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Characterization of Legacy Sediment variations in accretion and carbon dynamics following dam removal in a recently restored tidal freshwater wetland

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Introduction

Damming disrupts the natural flow of sediment to adjoining water bodies resulting in the accumulation of Legacy Sediments (LS). While the impact of LS inputs has been well investigated in lotic Mid-Atlantic piedmont stream restorations, (i.e. milldam removal [1,2,3,4,5,]), there have been few studies investigating LS following dam removal in low-gradient coastal plain streams. The objectives of this study were to quantify spatial and temporal variations of LS characteristics in a low-gradient tidal stream restoration within the lower James River watershed. Secondary objectives were to assess the current temporal and spatial variability in sediment deposition within the recently restored Kimages Creek wetlands and adjacent, unaltered wetlands of Harris Creek to investigate current sedimentation processes in a restoration setting.

Site History

The VCU Rice Rivers Center, located on the lower James River in Charles City County, Virginia, houses one of the largest wetland and stream restorations in the mid-Atlantic region. Running through the site is Kimages Creek (KC), which was dammed in 1927 at its confluence with the James River. This resulted in a 70 acre impoundment known as Lake Charles. Prior to damming, the KC basin was a forested tidal freshwater wetland (TFW) that was logged once before the civil war and once prior to the dam establishment. In 2007, the dam was partially breached and in 2010 a portion of the dam was removed, restoring tidal communication.

Figure 2. KC Wetland Restoration. Pre-restoration (upper left): Impoundment of KC, former Lake Charles. Transitional (upper right): partial breach in 2007. Restored (lower): partial removal of dam in 2010. By Bukaveckas & Wood, 2014

Figure 1. Historic Kimages Creek post first clear cutting circa 1864

Methods

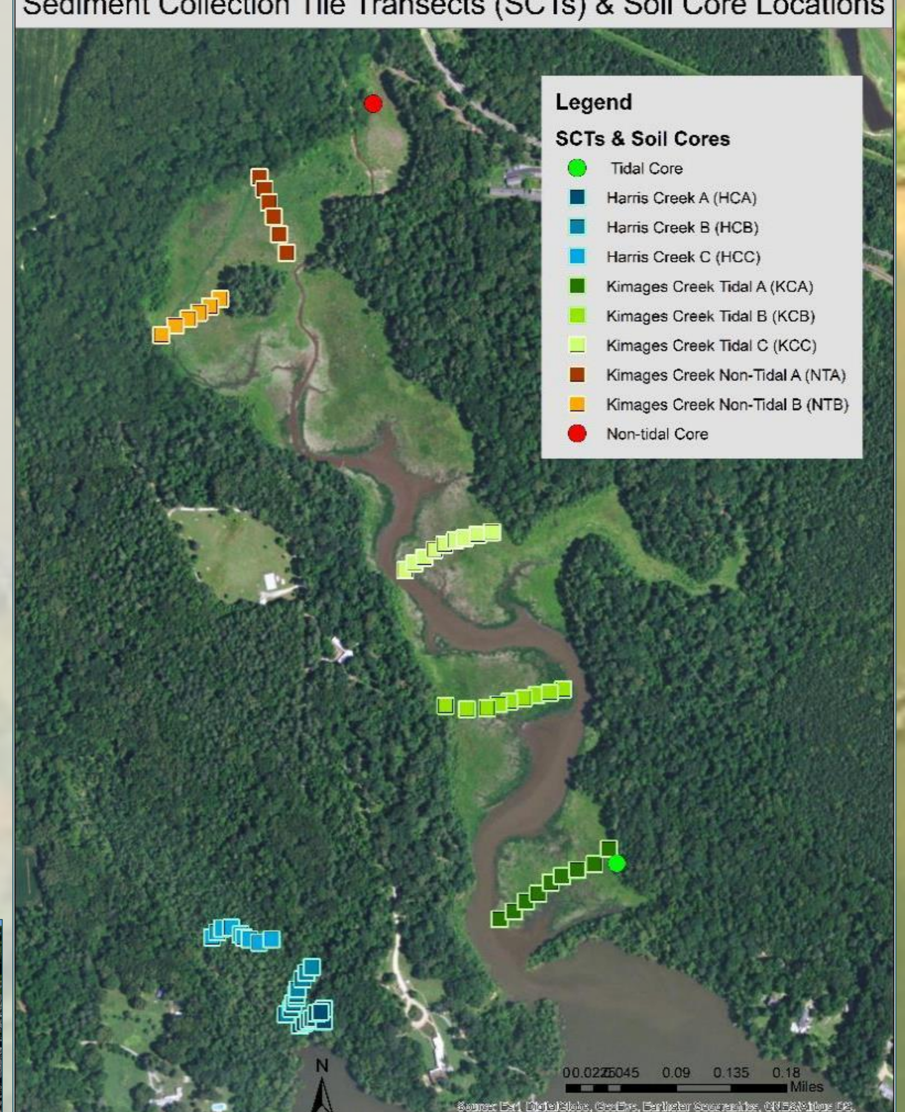
Legacy Sediment Characterization:

