



An ecosystem classification approach to assessing forest change in the southern Appalachian Mountains



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ABSTRACT

Multifactor ecosystem classification systems are designed to identify similar site units across the landscape based on repeating patterns of geomorphology, soil, and vegetation. Ecosystem classification models have been developed for numerous forest landscapes in North America and elsewhere, but few studies have employed multifactor classification techniques across forest disturbance and age gradients. With its myriad of landforms and history of logging, the 17,604-ha Jocassee Gorges tract in upstate South Carolina of the southern Appalachian Mountains, USA, represents an ideal landscape to examine both spatial and temporal variability in vegetation–environment relationships. We examined a dual ecosystem and forest-age gradient, including five ecosystem types (ranging from xeric, upland *Quercus* ecosystems to moist, *Tsuga canadensis* ecosystems) and four forest-age classes (5–25, 26–50, 51–70, and >70 years old) within ecosystems. On 111 replicate 0.1-ha plots across the gradient, we sampled species composition of tree and ground-flora stratum, which we analyzed using permutation and ordination multivariate techniques. Overall differences in species composition for both strata occurred among ecosystems within all forest ages, and differentiation among ecosystems strengthened as forests aged. Age-related variation was evident within an ecosystem type for several ecosystems, but was generally weaker than variation among ecosystems. Ground flora was generally most sensitive to the age and ecosystem gradient, but the tree stratum also differed among age classes and several ecosystems. Forest composition across this landscape was filtered primarily by distribution of ecosystems serving as the physical template and secondarily by forest ages within ecosystems. Application of ecosystem classification to the full range of forest ages on the landscape also illuminated numerous considerations for forest management, such as a finding that of the three *Quercus* ecosystems on the landscape, a submesic ecosystem may be least resistant and resilient for maintaining *Quercus* dominance following logging. Results suggest that effectiveness of ecological classification systems as tools for landscape-scale management is enhanced when they include both spatial and temporal heterogeneity among ecosystem units.

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1. Introduction

Understanding forest change – both spatially across landscapes and through time – is a fundamental goal in forest ecology and management. Forest composition on landscapes reflects both spatial influences (e.g., distribution of soil parent materials, topography) and temporal influences from different-aged forests developing under disturbance regimes (McCune and Allen, 1985). There is great potential for interaction between spatial and temporal influences, demonstrated if post-disturbance changes in species composition are ‘filtered’ by environmental influences (Kirkman et al., 2000). This

interaction manifests in different parts of the landscape displaying unique patterns of forest change and in composition of any given forest age class differing among locations (Elliott et al., 1997). On the other hand, there are examples where disturbance, or lack thereof, can change vegetation to converge towards similar composition among environmental sites (Palik and Pregitzer, 1992). Studies that simultaneously examine both spatial and forest-age gradients are uncommon compared to studies examining only one gradient, suggesting research potential for ‘coupling’ these gradients for advancing our understanding of the mosaic of forest compositions within forest landscapes (Prach and Řehouňková, 2006; Taylor and Chen, 2011).

By offering a biophysical template, ecosystem classification systems would seem to have potential for coupling spatial and

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temporal influences on forest composition within landscapes. Developing an ecosystem classification can be conceived as overlaying climate, landform (e.g., slope aspect), soil (e.g., parent material, texture), and old-age vegetation layers to identify repeating combinations of these layers across landscapes (Barnes et al., 1998). Ecosystem classification uses the operational definition of Tansley (1935) by defining an ecosystem as the unique combination of organisms and the physical components (e.g., soil, geomorphology) that are present. A given ecosystem type represents a collection of sites characterized by similar combinations of these elements, and landscapes consist of mosaics of ecosystems (Palik et al., 2000). Like single-factor classifications such as soil or vegetation maps, multifactor ecosystem classifications are tools for anthropogenic study and management of heterogeneous landscapes and reflect biophysical factors (e.g., soil texture) influencing forest development (Roberts and Christensen, 1988). Physical factors such as soil parent material as the foundation of ecosystem classification are generally stable compared to vegetation, the most ephemeral component (Host et al., 1987). As a result, ecosystem classification is a potential tool for examining a range of forests that may occupy combinations of physical site factors across landscapes (Goebel and Hix, 1997).

Several possibilities for forest development could arise following disturbance across the biophysical template of landscapes. After disturbance on a portion of the landscape, for instance, there could be an initial colonizing species composition that is similar across ecosystems. If ecosystem type is a 'filter', this colonizing species composition could then differentiate among ecosystems as forests age (Bergeron and Dubuc, 1989). The differentiated species composition may or may not resemble pre-disturbance composition, but regardless, forest composition would differ among ecosystems as forests age (Fralish, 1988). Alternatively, the initial colonizing species composition might persist (i.e. not differentiate among ecosystems), potentially resulting in 'homogenization' which can occur if developmental conditions (e.g., fire regimes) of the pre-disturbance vegetation sharply differ from developmental conditions of the post-disturbance ecosystems (Palik and Pregitzer, 1992). As an example of another possibility, the initial colonizing species composition might differ among ecosystems and remain distinguished as forests age (Halpern, 1988). Within an ecosystem, composition in developing forests may or may not resemble that of old forests occupying that ecosystem (Drury and Runkle, 2006). A conception of these possibilities is that plant assemblages are transient 'occupants' of the physical landscape, and understanding which 'occupant' has developed where and when can help reveal spatial and temporal forest development patterns.

