

Structural control and sediment dynamics in a deep Amazonian tidal channel

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ABSTRACT

Tidal channels are fundamental pathways for the exchange of water, nutrients, and sediments in estuarine-mangrove systems. Along the Amazon coast (western Equatorial Atlantic Ocean), more than 20 estuarine systems encompass approximately 8000 km² of mangroves interconnected by tidal channels. This study focuses on one such channel, the Muriá Channel, which is distinctive due to its structural origin, in contrast to the more common morphodynamic origin of most tidal channels. We conducted seasonal bathymetric, sedimentologic, and hydrodynamic surveys, capturing longitudinal and cross-sectional variations, along with detailed measurements at both ends of the channel (the Mocajuba and Curuçá estuaries). Results indicate that the channel is deep, with an average depth (10 m) twice the mean spring tidal range (5 m). Bottom morphology and sediment mapping revealed basement outcrops and minimal temporal variation. This stability contrasts with the dynamic equilibrium of shallow, high-connectivity tidal channels, where frequent sediment resuspension and deposition drive morphological change. The channel's structural framework maintains its characteristic deep, narrow morphology, which sustains continuous hydrodynamic circulation throughout the tidal cycle. This configuration results in substantially reduced bed shear stresses and minimized sediment transport convergence - both key factors that typically promote rapid infilling and instability in shallower systems. Acting as a conduit between the Mocajuba and Curuçá estuaries, the channel facilitates seasonal import of Amazon-derived particulate matter, imparting a distinct rainy-season signature to the system's sediment composition and dynamics.

1. Introduction

Tidal channels are the fundamental arteries of coastal wetlands, integral to the morphodynamic feedback loops that shape these globally valuable ecosystems. As the primary conduits for the exchange of water, sediments, nutrients, and organic matter, they directly control the geomorphic structure and ecological function of tidal flats, salt marshes, and mangroves worldwide (Perillo, 2009; Fagherazzi et al., 2012; Hughes, 2012). Their efficient drainage is a primary control on the development and stability of tidal plains, directly governing the establishment, productivity, and spatial extent of mangroves (Gomes et al., 2025) or salt marshes (Fagherazzi et al., 2012). This hydrodynamic

linkage is essential for the broader ecosystem, as channels allow the mass and energy transfers that sustain the high biological productivity of these areas, connecting the intricate internal creek network with the external coastal ocean (Wolanski et al., 1992; Novakowski et al., 2004; Perillo, 2009).

Formed over tidal plains and maintained by the bidirectional flow of tides (Fagherazzi and Furbish, 2001), these connecting environments represent a fundamental circulatory system through which water, nutrients, sediments, organic matter, and pollutants circulate between flooded zones and adjacent areas. They are often the first morphological elements to develop in flooded coastal regions (Perillo et al., 2009), with their formation being significantly influenced by tidal asymmetry (Wang

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et al., 2002; D'Alpaos et al., 2008; Mazda and Wolanski, 2009).

The classification of these environments considers both the persistence of water in the channels during low tide and the size of the watercourses (Perillo, 2009). Studies by Araujo Jr. and Asp (2013) and

Gomes et al. (2020) identified that the asymmetry of tidal currents, associated with the formation of estuarine maximum turbidity zones, can accelerate the infill of tidal channels and interconnected estuarine systems. High-connectivity tidal channels serve as important pathways

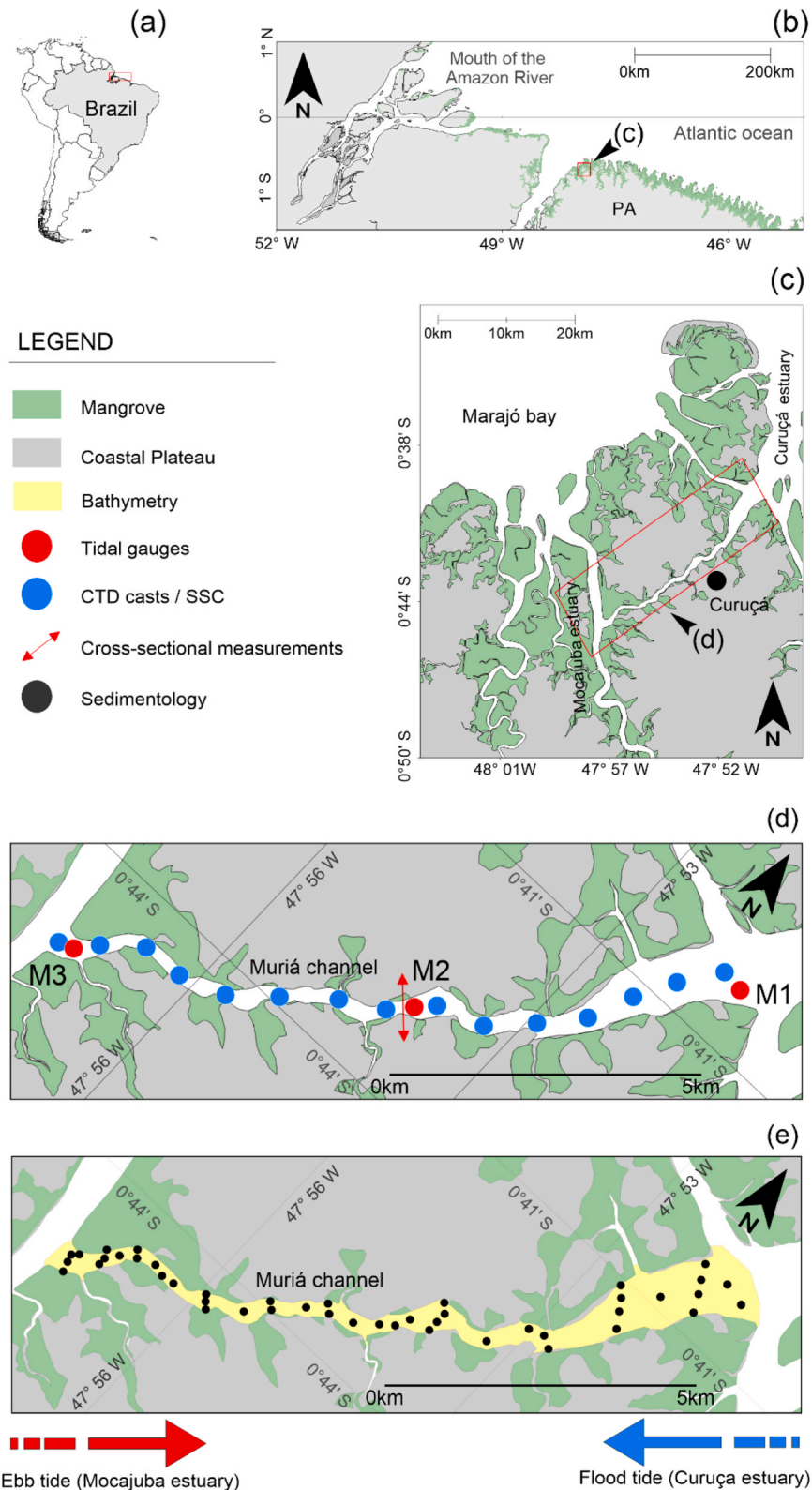


Fig. 1. Map of (a) - South America; (b) - Eastern sector of the Amazon coast; (c) - Location of the Muriá tidal channel between the Mocajuba and Curuçá estuaries; (d) - Muriá tidal channel, showing CTD cast points, and water-level measurements; and (e) - Muriá channel area of bathymetric survey, sediment sampling and moorings (hydrodynamics).

between adjacent estuaries, both from a hydrodynamic perspective (Araújo et al., 2013; Asp et al., 2012; Capo et al., 2006; Gomes et al., 2020) and a biological perspective (Magalhães et al., 2015; Pereira et al., 2017).

