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Decoupling of sediment sources in large river basins

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Abstract It has been suggested that sediment dynamics of the upper and lower basins of large rivers of the North Carolina Coastal Plain are decoupled. The argument depends in part on sediment discharge from coastal plain uplands sufficient to account for observed alluvial storage and to dilute upper basin sediment. A synthesis of recent work shows extensive historical upland erosion in the region, coupled with limited sediment delivery to estuaries. This points to extensive storage. Further, estimates of slope-to-stream sediment delivery in the coastal plain, based on threshold drainage areas, suggest that sediment discharge is sufficient to account for the upper 70 cm of all flood plains having a mineral soil and a dominantly coastal plain sediment source. This supports upper and lower basin decoupling, but suggests that it may be unique to the historic period.

INTRODUCTION

As geomorphologists have attempted to link fluvial sediment discharge, transport and storage, it has become increasingly apparent that steady-state relations, where the sediment supply balances sediment yield, are the exception, not the rule. Relations among erosion, fluvial sediment transport, storage and landscape denudation may be quite complex.

In drainage basins of the humid eastern United States, where upland erosion is the major sediment source, studies have generally shown extensive alluvial and colluvial storage and sediment delivery ratios of about 10 percent or less for basins larger than a few hundred km^2 (Roehl, 1962; Trimble, 1977; Meade, 1982; Phillips, 1991a, b; Lowrance *et al.*, 1986). At the same time, studies of sediment provenance in many estuaries receiving drainage from extensive inland river systems indicated either relatively low contributions of fluvial sediment, or limited evidence of input from the upper portions of the inland drainage basins (Nelson, 1973; Pierce & Nichols, 1986; Nichols, 1989; Wells & Kim, 1989; Phillips, 1991b; Benninger & Wells, 1993). This, in combination with extensive storage and low sediment delivery in the fluvial systems, raised questions about the influence of upper basin derived sediment on lower reaches of the river in large river systems.

A direct investigation used the distinct pedologic signatures of piedmont (upper basin), coastal plain (middle and lower basin) and coastal (fluvial-estuarine transition zone) sediment sources to map dominant alluvial sediment sources along the lower reaches of the Tar and Neuse Rivers, North Carolina (NC) (11 000 and 15 000 km^2

basin areas, respectively). Results showed clear dominance of coastal plain and coastal sediment sources up to 35 to 50 km upstream of the head of the estuary (Phillips, 1992a). On the Neuse River, a mineralogical indicator of a piedmont source (muscovite flakes) showed no evidence of a piedmont sediment source in the lower Neuse (Phillips, 1992b). Based on those results, I suggested that not only is storage important, and the relation between sediment discharge and delivery highly non-linear, but that the sediment dynamics of the upper and lower basin are essentially decoupled. Brizga & Finlayson (1994) reported similar findings in Australia.

For such decoupling to occur, relatively small proportions of eroded sediment must leave the piedmont, and there must be extensive storage of piedmont-derived alluvium in the upper and middle coastal plain. These have been reasonably well documented (Trimble, 1977; Meade, 1982; Phillips, 1991a, b; 1992a; b; Simmons, 1988). There must also be a significant supply of sediment eroded from coastal plain uplands to dilute the piedmont material. There is evidence of this, but sediment discharge and storage within the coastal plain have not been directly linked. Regional, sub-regional and local field studies in eastern NC (Cooper *et al.*, 1987; Phillips, 1993; Phillips *et al.*, 1993) have shown extensive upland erosion, despite the generally low relief and permeable soils. Further, sediment yields of many streams confined to the coastal plain are comparable to, or greater than, those of piedmont rivers (Simmons, 1988; Phillips, 1992b). This suggests that coastal plain erosion alone may be sufficient to account for the sediment loads in the lower reaches of piedmont rivers.

This paper synthesizes recent work and newly-derived estimates of slope-to-stream sediment delivery within the coastal plain, and of the extent of flood plains with a dominantly coastal plain sediment source. The purpose is to address the question of whether sediment discharge from coastal plain uplands accounts for the observed alluvial storage.

SEDIMENT DELIVERY TO ESTUARIES

Estuarine sediment in NC generally has a dominantly local source and limited fluvial input relative to other sources (Griffin & Ingram, 1965; Nelson, 1973; Wells & Kim, 1989; Benninger & Wells, 1993). Sediment sampling stations are well upstream of the estuaries, however, so fluvial input has been estimated.