- Using the standard penetration test coupled with current stratigraphic information of the site, 2 series of 5', 10', 15', and 20' 2" diameter PVC cores were driven down until the bedrock layer was located.
- The cores were split and segmented into 10 cm intervals. Each interval was analyzed for bulk density, organic and carbon content, texture, and color.
- A total of 5 samples (2 from the non-tidal core and 3 for the tidal core) were sent for radiocarbon dating at the University of Georgia Isotope Lab.

Contemporary Sediment Accretion:

- 5 Sediment collection tile (SCT) transects were established spanning elevational and tidal to non-tidal Gradients in Kimages Creek along with 3 transects within the neighboring Harris Creek (reference site) wetlands.
- Tiles were arranged in a block design (block A being closest to creek banks-block C closest to upland) and were sampled bi-monthly for the growing season and monthly thereafter.
- Simultaneously, shallow surface cores were taken to calculate bulk density while tile samples were analyzed for organic matter content.

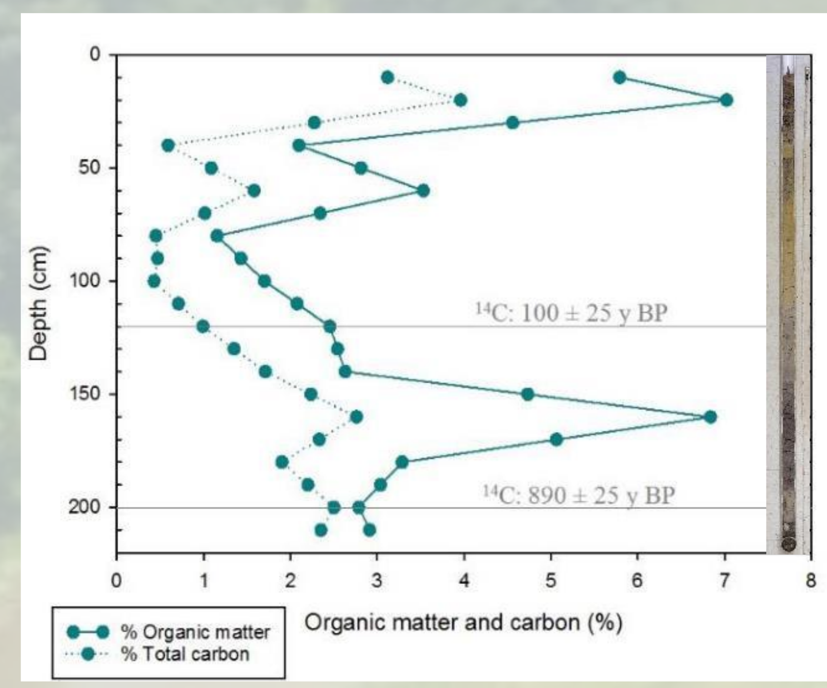
Sediment Collection Tile Transects (SCTs) & Soil Core Locations



Results

Contemporary Sediment Accretion:

- The relic hydric soil in the non-tidal core and modern hydric soil in the tidal core had a significantly higher average C:N Molar ratio compared to the LS in the non-tidal core (1-Way Test, ChiSquare Approximation, P>0.0026 and P>0.0005, respectively).
- Bulk Density was found to be significantly higher in the relic hydric non-tidal than relic hydric tidal soil and higher in non-tidal LS than modern hydric soil in the tidal core (1-Way Test, ChiSquare Approximation, P>0.0006 and P>0.0004, respectively).