In contrast to most channels in the Amazon Coastal Zone, whose evolution is strongly influenced by tides and results in shallow systems, there are also deep channels whose formation may be associated with neotectonic events (Costa et al., 1996). Among these is the Furo do Muriá channel, the subject of this study, stands out. Its morphological and hydrodynamic characteristics, such as low tidal asymmetry and an average depth exceeding 9 m, suggest a strong structural influence on its genesis and evolution.

While the geomorphology of shallow, tide-dominated channels in the region is increasingly documented (e.g., Asp et al., 2016; Gomes et al., 2020), the formative processes and evolutionary pathways of anomalously deep and stable channels remain poorly understood. Investigating such channels is therefore essential, not only to explain local anomalies but also to refine broader models of coastal evolution by quantifying the role of inherited structural controls in a modern sedimentary system, fed by sediments of a common origin, primarily from the discharge of the Amazon River (Asp et al., 2016).

Most watercourses along the Amazon coastal zone are typically shallow systems whose morphology and dynamics are primarily shaped by tidal processes and by the strong interaction between fluvial discharge and marine forcing (Asp et al., 2018; Nittroer et al., 2021; Xie et al., 2022). In contrast to this regional pattern, the Furo do Muriá channel stands out for its remarkable depth and relatively straight course, features that suggest structural control on its origin and evolution. Therefore, the main objective of this study is to investigate the morphological and hydrodynamic characteristics of this deep tidal channel, aiming to understand how neotectonic factors may have influenced its formation and differentiation from other coastal systems in the region

2. Study area

The Furo do Muriá tidal channel is located between the estuaries of the Curuçá and Mocajuba rivers. It spans approximately 16 km in length and features a significant depth with a relatively straight course (Fig. 1). Its location is defined by the coordinates 00° 43' 48" South latitude and 047° 51' 06" West longitude.

The coastal plain in this region exhibits highly dynamic transitional environments, shaped by the meteorological and oceanographic conditions of the area (Mácola and El-Robrini, 2004). Salinity in the region ranges from 7 during the rainy season to 39 during the dry season. The vegetation along the estuary margins is dominated by mangrove forests, particularly *Rhizophora mangle* L. and *Avicennia germinans* (L.) L., which are partially flooded during high tides.

The tidal range is approximately > 5 m during equinoctial spring tides (Gomes et al., 2021). Strong currents in the area reach velocities ranging from 0.97 to 1.081 m/s, which are the primary drivers behind the formation of numerous sandbanks arranged perpendicularly to the coastline (Mácola and El-Robrini, 2004). This equatorial region is characterized by an average temperature of approximately 27°C, a small thermal amplitude, and abundant precipitation exceeding 2000 mm annually. The rainy season occurs from January to June, while the dry season spans July through December (Martorano et al., 1993; Moraes et al., 2005).

The region's terrain is characterized as a low estuarine coastline, interspersed with the bays of Curuçá and Cajutêua, bordered by extensive muddy plains that are frequently drained by tidal channels. To the north, fluvio-marine plains dominate, while in the southern and south-eastern portions, a strip of plateaus belonging to the Lower Amazon Plateau can be found (Mendes et al., 2015). In terms of soil composition, the region is predominantly characterized by yellow latosols with medium texture, lateritic concretionary soils, and indiscriminate mangrove

soils (Silva et al., 2012).

3. Methods

3.1. Longitudinal and moored hydrodynamic surveys

In order to identify the propagation and deformation of the tide along the channel during low and high fluvial discharge, water levels were measured using Onset/HOBO® (U20-002-Ti) pressure sensors sampling at 1 Hz. These tidal gauges were installed at three points along the tidal channel, with approximately 4 km of spacing between locations (Fig. 1-d). The instruments were deployed in both dry season (16–22 October 2024) and rainy season (18–25 April 2025). The tide signal was analyzed at sea level using harmonic analysis.

Longitudinal profiles of salinity and suspended sediment concentration (SSC) were obtained along the Muriá tidal channel during the dry season under spring tide conditions on 18 October 2024 and neap tide conditions on 22 October 2025. During the rainy season, measurements were conducted under spring tide conditions on 20 April 2025 and neap tide conditions on 25 April 2025. Vertical water column profiles were collected using a Sea and Sun CTD 90 M probe (conductivity, temperature, and depth), which was additionally equipped with a Seapoint® turbidity sensor, with a sampling frequency of 24 Hz (24 samples per second). The water column profiles were spaced approximately 1 km apart, totaling 15 measurement profiles, performed during flood and ebb tides under both spring and neap tide conditions (Fig. 1-d).

Suspended sediment concentration (SSC) was estimated by collecting water samples with a Niskin sampler at approximately 30 cm below the surface. Sampling was conducted simultaneously with the CTD casts. Water samples were stored in plastic bottles, and SSC was determined through filtration using a vacuum pump and fiberglass filters with a 44 mm diameter and 0.6 µm pore size. Turbidity values were correlated with SSC, resulting in a quadratic polynomial relationship ($SSC (g \cdot L^{-1}) = 0.000006(OBS)^2 + 0.0005(OBS) + 0.1168$), with $R^2 = 0.824$. This equation was used to convert turbidity into SSC.

Current velocities were measured in the middle portion of the tidal channel using a Teledyne® Acoustic Doppler Current Profiler (ADCP), Workhorse Monitor model (1200 kHz). Measurements were conducted during the dry season under spring tide conditions on 17 October 2025 and neap tide conditions on 21 October 2024, and during the rainy season under spring tide conditions on 19 April 2025 and neap tide conditions on 24 April 2025. Data was recorded every 20 min and processed using WinRiver II software. In addition, CTD vertical profiles were collected every 30 min to obtain salinity and turbidity data over a 13-hour tidal cycle (Fig. 1-d).

3.2. Bathymetric and sedimentological surveys

Bathymetric data and bottom sediment samples were collected on 17 April 2015 to assess variations in bottom morphology along the tidal channel. Data were recorded using a Furuno 4100 echo sounder (50/200 kHz) and a Garmin 60Csx satellite positioning system (GPS) (Fig. 1-e). Approximately ~60 km of bathymetric profiles were surveyed, with a spacing of 50 m between the cross-sectional profiles. To evaluate the bottom sedimentology, 41 sediment samples were collected during the dry season. Due to its morphological characteristics and limited sediment supply, no significant seasonal variations are expected in bottom sediment characteristics. The samples were obtained using a Petersen grab sampler. Sampling followed a transverse profile pattern, with 4–5 cross-channel samples (Fig. 1-e).

