Hydrodynamic Processes and Resilience of Bare Creek-Flat Systems in Estuaries

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1. Introduction

In the Western Scheldt and other estuaries, creeks are common features, intersecting tidal flats and often fixated by vegetation (i.e. marshes or mangroves). On the bare tidal flat, creeks are also persisting without significant migration despite the absence of stabilizing vegetation (Figure 1). Our objective is to investigate the hydrodynamic processes and bed properties governing the stability of bare creek-flat systems, focusing on a site in the Loire estuary, France.

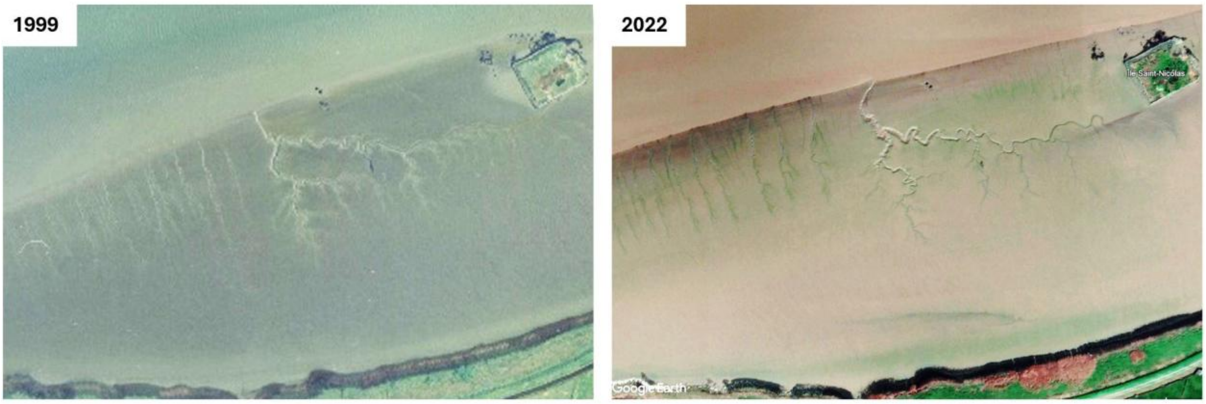

Figure 1: Tidal flat - creek system in the Loire Estuary (FR), 1999 (left) and 2022 (right). (IGN and Google Earth Engine). We measured in the creek indicated by the purple arrow.

2. Methods

Field measurements were conducted in the Loire estuary across two spring-neap tidal cycles to capture the hydrodynamics and sediment characteristics of a creek-flat system. In an extensive field campaign, we deployed frames to measure flow velocity and water level at 10 locations on the tidal flat, close to the creek and in the creek simultaneously. Additionally, sediment samples were collected from 55 sites, and photogrammetry drone flights captured changes in bathymetry during the campaign. Historical maps and images (1784 – 2024) provided insights into the long-term evolution of the creek-flat system.

3. Results

The creek-flat system in the Loire estuary has developed over 200 years, with a creek structure emerging after the siltation of a secondary channel in the 1970s. Since then, the creek has stabilized into a network of shallow runnels across the tidal flat, which has shown minimal morphological change over the last 25 years despite exposure to large erosive events (Figure 1). Bathymetric stability observed over two spring-neap tidal cycles further suggests the system's resilience.

The flow pattern on the tidal flat is influenced by the tidal flat shape and the tidal flow of the Loire river. Longshore tidal flows dominate the lower flat, likely limiting creek depth, while delayed dewatering on the upper flat enhances cross-shore flows, which may direct water toward the creek. Within the creek itself, the flow remains primarily parallel to the creek channel, a condition that reinforces the creek's stable form and prevents lateral migration. During spring tides, the net outflow volumes trough the creek are 2 – 3 times the geometric volume of the creek, implying that the creek not only dewaters itself but also part of the tidal flat. Although our frames near the creek did not capture direct flow pathways from the flat toward the creek, the veined network and continuous water flow within the creek during low tide suggest alternative pathways. This may include groundwater discharge or subsurface flow through the runnels, which act as drainage 'highways' channeling water toward the main creek. In the creek, peak flow velocities were reached at the end of the ebb tide, suggesting a self-scouring mechanism that maintains channel depth. The next step is to investigate how these peak velocities compare to the strength of the bed material to better understand whether the peak flows are sufficient to clear deposited material without eroding the bed, thereby contributing to the creek's stability.

With this research we unravel the hydrodynamic processes and resilience of bare creek-flat systems, providing a new understanding of the role of creeks in marine ecosystem functionality and morphological stability.