Human Agency, Holocene Sea Level, and Floodplain Accretion in Coastal Plain Rivers

Jonathan Phillips

Tobacco Road Research Team
Department of Geography
East Carolina University
Greenville, NC 27858, U.S.A.

ABSTRACT


The lower reaches of many rivers are subject to two distinct phenomena driving aggradation: Holocene sea level rise and culturally-accelerated erosion and sedimentation. It is critical to both geoscientists and resource managers to distinguish between the effects of these phenomena, but in many situations it is difficult to distinguish between historic alluvium associated with accelerated erosion, and other Holocene fill. In the Croatan area of eastern North Carolina, there are at least five field indicators which may allow one to distinguish historic from other Holocene floodplain sediments: Development of soil B-horizons, pedological and mineralogical indicators of a Piedmont sediment source, oxidized layers, dendrogeomorphic indicators, and burial of historic features. Examination of eight stream reaches showed evidence that the surficial alluvium (>1 m or more) is historic in seven cases. Burial of historic features in the Croatan suggests mean floodplain accretion rates of 3 to 9 mm yr⁻¹ and mass additions of 45 to 92 t ha⁻¹ yr⁻¹. Prehistoric mineral sedimentation rates; estimated from sediment budget considerations based on contemporary erosion and sediment transport in forested basins, were about 0.05 mm yr⁻¹ (0.65 t ha⁻¹ yr⁻¹). Maximum organic accumulation rates are no more than 0.3 mm yr⁻¹ (1.05 t ha⁻¹ yr⁻¹). Thus, in the Croatan, human agency has accelerated alluvial sedimentation rates by at least a hundredfold. The human-accelerated accretion is largely confined to the lower fluvial reaches of Croatan streams. In the fluvial-estuarine transition zone, organic-dominated infilling has been little affected on a large scale by human agency. So much upland sediment is stored in alluvial floodplains that the geomorphic impacts of accelerated erosion on estuaries has been minimal.

ADDITIONAL INDEX WORDS: Floodplain sediments, accelerated erosion, estuary, historic alluvium, Atlantic Coastal Plain, fluvial-estuarine transition zone.

INTRODUCTION

The lower reaches of many rivers are aggrading. These valleys are often subject to two distinct influences. First, Holocene sea level rise has been driving alluvial filling and swamp formation. Second, accelerated upland erosion associated with widespread land clearing has been supplying increased sediment loads in recent centuries. Both geomorphologists and sedimentologists studying floodplain evolution and river response to base level change, and resource managers concerned with impacts of sea level rise on rivers and wetlands need to know to what extent the upstream (accelerated erosion) and downstream (sea level) effects account for observed aggradation. This study will address this question in the Croatan area of eastern North Carolina.

The Croatan area has undergone extensive environmental change due to human agency in the past 300 years. Geomorphic change has been considerable despite the fact that the lower coastal plain is geologically stable, lacks steep slopes, has soils which are not particularly vulnerable to accelerated erosion (DANIELS et al., 1971; 1978; MARKEWICH et al., 1990) and has a humid subtropical climate which has relatively low seasonal contrasts compared to most other climates.

The recent geomorphic change, while extensive, is subtle. There are no eroded badlands, buried fencelines, denuded hillsides, or the like. The historic changes are often difficult to distinguish from other Holocene trends which operate independently of human agency and predate the extensive impacts associated with European colonization. With respect to alluvial sedimentation, streams were aggrading due to Holocene sea level rise before the first European arrived, so there is only rarely a stable, pre-European surface with a recognizable soil or other stratigraphic clues underlying historic sediments. This paper is concerned with recent aggradation in alluvial floodplains of the Croatan, with the goal of answering two questions: How can historic (post-European settlement) alluvium be distinguished from other geologically recent fill? How do historic sedimentation rates compare to prehistoric Holocene rates? By answering these questions, one can make some inferences about the relative importance of sea level and human agency as controls over sedimentation in lower river reaches, upper estuaries, and fluvial-estuarine transition zones. Because both relative sea level rise or coastal submergence and culturally-accelerated floodplain accretion are both widespread phenomena, the results should be relevant beyond the Croatan area and the southeastern U.S. coastal plain.

The problem of recognizing historic alluvium (i.e., distin-
Geomorph ic Change in Coastal Rivers

Figure 1. The Croatan Area of the lower coastal plain of North Carolina, showing some of the key features referred to in the text.

guishing it from other Holocene fill) is addressed first. Five field indicators useful in eastern North Carolina are identified. These are then applied in a reconnaissance study of eight stream reaches to gain a general appreciation of the extent of historic alluvium in the study area. Historic sedimentation rates are estimated based on the burial of historic features at six locations. These historic rates are then compared to prehistoric alluvial deposition rates; the latter estimated from sediment budget considerations.

STUDY AREA

The Croatan area (Figure 1) of the lower coastal plain of eastern North Carolina includes a mosaic of the Croatan National Forest and private land. The area was explored by Europeans from the late 16th century, and the first European settlements were established in the early 1700’s. There was already a long history of human occupation by native Americans throughout the North Carolina coastal plain, dating to the beginning of the Holocene (PHELPS, 1983), and these cultures had significant impacts on the the landscape. However, the pre-European anthropic impacts were minor compared to those after 1700, when human agency intensified dramatically (PHELPS, 1983, p. 5).

Vegetation change is considered elsewhere (FROST, 1995; PHILLIPS, 1994), but geomorphic changes are largely a response to forest change, due to the direct and indirect geomorphic impacts of vegetation alterations. Europeans cut trees for lumber and fuel, and cleared land for settlements and roadways. The main purpose, however, was for agriculture. Colonial agriculture was a form of swidden, where fields were farmed intensively until yields declined, and then abandoned (CATHLEY, 1956; MEINIG, 1986).