In the laboratory, salt was removed from each sample by rinsing with freshwater, and organic matter was removed by oxidation using H_2O_2 . For grain size distribution, the sediments were analyzed following the methodology proposed by Lindholm (1987), using sieves with $\frac{1}{4}$ -Phi (Φ) increments (Wentworth, 1922) to determine the granulometric variation of the samples. The methodology of Suguio (1973) was applied for

the fine sediment fraction, which is based on Stokes' law and considers sedimentation velocities for different particle sizes. Subsequently, a statistical analysis of the sediments was performed using the Sysgran software (Camargo et al., 1999), following the formulas of Folk and Ward (1957).

These methods allow the calculation of parameters such as mean grain size, standard deviation, kurtosis and grain-size skewness (Table 1), enabling the classification of grain-size distributions and providing insights into erosional or depositional trends, sediment sources, and sedimentary dynamics from a broader perspective (Folk, 1966).

Bathymetric and sedimentological data were subsequently evaluated using Surfer 13.0 software (Golden Software). In both cases, the grids were generated with a 1 m spacing using the kriging interpolation method with a linear variogram model. Spatial analysis based on kriging provides, on average, unbiased estimates with minimum variance (Ferreira et al., 2013).

4. Results

4.1. Morphology and sedimentology

Based on the bathymetric data, it was possible to identify the main morphological features of the Muriá Channel, characterized by pronounced depth and a predominantly straight course, with an absence of developed meanders. It presents a sinuosity of 1.085. The greatest depth recorded occurs in the portion closest to the estuary mouth of the Curuçá River, reaching up to 25 m (Fig. 2 - b). The average width of the channel is approximately 830 m (0.83 km), being wider at the confluence with the Curuçá River estuary (1689 m) and narrower at its terminal portions, with about 600 m in the sector connected to the Mocajuba River estuary and 610 m in the central portion.

The granulometric analysis of the sediments along the channel revealed the following average composition: gravel (~6 %), sand (~67 %), and silt (~27 %). The average depth of the channel is around 8 m, varying between 1 m and 25 m. The most filled portion of the channel is located at the end connecting to the Curuçá River estuary, evidencing a significant influx of sandy sediments from the continental shelf (Figure- 2-d). These sediments constitute the sandbanks formed by ebb and flood deltas, which are exposed during low tides in the bay of the Curuçá estuary.

The sedimentological distribution along the channel shows that coarse to medium sand fractions are concentrated in areas with outcrops of the Barreiras Formation. These outcrops serve as important local sediment sources, contributing to the presence of coarser grains. In contrast, fine to very fine sand fractions exhibit greater dispersion and are associated with direct contributions from the continental shelf. These fractions are characterized by well to very well sorted sediments and positive asymmetries, indicating more homogeneous deposition environments.

Finally, in samples from the central portion of the channel and near the connection with the Mocajuba River estuary, a distinct pattern was observed, with a tendency towards the presence of poor to badly sorted sediments. This behavior reflects the influence of rocky outcrops and cliffs located along the channel's margins, which promote greater

granulometric heterogeneity (Fig. 2-a). This mixture of fractions compromises natural selection and deposition processes, resulting in a more irregular and complex sedimentary configuration in these regions.

Regarding the channel cross-sectional area (Fig. 2- c and d), it can be observed that, in addition to the characteristic "V"-shaped profile, indicative of structural control, the mean depth ranges from 8 to 15 m. Channel banks are wider in the southwestern portion, where it connects to the Curuçá River estuary, resulting in a cross-sectional area approximately 80 % larger than in the northwestern sector, which connects to the Mocajuba River estuary and exhibits a narrower channel width.

4.2. Tidal propagation, hydrodynamics and sediment transport

In general, tidal wave dynamics propagate symmetrically along the tidal channel, becoming more pronounced during the rainy seasons due to increased fluvial input from adjacent estuaries. In the dry season, however, an asymmetry in tidal currents is observed. Owing to the morphological characteristics of the channel particularly its depth and predominantly straight course the tide propagates without significant frictional or convergence effects (Figs. 3 and 4).

Fig. 3-c shows that high tides propagate along the channel from M1 to M3, with a delay of approximately 50 min during the rainy season, along with a 10-minute difference in the transition from spring to neap tide. In the dry season, the tidal propagation delay is reduced to about 40 min (Fig. 4-c).

Regarding tidal phase durations, a slightly symmetric pattern was observed during the rainy season, with a ~25-minute difference between flood and ebb phases. However, this pattern became asymmetric in the dry season, where the ebb phase lasted ~1 h longer than the flood phase. During the rainy season, the average duration of the ebb and flood phases was approximately 6 h and 25 min and 6 h, respectively. In the dry season, the ebb phase lasted about 6 h and 45 min, while the flood phase lasted 5 h and 30 min (Figs. 3 and 4-b).

Harmonic tidal analysis was performed on the sea level time series at the Curuçá, Central Channel and Mocajuba stations in order to extract the sea level variation associated with the M2 tidal constituent. This constituent represents the main component of sea level variability in the Amazon region (Beardsley et al., 1995). A cross-correlation analysis was subsequently performed between the M2 amplitude time series, with Curuçá serving as the reference point. The spatial variability of the M2 amplitude and phase lag is summarised in Table 2. The damping ratio of the M2 amplitude between Curuçá and Mocajuba is 0.027 (1–2.16/2.22), indicating 2.7 % attenuation, and the estimated M2 tidal wave celerity is 14 km/h.

During the rainy season (Table 3), maximum suspended sediment concentrations (MPS) reached 2.0 g·L⁻¹ during flood phase and 1.32 g·L⁻¹ during ebb phase under spring tide conditions (Fig. 5-b). During neap tides, these values decreased to 1.64 g·L⁻¹ (flood) and 1.32 g·L⁻¹ (ebb). Salinity measurements (Fig. 5) revealed average values of 8 (flood) and 9 (ebb) during spring tides, while neap tides showed slightly higher averages of 10 (flood) and 9 (ebb). The highest MPS concentrations were consistently recorded in the southwest portion of the Furo do Muriá tidal channel, reflecting the strong hydrodynamic influence of the Mocajuba River estuary on this area. (Fig. 6)

During the dry season, the maximum values of SSC concentration, under spring tide conditions (Table 4), were 0.32 g·L⁻¹ (flood) and 0.84 g·L⁻¹ (ebb). Salinity varied between 24 and 36 during this period. Under neap tide conditions, the maximum SSC values were 0.72 g·L⁻¹ (flood) and 0.51 g·L⁻¹ (ebb), with salinity oscillating between 25 and 36 (Figs. 7 and 8).

During the rainy season, current velocities showed nearly identical average and maximum values between flood and ebb phases under spring tide conditions (Table 5). Suspended Sediment Concentrations (SSC) averaged 0.175 g·L⁻¹ during flood tide and 0.157 g·L⁻¹ during ebb tide, while salinity ranged from 8.25 to 9.18 (Fig. 9-a and b).

A similar pattern of phase equivalence was observed during neap

Table 1
Statistical granulometric parameters, according to Folk & Ward (1957).