Kim (1990), however, measured sediment concentrations for two years at the head of the Neuse River estuary at New Bern, NC (Fig. 1). Allowing for the typical range of discharge, he estimated mean annual sediment yield at the mouth of the Neuse River to be 0.03 to 0.06 t ha^{-1} $year^{-1}$. Typical sediment yield for coastal plain streams in the Neuse River basin (not including channelized streams, which have higher yields) are 0.10 to 0.17 t ha^{-1} $year^{-1}$. This implies that about 0.10 t ha^{-1} $year^{-1}$ of the sediment load transported in suspension by coastal plain streams is stored upstream of the estuary.

There is no evidence of substantially larger historical influx of sediment. Historical accounts of the harbor and waterways around New Bern (Fig. 1) from the early and mid 1700s give depths in the vicinity that are the same (to the nearest 0.3 m) as those at present. This is in contrast to some locations in the Chesapeake Bay area, where post-European erosion resulted in silting of harbors.

Limited sediment delivery to estuaries, combined with an estimate of historic upland

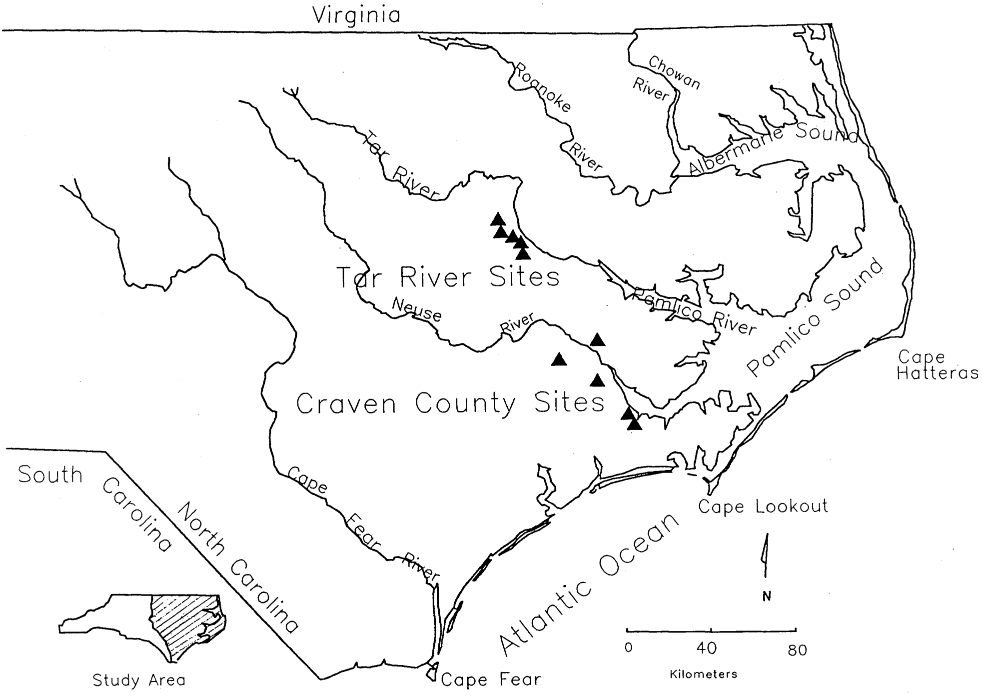

Fig. 1 Major piedmont draining rivers of the North Carolina coastal plain. Locations referred to in the text are indicated.

erosion of 9.5 t ha^{-1} $year^{-1}$ in the lower Neuse basin (Phillips, 1993), indicates extensive sediment storage, a proportion of which must be alluvial.

THRESHOLD DRAINAGE AREAS

There are fundamental differences between small, low order, headwater basins and larger basins. In the former there is (a) strong direct coupling between hillslopes and stream channels, (b) short lag times between hillslope runoff and erosion and streamflow responses, and (c) limited, transient alluvial sediment storage (Knighton, 1984; Clarke & Waldo, 1986; Graf, 1987). The recognition of a threshold separating small and larger basins is widespread and virtually universally accepted. However, the threshold drainage area involved has rarely been identified.

The presence of significant alluvial storage is a reasonable criterion for the transition from headwater to larger basins (Graf, 1987; Clarke & Waldo, 1986; Hupp, 1986). Sediment storage is not only important in and of itself, but a transition from no storage to storage indicates fundamentally different energy dissipation regimes, and the increasing dominance of the upstream catchment relative to the local hillslopes.