In less than a century, though much of the region was still forested, the forest bore little resemblance to that which existed before 1700 (MERRENS, 1964). The loblolly pine (Pinus taeda) originally occurred in the undisturbed forest on the margins of and ridges within swamps, and as an occasional invader of unshaded gaps or patches in hardwood-dominated forests (ASHE, 1894). This tree, however, is a ubiquitous invader of eroded, degraded, and abandoned land. Before the advent of pulp-producing tree farms in recent decades, loblolly dominance over extensive areas was indicative of cut-over and abandoned land. RUFFIN’s (1861) observations in 1840–60 indicate extensive stands of loblolly pine on “exhausted and abandoned soils,” but not in original or remaining relatively uncut forests (262). From just above the fall line (the inland boundary of the coastal plain physiographic province) to the coast, loblolly covered “almost every exhausted and abandoned space” regardless of soil, drainage, or other factors (RUFFIN, 1861, p.263). Pinchot and Ashe commented extensively in 1897 on vegetation modifications and changes in forest composition in the preceding two centuries, noting
that the influence of humans in changing and modifying the landscape of eastern North Carolina “in the 200 years that have followed (European settlement) has been enormous” (Penchot and Ashe, 1897).

An 1894 survey of timber resources contains evidence of forest change specific to the Croatian area, which includes portions of Carteret, Craven, and Jones Counties. By 1893, Carteret County had “scarcely any cypress” worth cutting. There were already about 30,000 acres (12,150 ha) of second-growth loblolly pine, and more than half of that had been lumbered. There were 20 million board-feet (61 million board-meters) of longleaf pine (Pinus palustris) in abandoned orchards where the trees had been cut and tapped to produce naval stores. Craven had experienced extensive lumbering for more than 50 years, and any large tracts of never-cut forest were second-growth loblolly pine. Supplies of cypress and ash in river swamps were exhausted. In Jones, cypress along the Trent River was largely removed. Most of Jones County, especially in the eastern part, was largely cut over loblolly forest (Ashe, 1894).

The legacy of vegetation change, where little of the original forests were ultimately untouched, and where even the “second forest” was heavily exploited by a century ago, shows that extensive human impacts on the landscape commenced approximately 300 years ago, and had affected the overwhelming majority of the study area by 100 years ago.

Geomorphic Setting

The Atlantic Coastal Plain is composed of mainly unconglomerated coastal, marine, and fluvial sediments of late Cretaceous to Holocene age. These are less than a meter thick at the inland edge to more than 18 m thick near the coast, and unconformably overlie older Cenozoic and Mesozoic strata. The inland edge of each of the stair-step sequence of marine terraces is terminated by a paleoshoreline representing a highstand of sea level, in some places recognizable as a scarp or beach ridge. There are six generally recognized terraces in North Carolina, oriented roughly parallel to the modern coast. Inland from the coast, they are progressively older, higher, and more dissected. Over geologic time scales the upland interfluves are quite stable (Markewich et al., 1990; Daniels et al., 1971).

Evolution of the terrace system has been attributed to global eustatic changes in sea level, isostatic adjustments, and tectonics. Quaternary evidence points to sea level changes as the dominant control. Higher sea levels during warmer interglacial climates allowed ocean encroachment and deposition of coastal and marine sediments. Falling sea levels caused entrenchment of streams and eolian dissection of coastal plain deposits. Simple transgressive or regressive sedimentary sequences are rare in North Carolina, however, as each tends to be truncated and overprinted by the other (Cronin et al., 1984; Soller and Mills, 1991; Riggs et al., 1992).

Terminology for the terrace surfaces varies, and I use the nomenclature of Daniels et al. (1978). The Lower Coastal Plain east of the Surry Scarp (a paleoshoreline) includes the Wicomico, Talbot, and Pamlico Terraces, and is less than 29 m in elevation. The Croatian area lies entirely on the Lower Coastal Plain and mostly on the Talbot Terrace, with the southern- and eastern-most portions on the Pamlico surface. The Talbot is Late Pleistocene, with a minimum age of about 145,000 years and maximum of about 220 Ka. Uranium-series dates of fossil corals in the Planner Beach formation underlying the Talbot terrace in the Croatian area show ages of 202 to 230 Ka (McCARTAN et al., 1982; Szabo, 1985). Surface elevations on uplands are 6 to 14 m.

The Suffolk Scarp separates the Pamlico and Talbot terraces. The scarp is prominent north of the Neuse River estuary, and in portions of the study area south of U.S. highway 70. In the latter location this paleoshoreline is known as the Newport Barrier (Minson and Pilkey, 1976). The Pamlico Terrace, entirely ~ 6 m above sea level, is late Pleistocene to Holocene, with a maximum age of ~ 115,000 years, and in the vicinity of the study area is younger. A sand sample from the Newport Barrier was dated using thermoluminescence (TL) lab no. W1816, Department of Geography, University of Wollongong, Australia; E.A. Bryant). The date of 77 ± 8.8 ka suggests that the barrier formed near the end of the last interglacial, and that the Pamlico terrace in and east of the Croatian area is less than 77,000 years old.

Pocosins

Much of the broad upland interfluve within the Croatian is occupied by pocosins. These are shrub bog wetlands with peat no more than 3 m, and generally < 2.75 m, thick. The peats unconformably overlie pre-Holocene mineral soils. As radio-carbon dates for basal peat in pocosins throughout North Carolina cluster around 10,000 years BP, they are generally agreed to be Holocene features associated with the rise in sea level following the Wisconsin Glaciation about 16,000 years ago (Whitehead, 1972; Daniels et al., 1977; Daniel, 1981; Otte, 1987). In the blocked drainages shallow water bodies developed, and organic debris began accumulating, but the specific cause of the impeded drainage is debatable. Daniel (1981) and others presume that Holocene sea level rise is responsible for the lack of drainage in these interfluves, but 10 to 12 Ka sea level was approximately 25 m below the present level, and the shoreline well out on the current continental shelf. This, plus the absence of extensive pocosins outside North Carolina, undermine eustasy alone as the driving force (Otte, 1987). Daniels et al. (1977) argue that low drainage density is sufficient to create the impeded drainage necessary to facilitate peat accumulation. Brinson (1991) suggests that North Carolina pocosins may have begun as smaller mires in depressions, or in blocked drainage systems that developed between about 200 Ka and the onset of peat accumulation. The latter suggestions, however, do not explain the absence of similar peat landforms in Pleistocene drainage ways elsewhere.

RECOGNIZING HISTORIC ALLUVIUM

The Fate of Historic Sediment

Accelerated erosion during historic times has produced a considerable amount of sediment (Phillips, 1983, 1995;
PHILLIPS et al., 1993; COOPER et al., 1987; WYRICK and JACKSON, 1996). Though some of the erosion has likely been aeolian, which may simply redistribute soil within field systems, most of it has been water erosion. The material thus mobilized can be stored as colluvium, stored as alluvium, or delivered to the Neuse/Trent River, Newport River, Bogue Sound, or White Oak River estuarine systems.