Parameters	Formula from FOLK & WARD (1957)
Mean	$M = \frac{\phi_{16} + \phi_{84} + \phi_{50}}{3}$
Standard deviation	$\sigma = \frac{\phi_{16} - \phi_{84}}{4} + \frac{\phi_{95} - \phi_{5}}{6.6}$
Skewness	$Sk = \frac{\phi_{16} + \phi_{84} - 2\phi_{50}}{2(\phi_{16} - \phi_{84})} + \frac{\phi_{95} + \phi_{5} - 2\phi_{50}}{2(\phi_{95} - \phi_{5})}$
Kurtosis	$KG : \frac{\phi_{95} - \phi_{5}}{2.44(\phi_{75} - \phi_{25})}$

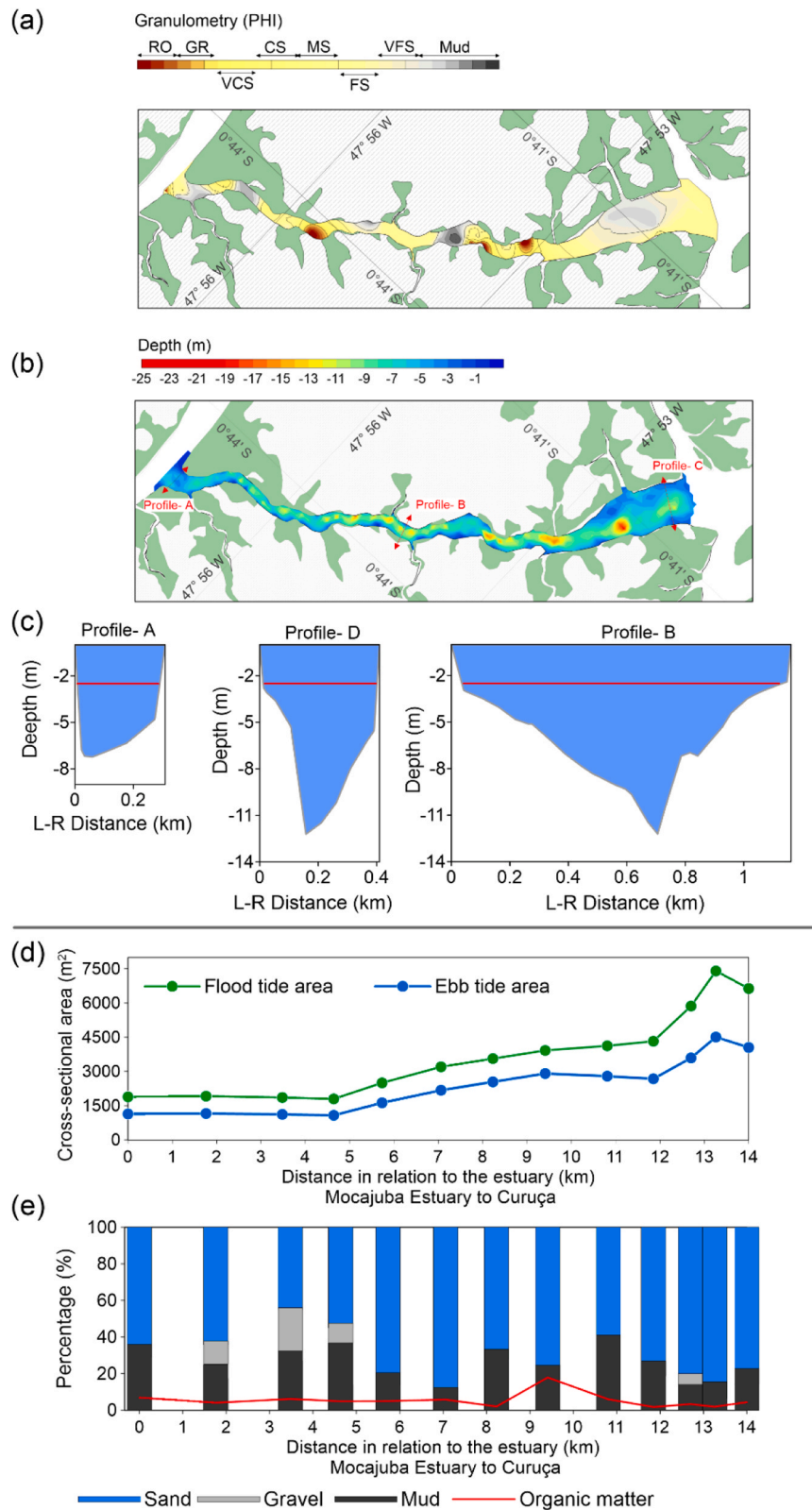


Fig. 2. (a)- Textural characteristics of bottom sediments in phi units (RO- Rock outcrop, GR- Gravel, VCS- Very coarse sand, CS- Coarse sand, MS- Medium sand, FS- Fine sand, FVS- Very fine sand and mud), (b)- Bathymetry of the Muriá tidal channel, (c)- Cross-sectional profiles "A, B and C" (red line - represents the low tide level), (d)- Cross sections of the tidal channel in flood and ebb conditions and (e)- Longitudinal variation of bottom sediments and organic matter.