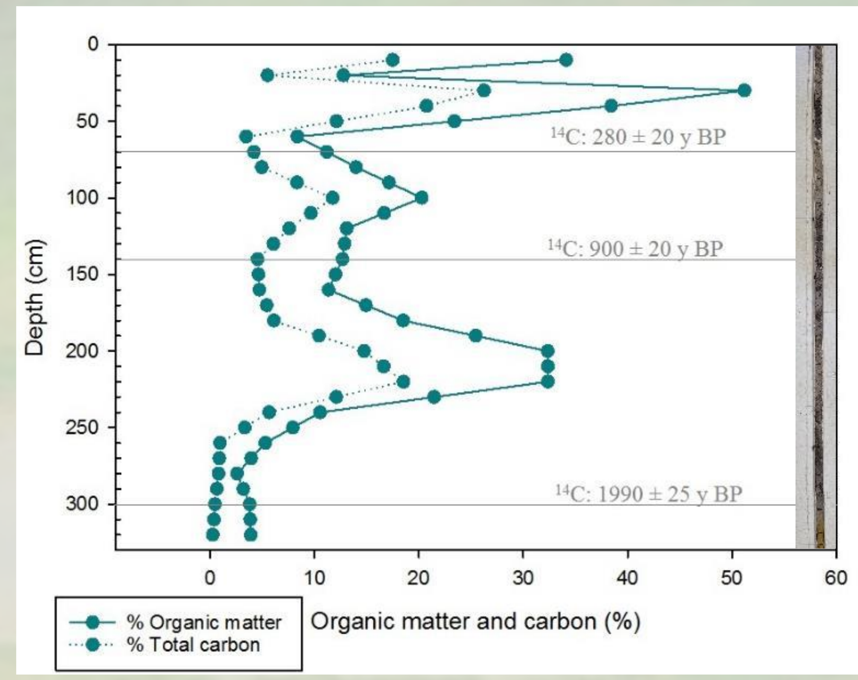


Figure 3 & 4. Non-tidal and tidal sediment core characterization with sediment organic content, percent carbon, and ^{14}C dates.

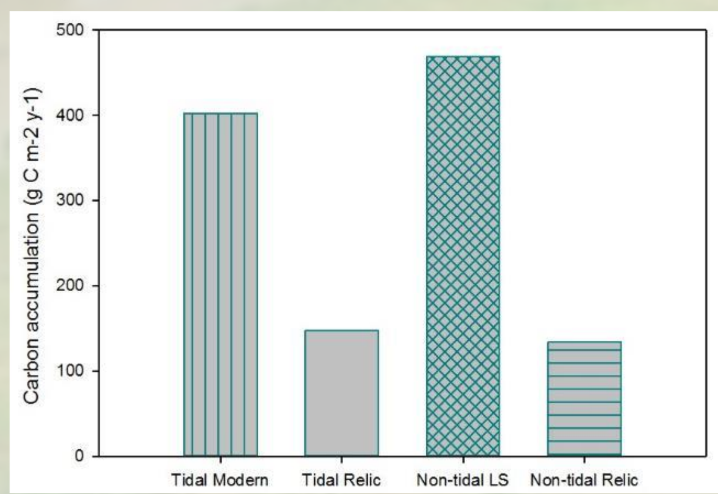


Figure 5. (left) Carbon accumulation rates (g C m^{-2} y^{-1}) across tidal and non-tidal sediment cores

Tidal Modern Hydric Soil
Tidal Relic Hydric Soil
Non-tidal LS Hydric Soil
Non-tidal Relic Hydric Soil

Figure 6. (right) Vertical accretion rates (mm y^{-1}) across tidal and non-tidal sediment cores