Previous work suggests historic and contemporary alluvial storage rates on the order of a few mm of vertical accretion per year. A sediment budget for the North Carolina coastal plain, based on a variety of data sources, suggests that, as a gross spatial and temporal average, in the historic era upland erosion has supplied just over 1.2 t ha \(^{-1}\) yr \(^{-1}\) of sediment to streams (PHILLIPS, 1995), with minuscule amounts delivered to estuaries (see below). The regional estimate suggests alluvial sediment storage of 1.2 t yr \(^{-1}\) per hectare of upland contributing area if this were spread uniformly over the current alluvial floodplain surface area in the region, it would constitute a mean deposition rate of 0.39 t ha \(^{-1}\) yr \(^{-1}\), and implies an average recent accretion rate of 2.8 mm yr \(^{-1}\). SIMMONS (1988) used suspended sediment transport data and cross-valley surveys to estimate a mean alluvial deposition rate of 4.3 mm yr \(^{-1}\) for a coastal plain reach of the Neuse River. The Chowan soil series (Thapto-his tic Fluvaquent) also provides some indication of historic, culturally-accelerated floodplain accretion in the lower coastal plain. This soil is mapped along the fluvial-estuarine transition zone of coastal plain rivers, and consists of 40 to 100 cm of mineral sediment overlying a buried swamp sapric organic soil (muck). Because the mineral sediment has a higher pH than is typical for the region, soil mappers have interpreted the Chowan series as a sapric organic muck similar to the Dorovian series buried by soil eroded from nearby limed croplands (National Soils Database 1992). The spatial juxtaposition of Chowan mapping units and nearby cropland supports this interpretation. (PHILLIPS, 1992a). The mean thickness of the mineral layer is 69 cm. If the interpretation is correct, the sedimentation could have commenced no earlier than 1700, and could have occurred over as little as a century. This implies mean accretion rates of 2.4 to 6.8 mm yr \(^{-1}\).

Sediment delivery to estuaries is not well known in North Carolina, but is clearly low. The only reliable direct measurements of sediment yield at a river mouth or estuary head are Kim's (1990) data for the Neuse River, which indicate a delivery rate for the Neuse basin of 0.03 to 0.06 t ha \(^{-1}\) yr \(^{-1}\). Well upstream, typical sediment yields in the coastal plain are on the order of 0.2 to 0.4 t ha \(^{-1}\) yr \(^{-1}\), and even in channelized streams are no more than about 0.6 t ha \(^{-1}\) yr \(^{-1}\) (SIMMONS, 1988). The Neuse and other nearby river systems have all been shown to have very low sediment delivery ratios (sediment yield divided by upland erosion) and/or low rates of fluvial sediment delivery to estuaries or lower river reaches (PHILLIPS, 1991a,b; 1992a,b; SIMMONS, 1988; CLEARY, 1971), implying high rates of colluvial and alluvial storage upstream. Studies of sediment provenance in North Carolina estuaries, including the Neuse, have also revealed a dominance of local, coastal, sediment sources, and limited inland input from river systems (WELLS and KIM, 1989; BENNINGER and WELLS, 1993; NELSON, 1973).

Aggradation and Sea-Level Rise

The Quaternary history of the North Carolina Coastal Plain is dominated by regressive and transgressive episodes of sea level, each overprinting the other to produce a complex stratigraphic record (RIGGS et al., 1992). During regression rivers generally downcut, and previous alluvial fills are partially removed and reworked. Rising sea level induces aggradation, leaving thick alluvial fills in lower river valleys. The alluvial sequences are associated only with rising or stable sea levels, and are common components of estuarine facies sequences and coastal stratigraphic records (CONGNIAN, 1993; NICHOLS et al., 1991). Holocene alluvial aggradation in lower river reaches has been found in the stratigraphic record in eastern North Carolina and adjacent areas (RIGGS et al., 1992; NICHOLS et al., 1991; FOURNET, 1990; ERLICH 1980; COLQUHOUN et al., 1991), and has been demonstrated experimentally (Koss et al., 1994).

In stratigraphic sequences, typical fluvial/alluvial sequences have channel and point bar deposits at the base, overlain by finer-grained overbank floodplain deposits. At the surface of the alluvial sequence is peat, muck, or organic-rich muds. The latter are deposited in environments similar to those in the contemporary fluvial-estuarine transition zone (FETZ). The FETZ begins at the upstream limit of tidal influence (in the case of the Croatan area and the Pamlico-Albemarle area of which it is a part, wind tides are dominant and current tides are small). It extends to the head of the estuary, where estuarine circulation and water level changes are always dominant over river flows. Alluvial fills in the FETZ in eastern North Carolina are mainly mucks, indicating both relatively rapid organic accumulation and low inputs of fluvial sediment. DANIELS et al. (1984) interpreted the Horovian muck soil series, quite common in this setting, as diagnostic of a river valley being drowned by sea level rise. PHILLIPS (1992a) concurred, finding that Dorovan and similar soils are not found outside the FETZ in North Carolina and that their upstream limits are well-defined and consistent between river valleys.

Apparently, little fluvial sediment, despite accelerated historic erosion, is reaching estuaries, and that most alluvial storage is upstream of the FETZ (PHILLIPS, 1992a,b). This is consistent with studies suggesting a predominance of local and nonfluvial sediment sources in the estuaries (BENNINGER and WELLS, 1993; WELLS and KIM, 1989), and further suggests that the estuaries, FETZ, and lower river reaches upstream of the FETZ are responding quite differently to the interplay of increased upstream sediment loads and sea level encroachment.

