if protected from another cut. Even so, recovery takes 50 or more years during which time ecosystem functioning would occur at less than its potential. In contrast, sites that have been intensively altered by mechanical land clearing, for conversion to agriculture or intensive silviculture, are less likely to return to prealtered conditions within 50 years without application of more intensive restoration efforts, including supplemental planting of heavy mast species.

Stands within the enclosures of the ordination diagram represent stands that would likely attain compositional and structural similarity to late-successional stands without intervention (assuming long-term protection), whereas stands outside the enclosures represent stands that may require some type of active management (an intensive approach) to achieve restoration of composition and other ecosystem functions. Data from randomly selected reaches in the sampled stream networks suggest that a large proportion of the forested reaches need only long-term protection or minimal intervention to reach structural and compositional conditions associated with late-successional forests. The remaining reaches, in addition to those without trees, may require more costly, intensive restoration approaches. Specific land use history of the early to mid-successional sites outside the enclosures is not known, but many of them were located in urban watersheds. Further, stands on land once cleared for agriculture are probably not well represented in this dataset because most of those lands, except for those in urbanizing watersheds, are still in agricultural production.

Although succession might be accelerated by planting shade-tolerant species in cutover stands, composition would be expected to recover over time without supplemental planting. In this sense, successional processes are a free service that occurs as ecosystems self-design; hence, applying extensive approaches over more stream length is more cost-effective than applying more intensive approaches over shorter stream length, especially if the intensive approaches include manipulating channel morphology. In contrast, we expect that succession on abandoned agricultural land would be less likely to become compositionally similar to late-successional forests in the ordination. This is because light-seeded tree species would have relatively more influence on initial recruitment than would heavy mast species, with distance to seed sources related positively to relative degree of influence. Therefore, supplemental planting of heavy mast species in riparian forests undergoing succession on former agricultural land would restore typical composition in less time than would relying solely on natural recruitment. However, in agricultural lands, other types of alterations (e.g., channelization) might have to be rectified for restoration to be effective.

Reference data from the various physiographic subregions could provide goals for restoring forest composition where supplemental planting is needed. Tulip poplar and Red maple are important in stands of low-order streams of all four identified physiographic subregions. Whereas Red maple competes well in both wetlands and mesic uplands, Tulip poplar is primarily a mesic, upland species and so is rare on floodplains. However, both species spread widely by seed and so would not have to be planted if seed sources were nearby.

Sweetgum, primarily important in southern Coastal Plain sites, also easily disperses. Like Red maple and Tulip poplar, Sweetgum would not need to be planted if there were an available seed source nearby. In contrast, Hemlock, important only in Ridge & Valley sites, would require supplemental planting if a nearby seed source were unavailable.

In contrast to the light-seeded species described above, oaks, hickories, and other heavy mast species would have a difficult time dispersing to new areas without supplemental planting. Planting heavy mast species would be particularly useful when restoring silvicultural or agricultural lands. However, each physiographic subregion would require planting a different set of species. Likewise, some heavy mast species are more appropriate for restoring upland portions of riparian zones, whereas others are more appropriate for wetland zones. In general, supplemental planting of heavy, animal-dispersed seeds is probably applicable to any forest ecosystem where such tree species are an important component of the ecosystem.

Oaks have a competitive advantage over Red maple in areas where fires are not suppressed (Shumway et al. 2001). As a result of past fire suppression and land clearing in North America since European colonization, there is evidence that oaks have declined relative to Red maple since colonial times (Lorimer 1993; Abrams 2003). In our stands, mesic oaks were of minor importance relative to Red maple in all low-order riparian stands in the study region, thus providing additional evidence for oak decline in North America following fire suppression. If oaks have indeed declined in abundance throughout the study area, then supplemental planting of appropriate native oak species in restoration projects might facilitate restoration of low-order riparian forests to a more historic composition.