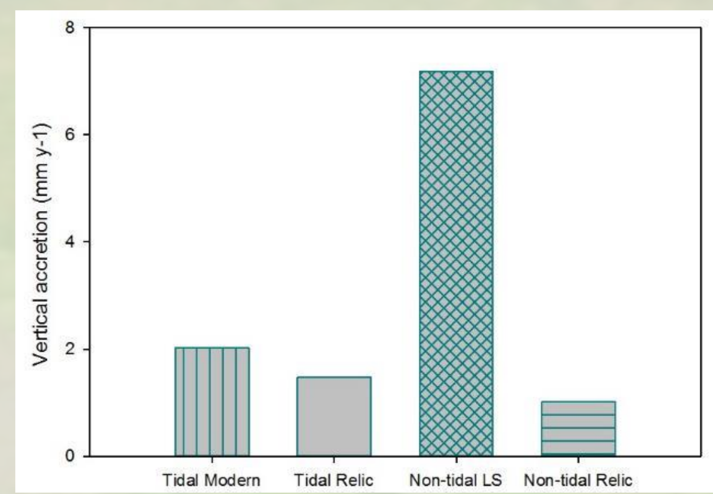


Table 1. Current channel morphometry metrics of Kimages Creek. Values for Width-depth ratio are means (±1 std. error)

	Sinuosity Ratio	Channel Gradient (cm/m)	Width/Depth Ratio
Non-tidal reach	1.03	0.6503	3.4634 (2.38)
Tidal Reach	1.02	0.0196	106.7879 (146.58)

Contemporary Sediment Accretion:

- Sediment deposition rates (g sediment m^{-2} d^{-1}) were highest in block A and generally decreased to block C across all transects in Harris Creek and Kimages Creek tidal reach.
- Average sedimentation rates were significantly lower in the Kimages Creek non-tidal transects compared to Kimages Creek tidal and Harris Creek transects (ANOVA, P<1x10^{-7}, Tukey's HSD, P<0.0001).
- Measures of sediment deposition rates using SCTs revealed considerable spatial variation within transects (with coefficients of variation ranging between 114 to 132%, 87 to 144%, and 148 to 224% across Harris Creek, Kimages Creek tidal reach and Kimages Creek non-tidal reach, respectively).

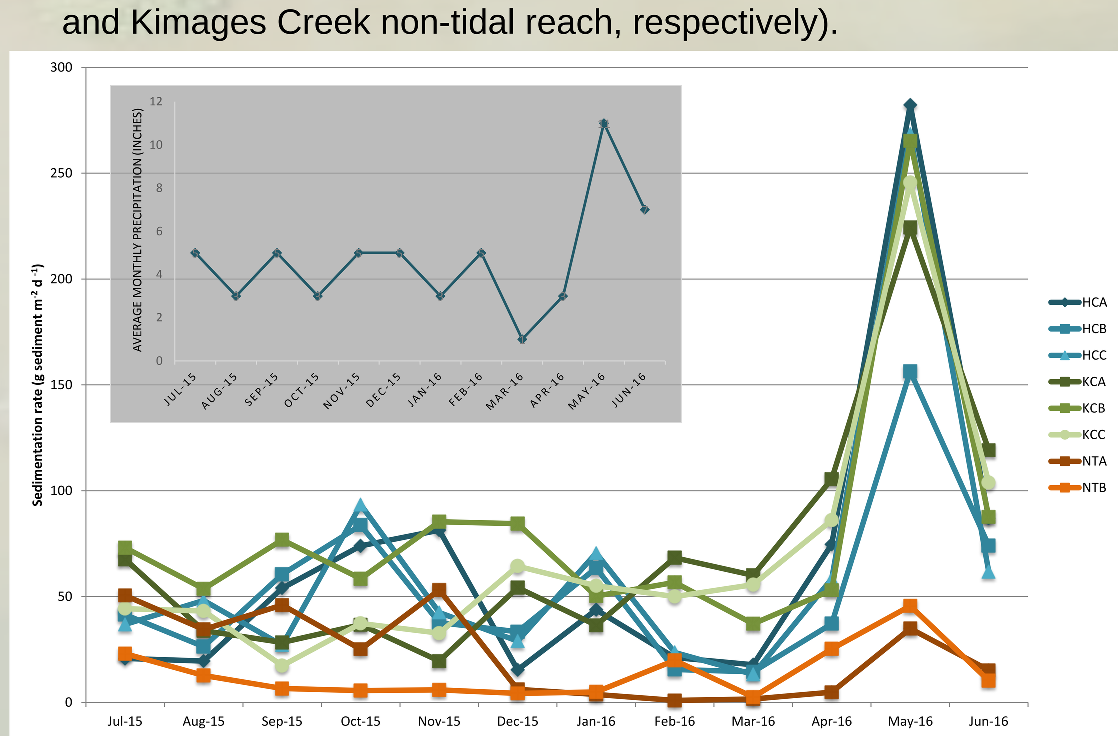


Figure 7. Average sediment deposition rates per month from July 2015 to June 2016 for all 8 transects.
*Within graph: Total monthly precipitation (inches) for Charles City County, VA during same time period.