Because there has been recent sea level-driven aggradation in the lower coastal plain, prehistoric alluvium has seldom been in place (or stable) long enough for soils to develop, and historic aggradation continues an ongoing trend, as opposed to reversing valley degradation or interrupting a hiatus. This leads to the problem of how to recognize historic alluvium when there is no apparent stratigraphic marker (such as a buried soil) at its base, and no apparent contrast in the nature of the pre- and post-historic deposits. Here "historic" refers to sediment associated with post-European accelerated
erosion. Prehistoric alluvium is pre-European, or is not associated with culturally-accelerated erosion (i.e., it would have been deposited in the absence of human agency). There are a number of methods for dating sediments, but some are inapplicable, in either time frame or resolution, to the past few centuries. Many dating techniques, such as radiocarbon, could establish that alluvium is prehistoric. However, more recent dates might have insufficient resolution to distinguish between late Holocene pre- and post-European sediment. Pollen profiles may also be helpful. In the Chesapeake region, for example, the oak:ragweed ratio is a reliable stratigraphic indicator of the onset of widespread European land-clearing (Brush and Davis, 1984). However, pollen profiles from floodplain sediments can be quite problematic due to diverse transport mechanisms and mixing (Delcourt and Delcourt, 1980).

The features cited below are oriented toward indicators of historic alluvium that can be recognized in the field. Detailed stratigraphic analysis and dating can be quite effective at a few sites; the indicators summarized in Table 1 and described below can be readily examined at a number of sites over a large area at reasonable expense, and can also be examined in reconnaissance surveys along stream reaches.

**Table 1 Indicators useful in distinguishing historic alluvium from other Holocene alluvium in the lower coastal plain of North Carolina.**

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Indicator Present</th>
<th>Indicator Absent</th>
</tr>
</thead>
</table>
| Soils of the North Carolina Coastal Plain have distinct mineralogical differences from the those of the Piedmont, in the upper basins of the Neuse and other larger coastal plain rivers. In terms of clay mineralogy, both piedmont and coastal plain soils have kaolinite clays, but in the latter kaolinite is the dominant silicate clay mineral. Piedmont soils also may have smectites and vermiculites, which are generally absent in soils formed in coastal plain sediments. Coastal plain Ultisols, and soils formed in alluvium derived from them, are generally in siliceous mineralogy classes, and lack mica flakes. Piedmont upland soils, and alluvial soils derived from them, are typically in mixed (or other non-siliceous) mineralogical families, and the alluvial soils have mica flakes (Phillips, 1992a, b; Daniels et al., 1984; Gamble and Daniels, 1974; Soller and Owens, 1991; Markewich et al., 1989). Note that these generalizations do not apply to the Pamlico terrace, which is mineralogically distinct from the rest of the coastal plain (Smith et al., 1976; Gamble and Daniels, 1974).

**Mineralogy and Pedology**

Soils in the lower fluvial reaches and fluvial-estuarine transition zone of the Neuse and nearby Piedmont-draining rivers lack mica flakes and other evidence of a significant piedmont contribution, and are dominated by local and coastal plain sediment sources (Phillips, 1992a, b). There is an organic clay member of the Flanner Beach formation exposed within the Croatan area, which represents deposition in alluvial swamps of the fluvial-estuarine transition zone of the ancestral Neuse during the Sangamon interglacial, under conditions quite similar to those which now exist in the PETZ (Whitehead and Davis, 1989). The sediments in that layer do contain mica flakes, which indicates a much greater relative importance of upper-basin, Piedmont sediment—or, more to the point, an absence of dilution by erosion within the coastal plain (Phillips, 1993). Pre-Holocene alluvium terrace soils along Piedmont-draining rivers also sometimes contain mica flakes which are absent in adjacent modern alluvium (Phillips, 1992b).

Thus, the absence of soil development does not allow one to distinguish historic alluvium from pre-settlement Holocene deposits. However, the presence of soil development is a clear indication that the alluvium is pre-settlement, and probably pre-Holocene. This has been exploited in previous work to show that the modern floodplains and lower terraces of the lower Neuse River are all late Pleistocene or younger (Phillips, 1993). There are a number of indices of soil profile development. However, in this case the development of a B-horizon is sufficient to indicate that the soil is not historic.

**Soil Development**

Because of the active aggradation during the Holocene, pre-settlement floodplains had little opportunity for soil formation. While buried alluvial soils are found occasionally, they are not widespread in the lower coastal plain. Due to their limited occurrences, buried soils cannot be relied upon for differentiating pre- and post-settlement alluvium.

Many soils on the Pamlico Terrace in the Croatan area are well developed Spodosols and Ultisols, with easily-recognized A-E-B horizon sequences. This shows that within the study area approximately 80 Ka is ample time to develop a soil profile with a B-horizon (Bw, Bt, Bh, or Bs) on a stable surface. Well-developed soil profiles are also present on alluvial terraces along the Trent River within the study area. These terraces must predate the Holocene aggradational phase. By contrast, no B-horizons were found in any historic alluvium at any of the sites investigated in this paper. Also, evidence of soil development was sought on an earthen dam built in 1768 (Tucker Creek site, described below). No B-horizon had developed in this 227-year-old material, which supported a full forest cover.

Thus, the absence of soil development does not allow one to distinguish historic alluvium from pre-settlement Holocene deposits. However, the presence of soil development is a clear
mont contribution, on the Talbot terrace, is indicative of material transported before the onset of widespread culturally-accelerated erosion within the coastal plain. However, one possible source of confusion is situations where pre-Holocene alluvial terraces are delivering eroded material to adjacent floodplains. If this can be ruled out, mica or other mineralogical indicators of Piedmont material represent pre-settlement alluvium.

Mineralogical indicators of historic alluvium may not be reliable on the Pamlico Terrace, or inland of the Talbot Terrace, where a contemporary Piedmont contribution becomes more likely as one proceeds upstream.

Oxidation

Unsaturated upland soils of the southeastern U.S. are often characterized by red, yellow, and yellowish brown colors associated with ferric forms of iron, either as sesquioxide clay accumulations in the B-horizon, or as coatings on mineral grains. When these iron oxides are placed in a water-saturated, anaerobic environment they are reduced to their ferrous forms if there is enough organic matter available. The presence of iron oxides in a poorly-drained alluvial setting often indicates recent deposition of material eroded from uplands, and has been used as an indicator of post-European alluviation in the southeastern Piedmont (Trimble, 1974).

The presence of layers of oxidized sediment in a poorly-drained floodplain in the study area thus indicates either deposition so recent that there has been no time for reducing reactions to occur, or that a great deal of sediment was deposited in a short time, so that little or no organic matter was mixed with the mineral sediment to fuel the reducing reactions. Thin layers of alluvial deposition, or those deposited gradually over time, will receive an annual influx of organic litter to drive reduction of iron. Thicker layers, deposited rapidly, may not include such litter. If one accepts the assumption that a large influx of upland sediment is likely to be associated with historic land-clearing, the oxidized layer may be taken as evidence of historic alluvium.

