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Historical erosion and sedimentation in two small watersheds of the southern Blue Ridge Mountains, North Carolina, USA

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ABSTRACT

Sediment bodies produced during historical periods of human land use, sometimes referred to as legacy sediment, may be found in various locations within drainage basins, and potentially remobilized by hydrogeomorphic processes accompanying land use change. The amounts and locations of stored legacy sediment can be significant factors in modern drainage basin function and should be accounted for when possible. In this study, late nineteenth-century erosion and sediment storage were investigated and used to construct approximate sediment budgets for two small Blue Ridge Mountain drainage basins in North Carolina (USA). Erosion was quantified using a distributed implementation of the Universal Soil Loss Equation (USLE), and calibrated on the separate bases of soil profile truncation data and recent published rates for long-term erosion in the region. Sediment yield information was reconstructed from pond sediments trapped behind a mill dam. Alluvial sediment storage was quantified using field studies of streambank and floodplain sediment profiles and digital elevation data. Colluvial storage was calculated as a residual in the sediment budget, and further evaluated using soil profile studies of footslope deposits, and soil survey maps. The proportions of erosion accounted for by the different budget terms in the most reliable budget are: 28% sediment yield (i.e., a sediment delivery ratio of 0.28), 69% colluvial storage, and 3% alluvial storage. Blue Ridge basins with low levels of ground disturbance erode like Piedmont basins at high levels of ground disturbance, primarily due to higher slope angles. Sediment delivery ratio is high relative to those given for much larger basins in the adjacent and more frequently studied Piedmont province, and generally in accordance with published sediment delivery curves that reflect higher hydrogeomorphic connectivities within smaller basins. Low values for alluvial storage in Blue Ridge basins may be explained by high sediment transport within steep channels. Colluvial storage values have high uncertainties because of the well known problem of error accumulation in residual budget terms. Field data on colluvial deposits reported here are not sufficient to correct for this problem, and in general, the acquisition of accurate field data on historical colluviation remains an important methodological issue in historical sediment budgeting.

1. Introduction

Effective land management decisions require a thorough knowledge of how different land uses affect earth surface processes and landforms. However, earth surface responses to contemporaneous land use are not always easy to generalize. The geomorphological state of any location is variably conditioned by earlier environmental regimes or events whose current effects may be conspicuous or subtle, and dependent on original impact magnitudes, intrasystem connectivity, relaxation time, and other variables (Fryirs et al., 2007; Phillips, 2009, 2013; Brierley, 2010; James, 2013). In many places, historical land disturbance resulting from human activities represents a major or even dominant antecedent condition for modern landscape function (Wohl, 2015). One example is the profound effect that nineteenth-century Euro-American agricultural land use had on fluvial sedimentation and landforms across large areas of the eastern and midwestern U.S. (Trimble, 1974, 1983, 1999; Knox, 1977, 1987). That many of these past processes continue today to significantly influence modern fluvial systems indicates their status as "legacy effects" (Bain et al., 2012). Due to the discontinuous nature of sediment movement, reactivation of sediment storage bodies in particular represents an important means of extending the effects of prior land uses over substantial time intervals.

The future propagation of land use legacy effects on sediment dynamics in fluvial systems remains the subject of study and debate. Remobilization of stored legacy sediment could be accelerated by new land development that changes water flow amounts and/or pathways in watersheds. Thus, assessments of modern human impacts on stream erosion and sedimentation should ideally account for the prior history

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of upland erosion and sedimentation going back from decades to a century or more (Jackson et al., 2005; Verstraeten et al., 2009; Bain et al., 2012; James and Lecce, 2013; Wohl, 2015).

Such information is unavailable in many instances, and may not always be confidently extrapolated from areas where it does exist. In the eastern U.S., it is unknown to what extent prior studies of the southern Piedmont may be applicable to adjacent areas of the Coastal Plain and southern Appalachian Mountains, where physiographic conditions are very different, and the state of knowledge regarding historical erosion and sedimentation is less advanced. Particularly within the mountains, few studies detailing sediment budgets and legacy sediment have been conducted, and most research has focused on sediment yields and not the delivery or storage of eroded soil at particular locations in watersheds (Taylor and Kite, 2006). Understanding the locations and sizes of these historical sediment bodies is of importance because these factor in to specifying the conditions under which legacy sediments are likely to be remobilized. Furthermore, previous sediment budgeting in the Appalachians has primarily focused on forested ecosystems, or those impacted only by forestry practices. Yet some areas in the southern Appalachians, along both gentle valley bottoms and on surprisingly steep valley walls, were planted in row crops after logging, without erosion controls. Such areas might be of particular importance to considerations of legacy sediment impacts in this now rapidly developing region.

In this study we analyze nineteenth-century erosion and sedimentation histories for two small watersheds in the Blue Ridge Mountains, part of the southern Appalachian chain, in North Carolina. Our goals are 1.) to determine how nineteenth-century land use affected contemporaneous sediment budgets and the production of persistent legacy sediment deposits, and 2.) to ascertain the differences between Blue Ridge historical sediment budgets and those from the adjacent Piedmont province, as well as other well-studied sites in the U.S. The broader purpose is to provide an historical perspective on watershed change that will increase the likelihood of successful management of fluvial systems in the Appalachian Mountains and similar forested steepland settings.