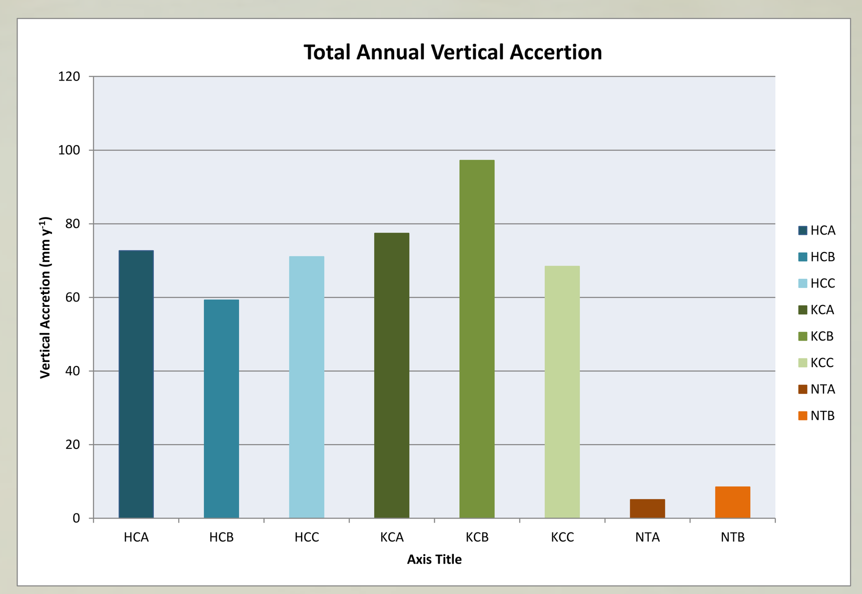


Figure 8. Total vertical accretion (mm y^{-1}) over study period for all SCT transects

Conclusions

Legacy Sediment Characterization:

- In milldam impacted, Mid-Atlantic piedmont streams, Legacy Sediment accumulation and stream incision increased with proximity to the dam. However, the opposite trend was observed within this low-gradient coastal plain stream[1,3,5].
- While the increase in carbon accumulation rates from relic soil to modern/LS soil were similar between the tidal and non-tidal cores vertical accretion rates were not. In the non-tidal portion of Kimages Creek, vertical accretion was sevenfold higher in the Legacy Sediments compared to relic hydric soils. However, within the tidal reach, vertical accretion was similar between the relic hydric and modern hydric soil and were comparable to the relic hydric soil in the non-tidal core. These findings suggest that in the tidal portion of the stream and adjacent wetlands, modern hydrology and sedimentation was not substantially altered from pre-impoundment conditions.
- In milldam-impacted streams, the accumulation of LS led to decreased floodplain connectivity through stream incision. Current research suggests removing LS to restore the naturally occurring, buried riparian wetlands[5]. However, our study suggests that in coastal plain streams impacted by dams, the subsequent LS may be a beneficial sediment source in stream reaches that are expected to be impacted by rising sea levels.

Contemporary Sediment Accretion:

- In the tidal reaches of Kimages and Harris Creek, the greatest rates of sediment deposition occurred closest to creek banks indicating tidal influence and duration of inundation are strong drivers in sediment deposition at this site.
- The significantly lower rates of sedimentation deposition in the non-tidal reach of Kimages may result from a lack of tidal subsidies and higher stream incision compared to the tidal transects, leading to decreased floodplain connectivity.
- While sedimentation rates were highly variable within and across transects, sediment deposition tended to follow precipitation patterns closely. The largest spike in sediment deposition across all transects occurred during May 2016 which corresponds to the wettest month during the sampling period.

Future Work

- Cesium^{137} dating will be conducted within Kimages Creek and Harris Creek to gain a more accurate estimate of decadal scale vertical accretion and carbon accumulation.
- Surface Elevation Tables (SETs) and feldspar marker horizons were established in both sites and in two neighboring tidal freshwater forested wetlands to understand how accretion/erosion/subsidence within Kimages Creek restoration site compares to natural reference wetlands in the lower James River watershed.

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