Five Tar River tributaries in the lower coastal plain (Fig. 1) were selected for field study, based on an absence of extensive hydrologic modifications (such as channelization). Beginning at the upper end of the streams, the channels were traversed to identify the first significant alluvial sediment storage downstream. The location was established using a global positioning system receiver, and plotted on a 1:24 000-scale topographic map. The drainage basin was drawn in, and its area calculated with a polar planimeter. Results (Table 1) show that the threshold drainage area associated with the transition from non-storage to alluvial storage ranges from 1.7 to 3.5 km^2 (mean = 2.7) in the study basins. Because no alluvial storage occurs at drainage areas smaller than the threshold size, sediment yield from such areas should reflect slope-to-stream sediment delivery.

Simmons (1988) established an empirical relation between mean annual sediment discharge (tons) and basin area (miles^2) for dominantly agricultural drainage basins within the coastal plain for basins smaller than 260 km^2:

$$Q_{sed} = 52.9\, DA^{0.801} \tag{1}$$

The regression was developed using data from NC basins, and produced a coefficient of determination of 0.78. An area of 1 square mile (2.6 km^2) approximates the threshold, and would yield 1.24 t ha^{-1} year^{-1} of sediment to the stream.

COASTAL PLAIN ALLUVIUM

Alluvial soils of the NC coastal plain have been classified as to the dominant sediment source (Phillips, 1992a). Soil survey data were used to estimate that there are 336 000 ha of alluvial flood plain in the NC coastal plain with mineral soil of a dominantly coastal plain origin. Given the area of the coastal plain (nearly 5.7 million ha) in the state, and a typical moist bulk density of mineral flood plain soils of 1.4 g cm^{-3}, the sediment supplied to streams would be sufficient to account for 2.8 mm year^{-1} of deposition if it were deposited in a uniform layer across the entire flood plain area. Over 250 years, this rate would account for a layer of alluvium 70 cm thick over the entire flood plain area. The regional erosion estimate for the NC coastal plain derived by Phillips *et al.* (1993) of 9.4 t ha^{-1} year^{-1} could cover the flood plains to a depth of 2.4 m.

Alluvium is not deposited in uniform layers. The purpose of the calculations is to show that estimates of slope-to-stream sediment delivery, extrapolated over the post-

Table 1 Threshold drainage areas for some coastal plain streams.

Stream	DA	Q_{bf}	Order
Hardee Cr.	2.9	6.46	2
Tyson Cr.	1.7	2.57	2
Otter Cr.	1.9	3.09	3
Kitten Cr.	2.5	1.28	3
Harris Run	3.5	0.75	3

DA = threshold drainage area, km^2; Q_{bf} = bankfull discharge estimated by slope/area method, m^3 s^{-1}; order = stream order.

European period, are sufficient to account for a large proportion of the recent coastal plain alluvium in the region.

DISCUSSION AND CONCLUSIONS

If there is true upper and lower basin decoupling of sediment dynamics in the NC coastal plain, one must show that local, coastal plain sediment sources are sufficient to account for the majority of the alluvial material interpreted as having a dominantly coastal plain source.

Not all soil eroded from uplands is removed by water, and not all of the fluvially eroded material is stored as alluvium, even over 200-300 years. Sediment yields provide a reasonable estimate of slope-to-stream sediment delivery if there is no significant alluvial storage. The threshold drainage area above which there is no alluvial storage, as determined from five field sites, is less than 3 km^2 for the NC coastal plain. An empirical sediment yield relation applied at this scale suggests that agricultural areas of the region yield 1.24 t ha^{-1} $year^{-1}$ to streams. Over the entire coastal plain, this yield is sufficient to account for 70 cm of alluvium over the surface occupied by alluvial soils of coastal plain origin.

These broad scale calculations are not meant to imply a simple picture. Instead, they are intended to demonstrate, at a regional scale, that there is ample sediment discharge from coastal plain uplands to account for the fluvial and alluvial sediment storage in the lower coastal plain.

The apparent upper and lower basin decoupling probably did not exist before European contact and the widespread land clearing and erosion that resulted. All available evidence suggests that with a natural vegetation cover, erosion and sediment yield from the coastal plain is insufficient to account for any appreciable dilution of material transported downstream (Phillips, 1993).

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