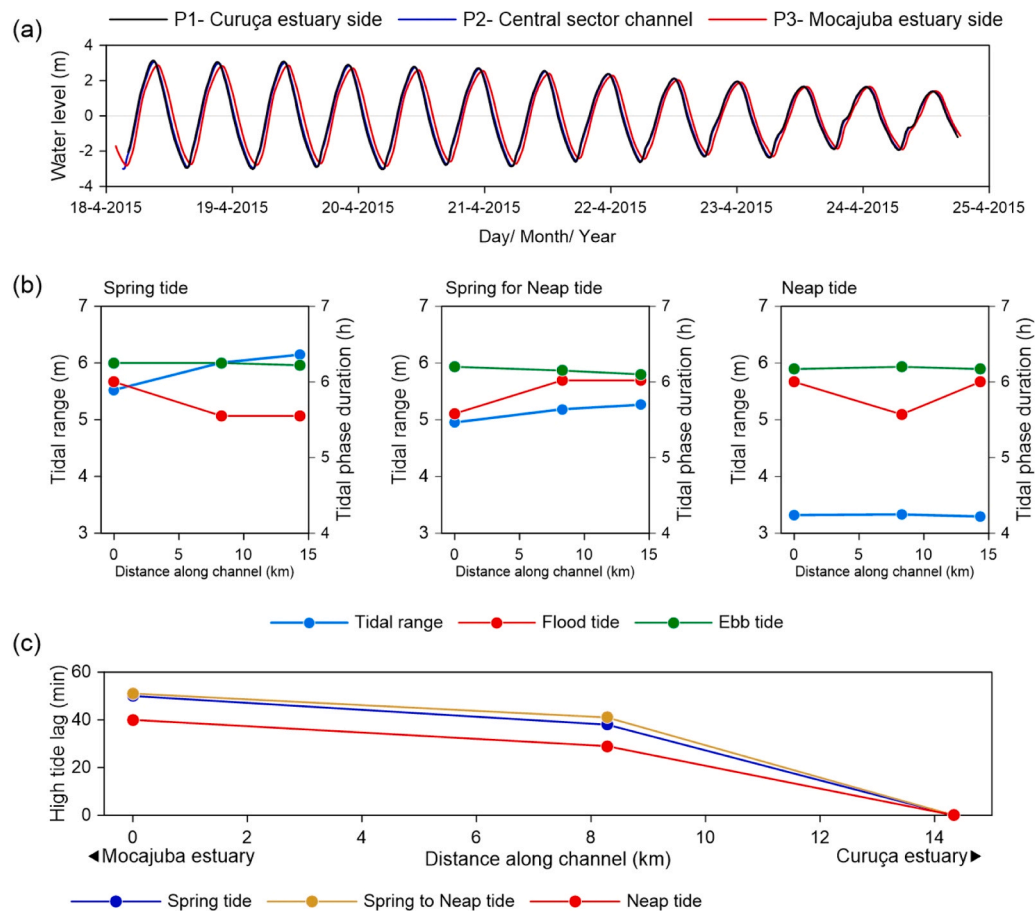


Fig. 3. Tidal records along the Muriá tidal channel, during the rainy seasons. (a)- Tidal variation at points (P1- sector of the Curuçá River estuary, P2- Central sector of the tidal channel and P3- Sector of the Mocajuba River estuary); (b)- Longitudinal variation of the tidal amplitude and duration of the tidal phases, in spring tide conditions, transition from spring tide to neap tide and neap tide and (c)- The time interval of the high tide along the channel, with the sensor closest to the Curuçá River estuary as reference.

tides for both SSC and current velocities (Table 5). However, current velocities were approximately 30 % lower than during spring tides, consistent with the reduced tidal amplitude and consequent decrease in tidal prism (Fig. 10-a and b). Under neap tide conditions, salinity values exhibited a slightly higher range of 9.11–10.72.

During the dry season (Table 6), both current velocities and SSC concentrations showed comparable average and maximum values during spring tides (Table 6), reflecting stable hydrodynamic conditions. This pattern of phase equivalence persisted during neap tides (Fig. 10-a and b).

Salinity measurements revealed consistently high values with minimal tidal variation: during spring tides, average salinity measured 34.43 (flood) and 34.94 (ebb), while neap tide conditions showed values of 34.85 (flood) and 34.79 (ebb) (Fig. 10-a and b). This narrow range (≤ 0.5) demonstrates the markedly uniform salinity regime, characteristic of the dry season.

5. Discussion

5.1. Relationship between morphology, sedimentology, and tidal propagation as a result of structural control

Following Leopold and Wolman's (1957) classification, a channel is considered meandering when its sinuosity (defined as the ratio of thalweg length to straight-line channel distance) exceeds 1.5, with perfectly straight channels having a theoretical sinuosity of 1. The Furo do Muriá Channel exhibits a sinuosity of 1.085, demonstrating significantly

straighter morphology compared to tidal channels in the region without structural controls (average sinuosity = 1.355). These characteristics indicate a strong tectonic control in its formation (Snyder et al., 2003).

Regional studies (Asp et al., 2018; Gomes et al., 2021; Silva et al., 2023) have demonstrated that tidal channels and estuaries generally display "W"-shaped cross-sections, resulting from the differentiation of flow between flood and ebb tides, which is typical of shallow coastal systems. In contrast, "V"-shaped profiles are characteristic of fluvial systems with unidirectional flow. In the study area, the cross-sectional profiles are exclusively "V"-shaped (Fig. 2-C), suggesting a strong geomorphological inheritance in which antecedent morphology exerts structural control over the contemporary channel configuration, as also observed by Silva et al. (2023) in the Mocajuba River estuarine system, adjacent to the investigated area.

An incision, due to strong currents, would be a possible explanation for the observed shape and depth of the Muriá Channel, but the observed currents are relatively slow, in comparison to other, shallower, channels in the region. Therefore, the channel geometry in terms of depth and cross-sectional shape are not consistent with the observed hydrodynamic regime, implying that the system is presently out of morphodynamic equilibrium, whereas the reason for that would be the inherited channel morphology due to structural control.

The Muriá channel is located at the so-called Pará Platform, a coastal plateau with deposition of sediments after a tectonic stabilization in the Neogene (Silva et al., 2023). Subsequently, during the Holocene, the continuous rise in sea level caused the drowning of drainage basins and part of coastal plain, and in addition activated normal faults due to

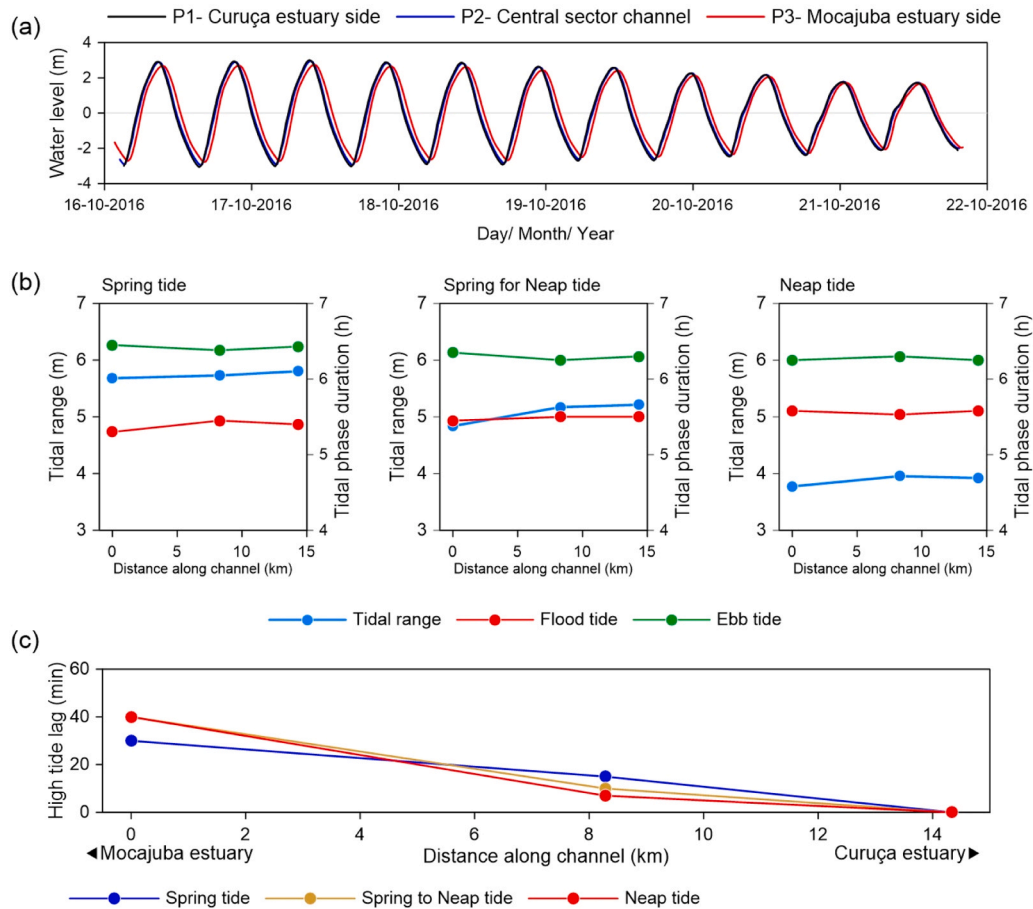


Fig. 4. Tidal records along the Muriá tidal channel, during the dry seasons. (a)- Tidal variation at points (P1- sector of the Curuçá River estuary, P2- Central sector of the tidal channel and P3- Sector of the Mocajuba River estuary); (b)- Longitudinal variation of the tidal amplitude and duration of the tidal phases, in spring tide conditions, transition from spring to neap tide and neap tide and (c)- The time interval of the high tide along the channel, with the sensor closest to the Curuçá River estuary as reference.