2. Background

Within the southern Piedmont physiographic province, late-19th and early-20th century agricultural erosion removed up to 0.25 m of soil across large expanses of the uplands (Trimble, 1974). A substantial proportion of this material moved into river channels producing one or more sediment waves and causing channel bed aggradation and extensive overbank sedimentation onto floodplains (Trimble, 1974; Jacobson and Coleman, 1986; James, 2006; James, 2013). On many smaller (~3rd-order) streams, much sediment was trapped behind mill dams which have since collapsed (Walter and Merritts, 2008). Fluvial erosion has been evacuating these legacy deposits, shifting sediment downstream, and leaving behind high channel banks as terraces capped with historical alluvium (James and Lecce, 2013; James, 2013; Royall, 2013). The sediment comprising these terraces is reworked into channels by incremental fluvial scour and mass wasting of banks, but may be stored in these often expansive landforms for long periods (Jackson et al., 2005; James, 2013). Legacy sediment inputs can elevate watershed sediment yields decades to centuries or longer, following their initial emplacement atop older floodplain surfaces (Phillips, 1991; Meals et al., 2010; Kennedy, 2013; Brierley, 2010).

The notion of the aggradation-degradation episode (James and Lecce, 2013), here described for the southern Piedmont, should be generally applicable to a wide range of humid-climate environments, including the adjacent Blue Ridge Mountains, where locally, highly erosive historical land uses have given way to reestablishment of vegetation cover, limiting new sediment production. Indeed, Leigh (2010) and Rogers and Leigh (2013) have recently documented the occurrence of well-developed historical sediment terraces in parts of the southwestern Blue Ridge. The details of sediment dynamics including the pathways, types, and rates of sediment movement, as well as exact quantities and locations of sources and sinks are also important for effective and spatially explicit environmental management. A full knowledge of the conditions leading to the emplacement of legacy sediment bodies would include the spatial and temporal distribution and severity of erosion, the amounts of eroded material delivered to stream channels and various upland storage sites in watersheds, and the amount of sediment exported from the system. Linked together within the drainage basin process context, these phenomena collectively constitute a sediment budget (Dietrich and Dunne, 1978, Trimble, 1983, 1999; Taylor and Kite, 2006). For any given land surface area, the sediment budget can be expressed as: sediment input minus sediment output equals change in sediment storage.

Constructing a detailed sediment budget for even a small watershed is usually difficult and time-consuming, and thus also costly; as a result it is infrequently done. However, even a partial sediment budget can be informative and useful in land and water-resource management. Sediment budgeting is typically accomplished using direct observations and measurements often over a short period of time, as dictated by financial costs and the often immediate needs prompting the work. Reconstructing historical sediment budgets adds a further level of difficulty because it poses a different methodological problem: being unable to directly monitor historical processes (Bain et al., 2012). Fortunately, bodies of legacy sediment themselves preserve at least a partial record of past sediment budgets, and the method becomes one of characterizing the deposits in time and space, and filling in the gaps using theory, modeling, and quasi-ergodic reasoning from prior studies in similar environments. Recent advances in erosion and sedimentation modeling, particularly in the incorporation of transport capacity submodels to determine the balance of erosion and deposition at a point, have enhanced the potential for reconstructing historical sediment budgets under some circumstances (Van Rompaey et al., 2001; Verstraeten et al., 2007; DeMoor and Verstraeten, 2008; Mitasova et al., 2013a, 2013b). Although the data requirements for calibrating and using such models may be high, more physically-based modeling potentially allows greater differentiation of internal dynamics and thus offers greater explanatory and predictive power.

Obtaining an account of the historical sediment dynamics and legacy sediment storage in Blue Ridge Mountain drainage basins is the subject of this research. The Blue Ridge adjoins the better-studied southern Piedmont province to the southeast, and has a parallel, if slightly lagged, history of European settlement, although at a lower population density. The province differs fundamentally from the Piedmont in having steeper average hillslope and stream gradients, often stonier soils with less clay, more limited terrain suitable for row-crop agriculture, and a more intact forest cover, both currently and historically. Over the last several decades, changing economies, construction of highways, and natural growth have combined to increase population in these mountain areas, and, along with redistribution of existing population closer to urban centers, continue to drive land development (Price and Leigh, 2006). Thus, new land uses and geomorphic processes are being applied to landscapes already altered by earlier and different nineteenth century land uses, to a largely unknown extent. These changes could influence the reworking of legacy sediments and have sedimentation effects out of proportion to what might be expected from new land use alone. Providing a basin-scale sediment budgeting context for these sedimentation dynamics would allow the determination of process linkages critical to wise land use decisions.

Our analysis of historical erosion and sedimentation effects and approximate sediment budgets for two small Blue Ridge watersheds relies on existing historical sediment yield data, erosion modeling, the mapping and quantification of historical valley alluvium, and observations of soil profiles. Although the study watersheds are smaller than those for which most existing Piedmont data have been derived, small drainages represent the first line of impact by new development in these mountain areas where, outside of floodplains, gently sloping land is in limited supply.