Mottles, lenses, or other localized accumulations of oxidized material do not necessarily indicate recent and/or rapid deposition, as these can form in zones of water table fluctuation or in seasonally dried-out alluvium. Also, iron-stained material is often found in the zone of water table fluctuation where groundwater discharges along valley side slopes.

Dendrogeomorphology

The burial of tree root crowns, buttresses, and cypress knees by alluvium shows that the alluvial deposit postdates the establishment of the tree. In some cases tree ring counts, in combination with sediment measurements, can allow determination of average deposition rates. These dendrogeomorphic indicators are relatively well-known and are not discussed in detail here, as they are described by Hupp (1988), who has used them in southeastern U.S. floodplain swamps (Hupp and Bazemore, 1993; Hupp and Morris, 1990; Hupp et al., 1993).

Burial of Historic Features

If a feature known to be historic is found buried in alluvium, it can generally be assumed that the sediment burying it postdates the feature. For example, if a roadbed known to have been constructed in 1895 lies under 1 m of alluvium, we know there has been 1 m of deposition in the past century, and a mean rate of at least 1 cm yr⁻¹ (though, of course, most or all the material could have been deposited in 1896 or 1994, or anytime in between). Objects subject to deliberate burial (such as bottles, cans, or other refuse) are not reliable indicators. One should also look for evidence that processes other than, or in addition to, fluvial deposition (such as bioturbation) may account for burial of the feature. Also, in measuring or estimating sedimentation rates from buried features, one should be alert for situations where the feature may have locally caused or accelerated sediment accumulations, particularly on the upstream or upflow side. Examples in the literature of the use of burial of historic features to estimate sedimentation include Gottschalk (1945), Trimble (1974), and Barnhardt (1988).

HISTORIC ALLUVIUM IN THE CROATAN
Stream Valley Reconnaissance

Six stream reaches within the Croatan area, and an additional two nearby on the Talbot terrace, were examined with respect to the indicators listed above, to determine whether the upper 1 to 2 m of alluvium is historic. The reaches were traversed by whatever combination of foot and canoe travel enabled access for sampling with soil probes and augers, and visual inspection. All eight reaches contained evidence of significant to extensive historic sedimentation. No evidence of soil B-horizons was found in the upper 2 m of alluvium at any reach, and no mica flakes were detected.

Anderson Creek Near Havelock

Here there was scattered burial of tree root crowns and cypress knees, indicating historic alluvium. Not all tree bases are buried, and there is considerable local spatial variability in the presence and degree of burial. There is an historic mill dam, the base of which is buried by alluvium. The date of the dam could not be established, but other mills and dams in the Slocum Creek system date from the 1760’s. Encroachment of alluvium on adjacent uplands is apparent around the edges of the floodplain; this is what would be expected due to overbank deposition associated with either sea level or upland erosion-induced aggradation from upstream. The forest adjacent to one side of the stream corridor was clearcut in 1993, and the system has been severely impacted by residential construction and golf course development over the past 15 years. Some samples contain oxidized layers several cm thick.

Brices Creek Near New Bern

This stream is a major tributary of the Trent River; the reach from Catfish Lake Road to the Trent was examined. Some tree root crowns and cypress knees were buried, but
not all, and the spatial variability was high. There is a mill dam on this reach. It could not be precisely dated, but court records (Craven Precinct Court Minutes, 1738–1771) show a number of petitions for grist mills on Brices Creek in the 1760s. The dam found during field work, locally known as Evans Mill, was present at the time of the Civil War battle of New Bern in 1862. The atypical design of this mill involved an excavated cutoff channel, and there appeared to have been considerable disturbance, so no reliable estimates of historic sedimentation were obtained. Alluvial encroachment onto adjacent uplands was again ubiquitous at the floodplain margins. In the lower reaches of the creek, organic soil (Dorovian series) one to >2 m thick overlies mineral alluvium. This soil is common in, and diagnostic of, lower river reaches being drowned by rising sea level (Daniels et al., 1984; Phillips, 1992a). Visual evidence of oxidation is uncommon.

Core Creek Near Cove City

A short reach of this stream, in Craven County but not in the Croatan area, was examined because a millpond dating from at least the 1850s still exists here. The mill dam itself is completely inundated by historic alluvium. Accurate measurements of alluvial thicknesses on the feature were not possible, however, because of hazardous conditions for measurement. Behind the dam, near the margins of the swamp, 30 to 100 cm of dark silty clay overlie the sandy soil of the surrounding upland. Burial of tree bases and cypress knees was evident in the pond backwater area. There is no obvious oxidation in the alluvium, other than streaks and mottles.

Slocum Creek, Havelock

There is considerable historic sedimentation behind an 18th century mill dam, as described in the next section. Along the creek banks there is widespread burial of root crowns, buttresses, and cypress knees, ranging from a few cm to nearly a meter. Upland encroachment is evident at the floodplain margins, and there are scattered buried soil profiles. The latter, pre-European soils, are covered by 90 to 200 cm of alluvium. In some samples a 45–50 cm thick layer of oxidized sandy clay loam was found 20 to 25 cm below the surface.

Swift Creek Near Ashkin

Swift Creek is a major Neuse River tributary within Craven County, but outside the Croatan. A reach near the confluence with the Neuse was examined because sedimentation was observed during flooding in 1994. The Dorovian muck, 40 to 200 cm thick, overlies mineral alluvium in the lower reaches of the creek, and dark alluvium is encroaching on adjacent uplands. In some locations 5 to 30 cm of mineral sediment, believed to be from floods in recent years, overlies the organic soil. Scattered burial of tree root crowns and buttresses was observed, with extensive spatial variability in the latter. No oxidized material was found.

Island Creek

This is a Trent River tributary between New Bern and Pollocksville. In general, the alluvium here is dark brown to black, organic rich sandy clay loam to clay loam with no evident soil development, >2 m thick. Occasional burial of tree bases is evident, but not ubiquitous. Some samples contain evidence of oxidized layers, but these are too dark to be conclusive. In one abandoned channel 110 to 130 cm of mineral alluvium overlies a black organic soil. This suggests historic alluvium inundating an infilling oxbow swamp.