Table 2
Amplitude and lag of the M2 tidal component at P1, P2, and P3.

Station	Amplitude of the M2 tidal component (m)	Lag relative to P1 (hour)
P1	2.22	0
P2	2.19	0
P3	2.16	1

recent movement (Soares Júnior et al., 2010). The formation of faults and grabens in NW-SE direction from the Upper Triassic to the Lower Cretaceous, includes the formation of the Vigia-Castanhil Fault (Rossetti and Góes, 2004), which controls the geometry of the Mocajuba River. The orientation of the Muriá Channel is nearly orthogonal to the

Vigia-Castanhil Fault, and would have been formed later, with the advance of sedimentation on the continental margin of the Amazon River load, resulting in subsidence there, as well as uplift and minor faulting in the Pará Platform (Souza-Filho et al., 2009).

The sedimentological and geomorphological evidence strongly supports a structural origin for the Furo do Muriá Channel. The abundant gravel deposits along the channel bed and margins likely result from subsidence and uplift of Barreiras Formation blocks. Tidal flows mainly transport fine sands during peak flood and ebb phases, with mud deposition occurring during lower-energy periods. Grain-size analysis revealed that > 50 % of sediment samples were poorly sorted, and nearly one-third exhibiting negative skewness. This contrasts sharply with Furo Grande, a “morphodynamic” tidal channel where < 25 % of samples were poorly sorted, and only 3 % showed negative skewness

Table 3
Salinity and SSC data for spring and neap tide conditions during the rainy season.

Spring tide	Flood tide			Ebb tide		
	Maximum	Minimum	Average	Maximum	Minimum	Average
Salinity	8.79	7.58	8.18	9.65	8.31	9.09
SSC (g.L ⁻¹)	2	0.10	0.28	1.31	0.13	0.26
Neap tide	Flood tide			Ebb tide		
	Maximum	Minimum	Average	Maximum	Minimum	Average
Salinity	10.65	9	10	9.65	8.3	9.09
SSC	1.64	0.10	0.12	1.31	0.13	0.26

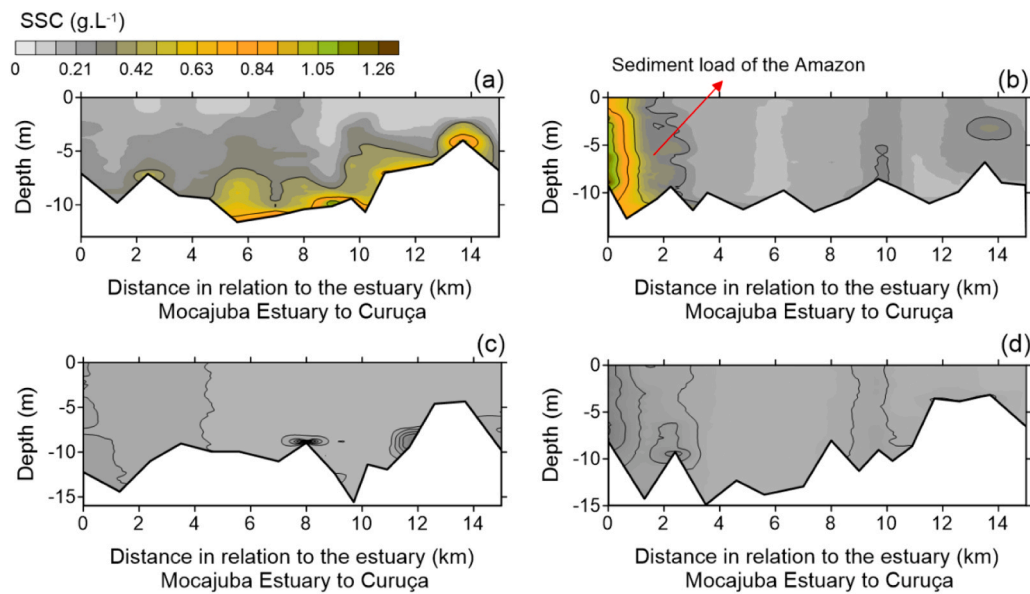


Fig. 5. Longitudinal and vertical variation of SSC in spring tide conditions (a) - flood tide and (b) - ebb tide; and neap tide condition (c) - flood tide and (d) - ebb tide during the rainy season.

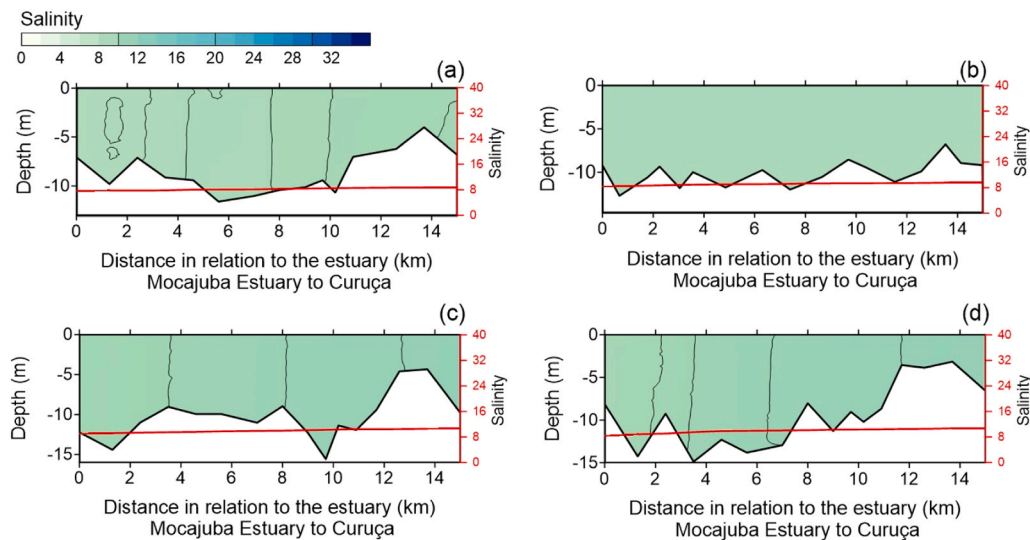


Fig. 6. Longitudinal and vertical variation of Salinity in spring tide conditions (a) - flood tide and (b) - ebb tide; and neap tide condition (c) - flood tide and (d) - ebb tide during the rainy season.