Besides species composition, structural features are also important in providing habitat quality in low-order riparian forests and in maintaining or improving the quality of water entering adjacent streams. Although we did not directly measure stand age, BA seemed to be a reasonable surrogate for successional status. Chemical, physical, and biotic integrity improve with forest maturity. Late-successional forests provide structural features lacking in early to mid-successional forests, such as standing dead wood (snags) for denning and nesting (Harmon et al. 1986; Loeb 1999; Steel et al. 1999), large down wood for vertebrate and invertebrate habitat (Seastedt et al. 1989; Harmon & Hua 1991; Pyle & Brown 2002; Rubino & McCarthy 2003), litter for in-stream biota (Wallace et al. 1997), and soils high in organic matter (Harmon et al. 1986) useful as fuel for denitrifying bacteria.

Many riparian forest ecosystems on low-order streams have been altered by human activities, such as clear-cutting, conversion to agriculture, and urbanization. For animal species that rely on late-successional riparian forest corridors for habitat or for facilitating gene flow, widespread alteration of low-order riparian habitats has diminished this function. Appropriate indicators of low-order riparian condition are needed to census the condition of those resources, diagnose problems, and provide insight into solutions. With assessment tools in place, random sampling stream networks could be conducted to identify networks in most need of restoration (Rheinhardt et al. 2005) and identify where extensive approaches might be most effective.

Assessments of riparian condition from random points in stream networks, of which this study was a part (Rheinhardt et al. 2007), could also help monitor changes in low-order riparian forest resources over time. The Forest Inventory and Analysis Program under development by the USDA Forest Service is being designed to gather similar data to assess and monitor forest ecosystem condition over a wide variety of forest types (Smith 2002; McRoberts et al. 2005), but it is unclear at this point if it will be implemented at a scale appropriate for assessing low-order riparian ecosystems or their stream networks.

Forest composition and BA of forest as an indicator of riparian zone condition are only two, among several, ecosystem attributes. Channel morphology, hydrologic and fluvial processes, and nutrient and sediment dynamics are other essential components of fully functioning streams and their floodplains (Palmer et al. 2005). However, standards for stream restoration cannot be met unless the functions provided by late-successional forests are in place, especially in riparian zones of low-order streams where forest biomass and dependent processes dominate ecosystem structure and function. Data on forest composition, similar to those presented in this study, could be used to monitor the condition of low-order riparian forests and help gage the success of efforts to restore the hydrologic, habitat, and biogeochemical functions of late-successional riparian forests everywhere.

Conclusions

Riparian zones of low-order (first- to fourth-order) ecosystems are the most important interface between stream networks and upland land use because they potentially buffer about 90% of total stream network length (Rheinhardt et al. 1999, 2005). Late-successional riparian forest represents the most functionally beneficial condition of riparian buffers because it provides complex three-dimensional structure for forest-dwelling species and high-quality detritus in the form of snags and large down wood. These ecosystem components provide both habitat for a wide array of species and a source of dissolved and particulate organic matter for fueling microbially mediated nutrient transformations. Yet, most low-order riparian forests in the mid-Atlantic region are in need of restoration due to past alterations of clear-cutting and land clearing. Unfortunately, quantitative data have been lacking on the natural composition of late-successional riparian forests (restoration targets).

Quantitative vegetation data collected in this study from riparian forests over a large geographic region show that in many cases an extensive approach to restoration may be the most efficient and lowest cost option for restoring low-order riparian forests. To achieve this, riparian buffer zones could be protected to allow natural succession to proceed unhindered; that is, supplemental planting could be implemented only in cases where native oaks and other heavy mast species have not regenerated or where large-scale land clearing has been practiced.

Implications for Practice

- Late-successional stands (BA $\geq 30\ m^2/ha$) provide important habitat and biogeochemical functions of riparian zones attributed to forest structure and composition.
- The composition of late-successional stands can be used to provide restoration targets for riparian headwater forests if physiographic region is taken into account.
- Canopy composition of early successional stands can be examined to determine if supplemental planting of heavy mast species is needed for restoring compositional attributes of low-order riparian forests.

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