White Oak River

In the reach sampled, from Holston Creek to Haywood landing, all alluvium was Dorovian muck >2 m thick. Many wood fragments are evident in the muck, and some samples had a hydrogen sulfide odor. Little or no tree burial is evident.

Holston Creek

A reach of this White Oak tributary near North Carolina Highway 58 was examined. Occasional, but not ubiquitous, burial of tree bases is evident. In most samples there is 100 to 140 cm of fine-grained alluvium (loam to sandy clay loam) overlying sand or loamy sand, the latter with oxide coatings or uncoated. The buried sands are similar to the adjacent upland soils, but could also be channel sands. The ubiquity of the underlying sandy layer supports the former interpretation, and I believe the alluvium represents historic aggradation. Obvious oxidation is not present in the fine-grained alluvium, however, except in mottles and streaks.

Historic Sedimentation at Dam Sites

Along one of the reaches above (Slocum Creek) and at five additional sites, historic features were found which allowed for reliable measurements of historic sediment accumulations. Five sites are mill dams dating from the 18th century; the sixth is a short section of buried logging railroad from the late 19th century.

Low gradients and slow flows in coastal plain streams are not ideal for water power, but it was a necessity in the 1700s and 1800s. Few water mills remain in eastern North Carolina; none within the study area. However, their former prominence is reflected in place names. The Croatan area includes at least seven creeks or water bodies with “mill” in the name. Founders of New Bern complained in 1711 of the absence of gristmills in the region, and built one that year (Watson, 1987). The shortage was short-lived. Colonial courts typically favored grist and saw mill petitions. From the mid 1760s to the mid 1770s, Craven County (then including current Carteret, Jones, and Pamlico Counties) got an average of five mill petitions a year, most of which were approved (Watson, 1987).

Surviving dams are all earthen. They are found at points along low-order streams where the floodplain is narrow, and where steep valley side slopes are adjacent to the stream channel on at least one side. Scallop-shaped upland borrow areas are obvious on the upland valley sides on at least one side at each dam site. The dams have at least one opening over the main stream channel, and often a secondary opening at a slough or subchannel. The location and geometry of the
main openings suggest that these were the locations of the mill structures, long since destroyed by storms, floods, decay, salvaging, or removal to allow navigation.

Measurements of alluvial thicknesses at the dam sites were made upstream of the dams, near the edges or backwater areas of the millponds, or adjacent to the dams. While such measurements may underestimate sedimentation, this method ensures that the alluvium measured is entirely historic material deposited behind the dams. Topography and stratigraphy of the floodplains is generally similar up- and downstream of the dams. The dams must have some influence on sedimentation, so this may imply that adjustments since the dams were breached have diminished up- and downstream differences, and/or that backwater flooding is important for sedimentation processes. In any case, the location of measurements was chosen to ensure that historic alluvium was being measured rather than to describe typical cross-sections. Depth was measured with a Dutch-style mud auger by digging to a buried upland soil, coarse sand channel deposits, or the buried dam base. Sampling depth was generally limited to about 2 m by the extreme hydraulic suction and poor recovery at and below the 180 to 200 cm depth. Samples were taken for laboratory determination of bulk density.

Maximum and minimum sedimentation rates were estimated for each site based on the maximum and minimum depths of historic sediment, and the date of the feature. The “best estimate” given in Table 2 is based on the modal depth of historic sediment and my best estimate of the date of the feature (where the latter is in doubt). As these data have been published elsewhere (Phillips, forthcoming), they are summarized in Table 2.

The mean historic sedimentation rate is 6.8 mm yr⁻¹ of vertical accretion, or 71.1 t ha⁻¹ yr⁻¹. The dam site measurements are qualitatively consistent with indicators of historic sedimentation on the stream reaches described previously, and Table 3 shows that the rates are generally consistent with other measurements in forested floodplains on the Atlantic and Gulf Coastal Plains of the southeastern U.S.

**HISTORIC VS. PREHISTORIC SEDIMENTATION RATES**

A substantial amount of aggradation has occurred since European settlement and land-clearing. Historic alluvium is ubiquitous, and data from the buried historic features suggests historic sedimentation rates on the order of 3 to 9 mm yr⁻¹. How do historic sedimentation rates compare with those before European settlement? To what extent would the historic aggradation have occurred anyway, without accelerated erosion and deposition attributable to human agency?

The time-honored stratigraphic approach to estimating sedimentation could, conceivably, be used to estimate prehistoric or total Holocene sediment thicknesses, from which rates could be estimated. This method is based on the principle of dating an alluvial layer or sequence, and dividing its mass or thickness by the window of time in which it apparently existed, to derive a mean deposition rate. In the Croatan area, no stratigraphic data are available which will allow the determination of a prehistoric deposition rate. There are some sections where Holocene alluvium overlies a recognizable layer organic clay of the Flanner Beach formation, which outcrops nearby. However, the Holocene alluvium at these sites is indistinguishable from the demonstrably historic alluvium nearby.

A more fundamental problem than the absence of convenient stratigraphy is that the measured rate of geomorphological processes is directly related to the period or time scale.
of measurement; i.e., the longer the period over which sedimentation (or other processes) is measured, the slower the rate obtained (Snow, 1992; Gardner et al., 1987). The longer the time period covered by a measurement, the more likely it is to include periods of quiescence or relative inactivity, thus producing lower rates averaged over time (Snow, 1992; Gardner et al., 1987). See, for example, Jiongxin’s (1995) study of Holocene accumulation rates in the Yellow River floodplains. Sedimentation rates for 12 Ka to 1 Ka measured by stratigraphic means, covering periods of 1,800 to 5,000 years, produce rates of 1.4 to 7.5 mm yr⁻¹. Historic and contemporary estimates and measurements of accumulation rates, covering periods of 15 to 661 years, indicate accretion of 12.5 to 82 mm yr⁻¹ (Jiongxin, 1995: Table 1). It is difficult to know to what extent there has been a real acceleration of erosion (this is Jiongxin’s interpretation, which is almost certainly at least partly correct) and to what extent the disparity in rates is related to the temporal scales.

To avoid problems associated with the dependence of rates on measurement period, this study will rely on determining prehistoric sedimentation by estimating the alluvial accretion rates on an average annual basis. This will produce estimates that allow for a direct comparison with the measured historic rates.