Table 4
Salinity and SSC data for spring and neap tide conditions during the dry season.

Spring tide						
	Flood tide			Ebb tide		
	Maximum	Minimum	Average	Maximum	Minimum	Average
Salinity	35.92	30.67	35.10	35.94	24.25	35.46
SSC (g.L ⁻¹)	0.30	0.10	0.15	0.84	0.10	0.15
Neap tide						
	Flood tide			Ebb tide		
	Maximum	Minimum	Average	Maximum	Minimum	Average
Salinity	36	25.58	35.04	36.12	27.66	35.74
SSC	0.7	0.01	0.14	0.51	0.10	0.11

(Gomes et al., 2020). Tidal asymmetry, a key feature of coastal systems driven by nonlinear shallow-water processes (Dronkers, 1986; Speer, 1984; Silva et al., 2023), manifests in the Furo do Muriá channel near the Curuçá river estuary due to its reduced cross-sectional area (Fig. 2 -c). In Amazonian coastal systems, such asymmetry fundamentally controls

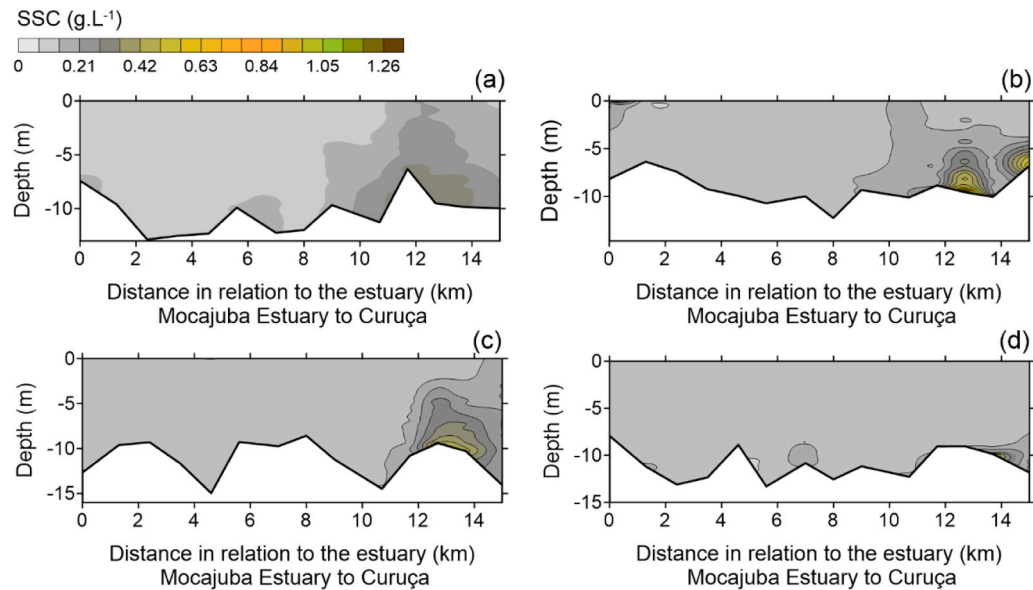


Fig. 7. Longitudinal and vertical variation of SSC in spring tide conditions (a) - flood tide and (b) - ebb tide; and neap tide condition (c) - flood tide and (d) - ebb tide during the dry season.

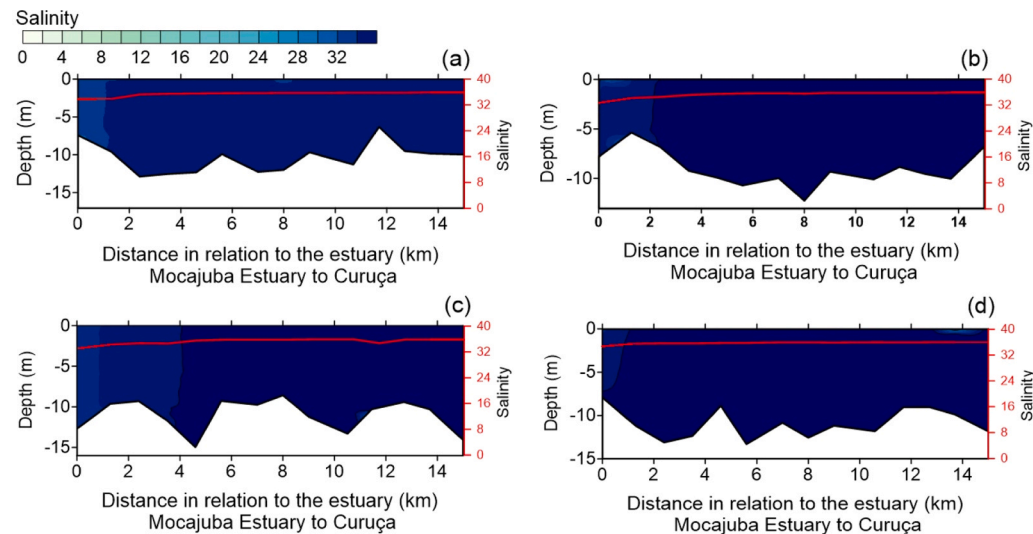


Fig. 8. Longitudinal and vertical variation of Salinity in spring tide conditions (a) - flood tide and (b) - ebb tide; and neap tide condition (c) - flood tide and (d) - ebb tide during the dry season.

Table 5
Current velocity, salinity, and SSC data from the middle portion of the Muriá channel during the rainy season.

Spring tide						
	Flood tide			Ebb tide		
	Maximum	Minimum	Average	Maximum	Minimum	Average
Current Velocity	1.01	0.16	0.77	1.13	0.14	0.80
Salinity	8.99	8.32	8.74	9.18	8.25	8.88
SSC	0.19	0.15	0.17	0.20	0.07	0.15
Neap tide	Flood tide			Ebb tide		
	Maximum	Minimum	Average	Maximum	Minimum	Average
	0.79	0.05	0.50	0.84	0.08	0.56
Current Velocity	10.68	9.11	10.02	10.72	9.48	10.21
Salinity	0.12	0.07	0.09	0.12	0.05	0.09
SSC						