Identifying these patterns of forest development could result in several implications for forest management. For example, a certain species composition of old-age forests might provide particular functions that meet management goals. By providing mast for wildlife and hardwood lumber, *Quercus* forests might be one example. If young forests are not displaying development trajectories to management-priority forests such as *Quercus* forests, then this early knowledge might help enact management strategies while the young forests are most 'impressionable'. For example, management using prescribed fire often is most effective for influencing forest composition in young forests when stems of fire-intolerant species are readily killed by fire, as opposed to in older forests when only high-intensity fire might kill these stems (Brose et al., 2013). Moreover, an ecosystem classification framework might help identify which ecosystems of young forests already have greatest quantities of desired species and might most readily respond to management intervention to help shape forest development (Goebel and Hix, 1997).

We applied a landscape ecosystem framework for evaluating spatial and forest-age gradients on a forest landscape containing a

mosaic of ecosystems each in turn supporting a range of different-aged forests developing after timber harvest. We asked: how does forest composition differ among forest age classes within an ecosystem, and how does forest composition differ among ecosystems within forest age classes? We addressed these questions as testable predictions that: (1) all age classes within an ecosystem differ in species composition, and (2) differentiation of species composition among ecosystems is stronger in older forests. Evidence supporting the first prediction could include that variation in species composition among age classes within an ecosystem is greater than that expected by chance. Evidence consistent with the second prediction could include that forest composition is more similar among ecosystems in young forests than it is in older forests. Our study included 111 sites within a southern Appalachian landscape containing vegetation such as *Quercus* forests occupying much of eastern North America, and the approach of 'coupling' spatial and temporal gradients in an ecosystem framework might be transferable elsewhere for understanding forest development.

2. Methods

2.1. Study area

Jocassee Gorges encompasses 17,604 ha within northern Oconee and Pickens counties in northwestern South Carolina along the South and North Carolina border, in the southeastern USA (Fig. 1). The tract occupies the Blue Ridge escarpment region – an abrupt transition between the lower-elevation Piedmont physiographic province and the higher-elevation Blue Ridge Mountain physiographic province which is part of the southern Appalachian Mountains (Mowbray and Oosting, 1968). Here, the escarpment forms a prominent south-facing embankment characterized by heavily dissected, steep terrain with elevations ranging from ~300 to 1100 m and localized stream-to-ridgetop elevation differences approximating 150–300 m. Climatic means are likely in between two nearby weather stations: (1) Lake Toxaway, NC, 15 km north of the study area, with the following means: 230 cm/yr of precipitation (including 29 cm of snow), -4°C January daily minimum, and 26°C July daily maximum (940 m in elevation, 1950–2012 records); and (2) Salem, SC, 15 km southwest of the study area, with the following means: 166 cm/yr of precipitation (including 7 cm of snow), -3°C January daily minimum, and 31°C July daily maximum (300 m in elevation, 1952–2005 records; Southeast Regional Climate Center, Chapel Hill, NC). Predominant soil parent material in the study area consists of igneous and metamorphic rocks of late Precambrian or early Paleozoic age, such as biotite gneiss, granite, and mica schist (Mowbray and Oosting, 1968). Major soil taxa include Typic or Humic Hapludults and Typic Dystrichrepts, all of which are acidic throughout the profile ($\text{pH} < 5.5$) and have sandy loam or sandy clay loam textures (Abella et al., 2003). Jocassee Gorges is within the southern extreme of Braun's Oak-Chestnut Forest Region (Braun, 1950) and Bailey's Blue Ridge Province Level III Ecoregion and the Southern Crystalline Ridges and Mountains Level IV Ecoregion (Griffith et al., 2002). Upland forest overstories are dominated by *Quercus* spp., while stream ravines and moist hillslopes support *Tsuga canadensis* and numerous deciduous species (Abella and Shelburne, 2004). Ericaceous species such as *Kalmia latifolia*, *Rhododendron* spp., and *Vaccinium pallidum* dominate subcanopy and shrub strata in many dry, upland forests, while *Leucothoe fontanesiana* and *Rhododendron maximum* inhabit moister sites.

2.2. Stand selection and plot establishment

We selected stands for sampling across a two-way ecosystem and forest age gradient (Fig. 2). Previous research developed an

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