**Sediment Budget**

It is assumed that upland erosion and sediment yield in the pre-European-Croatan approximated the rates which now exist on forested land. Suspended sediment yields from mainly forested basins in the North Carolina coastal plain are small; about 0.02 t ha⁻¹ yr⁻¹ (Simmons, 1988). Patric (1976) synthesized erosion data from forests of the eastern U.S., and despite variations in geologic, ecologic, and climatic settings, found a typical mean range of 0.11 to 0.22 t ha⁻¹ yr⁻¹. If these are typical of the study area, it would imply that, on average, 82 to 89 percent of the sediment eroded from uplands is delivered to streams. These percentages compare well with estimates of coastal plain sediment delivery under contemporary conditions in agricultural basins, though the masses of sediment involved are one to two orders of magnitude higher for the latter (Phillips, 1993, 1995; Cooper et al., 1987; Sheridan et al., 1982).

At least some of the sediment transported to streams must have been delivered to the estuaries, though at present both the proportion of river sediment and the mass involved are very low (Phillips, 1995). The ratio of upland sediment-producing areas (non-wetland areas with mineral soils) to the area of alluvial floodplains with a dominantly coastal plain sediment source is 32.7 to 1. If we assume that all sediment delivered to streams is ultimately stored as alluvium, then the 0.02 t per hectare of upland area would amount to 0.65 t per hectare of floodplain. At a bulk density of 1.4 g cm⁻³, this gives a mean deposition rate of 0.05 mm yr⁻¹.

In the poorly-drained forested swamps of eastern North Carolina, organic accumulation rates are significant. In the lower Roanoke River, North Carolina, Erlich (1980) found that almost half the alluvium deposited in the past 5000 years was organic. However, the typical organic matter content of alluvium in the Croatan area (other than the mucks of the FETZ) is 8 to 20 percent (Goodwin, 1978, 1989). If the maximum mineral deposition rate calculated above is increased by 20 percent, an estimated rate of 0.06 mm yr⁻¹ is obtained (0.78 t ha⁻¹ yr⁻¹).

**Organic Accumulation**

Because poconis formed in blocked drainages during the Holocene, and exist on upland interfluvies, it is possible that the rate of sediment accumulation would approximate that of a lower coastal plain alluvial floodplain, receiving very small inputs of river sediment. While organic accumulation rates in poconis may not be typical of those in lower coastal plain floodplains, they do provide an estimate of organic accumulation rates which occur in the region in situations dominated by climatic and biological controls rather than episodic deposition and erosion. Because organic accumulation depends on the balance between litter production and decay rates, and is not subject to the discontinuity inherent in erosion and sediment transport, I assume that Holocene accumulation rates characterize the undisturbed presettlement poconis. Percent organic matter of the poconis peats ranges from 20 to 95 percent, but is typically greater than 50 percent.

The deepest peats of the Croatan are less than 5 m thick. This implies a maximum net rate of net accumulation in these Holocene bogs of about 0.3 mm/year. Bulk densities are typically 0.40 to 0.65 g cm⁻³, giving a maximum mass accumulation rate of 1.2 to 1.85 t ha⁻¹ yr⁻¹. The Doveran muck soils are typically 130 to 200 cm thick, with a bulk density of about 0.45 g cm⁻³. If this has been deposited over the Holocene, the inferred mean rate is 0.13 to 0.20 mm yr⁻¹ or 0.58 to >0.90 t ha⁻¹ yr⁻¹.

Brinson (1977) measured littelfall and decomposition rates in a swamp forest on the lower Tar River, North Carolina, and the rates are generally consistent with those measured in other alluvial swamps of the southeastern U.S. (Mitsch and Gosselink, 1986). Littelfall rates are 6.1 to 6.8 t ha⁻¹ yr⁻¹, and decay coefficients suggest about 85 percent of the leaf and 25 percent of the twig biomass is lost in one year (not including losses by physical transport). Other studies in southeastern swamps give litterfall rates of 3.3 to 7.6 t ha⁻¹ yr⁻¹, and decay coefficients indicating that 21 to 75 percent of the litter biomass is lost within one year, and >99 percent within 10 years (Mitsch and Gosselink, 1986, pp. 338-343). Litterfall rates may be taken as an absolute upper limit to organic accumulation rates; i.e., that which would occur if no mass is lost.

Certainly logging and other alterations have had significant short-term local impacts on organic mass balances. However, where floodplains in the FETZ remain forested, there is no reason to believe that human agency has dramatically changed accumulation rates.

**Comparison of Historic and Prehistoric Rates**

Historic alluvial sedimentation rates in the Croatan range from about 3 to 9 mm yr⁻¹ of vertical accretion or 45 to 92 t ha⁻¹ yr⁻¹, with mean values of 6.8 and 71.1. The mean values are about 100 times the rate of prehistoric alluvial deposition.
estimated from sediment yields from forested basin, on the basis of sediment budget considerations.

In the FETZ, there is little apparent difference between pre- and post-historic sedimentation rates. The high rates of sediment storage upstream of the FETZ and the low inputs to estuaries implies that culturally-accelerated erosion is having little impact on estuaries in the Croatian area.

**DISCUSSION**

**Upstream Sediment Loading vs. Base Level Aggradation**

In many aggrading valleys there are both downstream base level effects and upstream sediment supply effects driving the alluvial accumulations. Their relative importance is critical not only for understanding recent and future responses of rivers to sediment loading and sea level change, but also for efforts to use modern sedimentation regimes to understand the stratigraphic record. The issue is also of critical importance to resource managers, particularly because the sediment supply factor can be influenced by management, whereas the base level factor cannot. This raises the two major issues raised in the introduction; i.e., how to distinguish recent alluvium derived from accelerated erosion from earlier Holocene sediments, and how the historic alluvial sedimentation rates, accelerated by human agency, compare with pre-historic Holocene rates with little or no anthropic influence.

In an aggrading valley, pre-European floodplain surfaces are unlikely to have well-developed soils or other features which readily distinguish them from historic sediments. Detailed stratigraphic analysis and dating can be quite helpful, but even then one has to extrapolate and correlate from a limited number of sites to a broader area. It is useful to have alternative, or supplementary, field indicators which may help in distinguishing historic and prehistoric sediments.

In the Croatian area, there are at least five such indicators which are readily observable in the field. Some indicators—burial of historic features and dendrogeomorphology—should be universally applicable. Soil development should be widely applicable as a general principle, though the specific criterion (presence of a B-horizon) used in eastern North Carolina is less so. Oxidized layers and mineralogical indicators are certainly not unique to the southeastern U.S. Coastal Plain, but are not directly transferable elsewhere, though analogous indicators are likely in a variety of settings. In the study area, these indicators suggest that the upper 1–2 m of sediment in most floodplains is historic.

Human agency in the post-European era has accelerated floodplain deposition rates by about a hundred-fold, and represents something more significant than a minor exacerbation of an existing trend. Estimates of historic and prehistoric rates indicate that 92 to 99 percent of the recent deposition is accounted for by human agency. Put another way, only about one to eight percent as much alluvium would have accumulated in the past two to three centuries in the absence of culturally-induced sediment loading from upstream.

Historic accretion rates in floodplains throughout the southeast (Table 3) range from about 2.4 to 26 mm yr⁻¹, with the higher rates generally associated with sites where accelerated sediment loading is obvious. Even if these sites of apparent rapid accretion are discounted, the range of 2.4 to 7.6 brackets the mean rate of 6.8 mm yr⁻¹ in the Croatan. Few data are available for prehistoric sedimentation. ERLICH’S (1980) rate for the past 5,000 years (2.7 mm yr⁻¹) is comparable to historic rates in the region, but include historic sediment. Foumèt’s (1990) Tar River cross sections also include
Implications

Goudie (1995), suggests a mean Holocene floodplain accretion rate of 10 mm yr⁻¹ as a “rule of thumb,” and cites studies of the Indus Plain to suggest that much of this occurred during the early Holocene. This does not seem to have been the case in China’s Yellow River valley, where despite issues associated with the dependence of apparent rates on measurement periods, early Holocene accretion rates appear to be lower than middle- and late-Holocene rates (Jiongxin 1995). The results obtained here suggest recent acceleration of sedimentation, and thus agree more closely with Jiongxin, but the small streams of the Croatan are quite different from the Yellow and Indus River systems. The question of whether an acceleration in the rate of sea level rise could lead to a major change in sedimentation rates, or to a change in the relative importance of base level and sediment supply controls, deserves further investigation, particularly given predictions of an acceleration of eustatic sea level rise in the near future.

In the study area, the impacts of accelerated erosion are confined mainly to uplands, where a predominance of the eroded sediment is apparently stored as colluvium, and stream valleys. While colluvial storage is evident on the landscape, quantitative estimates are difficult because only detailed field examination can, at this point, allow one to distinguish colluvial from residual soils. This problem should be addressed by future research. Considering only sediment removed from the uplands, impacts are felt mainly within the coastal plain river valleys which buffer the estuaries from the effects of the increased erosion rates. In the FETZ alluvial sediments are still dominantly organic, except locally where mineral material eroded from adjacent land has buried the mucks. There is no historic evidence of accelerated sedimentation at estuary heads in the region (Phillips, 1993, 1995), and fluvial sediment inputs to estuaries are low (Kim, 1990; Benninger and Wells, 1993; Phillips, 1991a, 1992b). This is in contrast to some other coastal systems, such as Chesapeake Bay, where post-European upland erosion has sometimes greatly altered tributary estuaries and marshes, and increased sedimentation rates in the bay (Gottschalk, 1945; Froomer, 1980; Brush and Davis, 1984). In coastal North Carolina, we cannot expect increased inland sediment inputs to help offset coastal submergence in estuaries and wetlands.

This study also highlights some important gaps in knowledge and data. Sedimentation rates, by necessity and for comparison with other rates, are presented as gross spatial and temporal averages of a process which is notoriously variable in both space and time. We need better information on this variability. For example, to what extent does the historic sediment represent major “slugs” of sediment associated with short-lived episodes of logging, land-clearing, or urbanization, or with particular floods or hurricanes? There are also clearly different rules operating in the fluvial-estuarine transition zones, where organic mucks are prevalent, and other lower coastal plain fluvial reaches, where mineral alluvium is dominant. We know little about fluvial and alluvial processes currently operating in these settings.

Finally, the results from the Croatan raise some important questions about global change and human agency. If human-induced sea-level change produced even a 10-fold increase in alluvial sedimentation rates attributable to base level effects, these would still be an order of magnitude lower than the effects of human agency on the local scale. This implies that for at least some issues, studies of environmental change which focus on broad-scale regional and global change but ignore the local effects of human agency may overlook important transformations.

CONCLUSIONS

(1) There are at least five field indicators in the lower coastal plain of North Carolina which may allow one to distinguish historic alluvium from other geologically recent deposits. The presence of soil B-horizons, or of pedological and mineralogical indicators of a piedmont sediment source on the Talbot terrace, are diagnostic of prehistoric alluvium. Buried tree buttresses, knees, and root crowns, buried historic features, and oxidized sediment layers indicate historic sediment.

(2) In seven of eight lower coastal plain streams examined, the indicators above suggest that the upper 1–2 m of alluvium is historic.

(3) At five mill dams and one railroad bed buried by alluvium in the Croatan, mean historic sedimentation rates range from about 3 to 9 mm yr⁻¹, or from 45 to 92 t ha⁻¹ yr⁻¹, with means of 6.8 and 71.1. About 0.5 to >2 m of sediment have accumulated since the 1760’s.

(4) Prehistoric floodplain accretion rates were about 0.06 mm yr⁻¹ or 0.78 t ha⁻¹ yr⁻¹.

(5) Human agency has increased sedimentation rates by about 100-fold. Recent sedimentation rates are mainly accounted for by upstream sediment loading. In the absence of accelerated loading, accretion rates would be only one to eight percent of the historic rates. This illustrates the point that local human impacts on the environment may greatly overshadow changes associated with regional- or global-scale phenomena such as sea level rise.

(6) Estuaries in the study area are largely buffered from the effects of upstream sediment loading, which are concentrated in the valleys just upstream of the FETZ. In the FETZ and estuaries the contemporary and historic effects of human agency on aggradation are minor, and base level is still the major control.

ACKNOWLEDGEMENTS

The U.S. Forest Service, Croatan National Forest, funded this work through a cooperative cost-share agreement as part of a project to establish pre-settlement environments in the forest. Nathan Phillips was an able field assistant, and Paul
Gares provided helpful comments on an earlier draft. Only the author, however, is responsible for the contents.

LITERATURE CITED