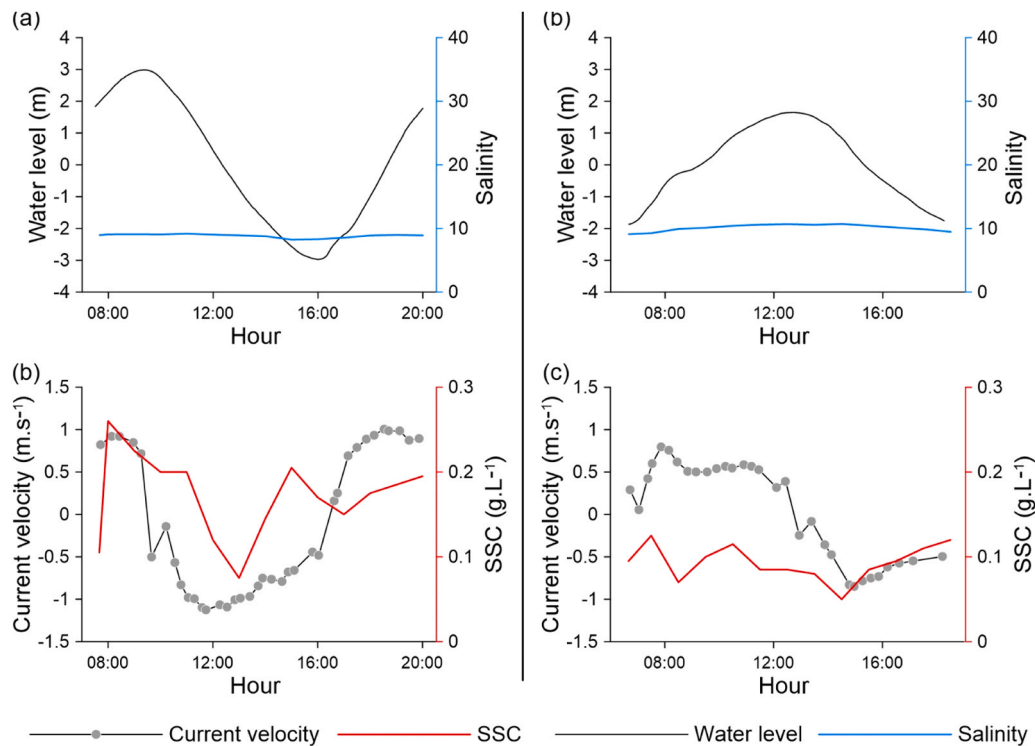


Fig. 9. Hydrodynamics during the rainy season:(a) Water level and salinity and (b) SSC and current velocity under spring tide conditions; (c) Water level and salinity and (d) SSC and current velocity under neap tide conditions.

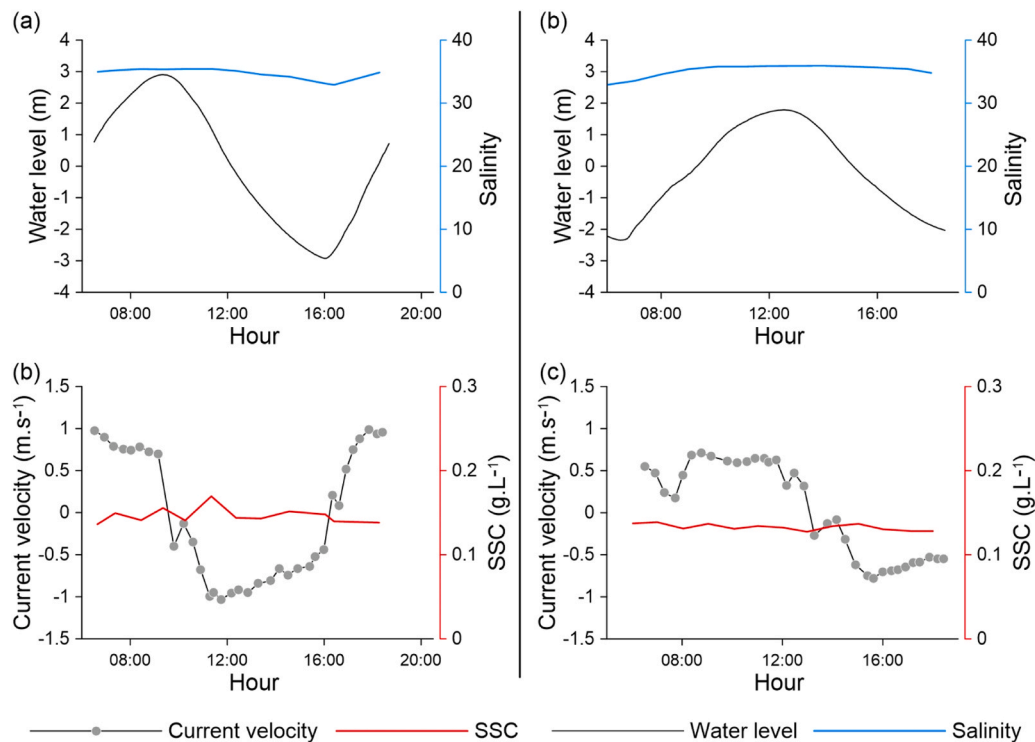


Fig. 10. Hydrodynamics during the dry season:(a) Water level and salinity and (b) SSC and current velocity under spring tide conditions; (c) Water level and salinity and (d) SSC and current velocity under neap tide conditions.

coastal morphodynamics by determining sediment import/export regimes in estuaries (Asp et al., 2012; Asp et al., 2016; Gomes et al., 2021; Santos et al., 2025) and influencing transport convergence in high-connectivity tidal channels (Gomes et al., 2020), often leading to

channel infilling. Unlike typical shallow systems, the deep Furo do Muriá channel exhibits minimal tidal wave deformation along its length. Here, tidal asymmetry becomes apparent only during transitional (spring-to-neap) and neap tide conditions (Figs. 3 and 4-b), reflecting its

Table 6

Current velocity, salinity, and SSC data from the middle portion of the Muriá channel during the dry season.

Spring tide						
	Flood tide			Ebb tide		
	Maximum	Minimum	Average	Maximum	Minimum	Average
Current Velocity	0.98	0.39	0.73	1.03	0.13	0.70
Salinity	35.13	33.94	34.43	35.43	34.20	34.94
SSC	0.15	0.13	0.14	0.17	0.14	0.14
Neap tide						
	Flood tide			Ebb tide		
	Maximum	Minimum	Average	Maximum	Minimum	Average
Current Velocity	0.71	0.17	0.52	0.78	0.08	0.53
Salinity	35.90	32.94	34.85	35.60	35.94	34.79
SSC	0.13	0.13	0.13	0.13	0.12	0.13

distinct hydrodynamics compared to shallower counterparts.

Studies conducted in the North Branch of the Yangtze River (Dai et al., 2011; Dai et al., 2016), Nanhui and Jiuduansha Shoal in the mega-Changjiang Delta (Wang et al., 2024), in the Hangzhou Bay (Xie et al., 2013) and in the Qiantang Estuary, China (Xie et al., 2017, 2022), have demonstrated that tidal current propagation exerts a strong influence on the morphodynamic evolution of coastal systems. The interaction between tidal propagation and local morphological patterns directly controls the processes of channel infilling and estuarine evolution.

5.2. Effect of structural control on hydrodynamic connectivity

The Furo do Muriá channel represents a tectonically controlled system, embedded within the peninsula, as a fault-controlled feature (Costa et al., 1996). This structural origin imparts distinct characteristics that contrast markedly with typical coastal plain tidal channels, which are generally shallow and prone to intense sediment infilling (Gomes et al., 2020).

Tidal channels that connect adjacent estuarine systems are defined as high-connectivity channels by, as they are situated in shallow environments with extensive sandbanks that obstruct flows during low tide. This obstruction creates strong pressure gradients between adjacent estuaries, generating intense shear stresses during tidal overflow that promote sediment resuspension and significantly influence sediment budgets.

In contrast, the Furo do Muriá channel, due to its tectonic origin and substantial depth, exhibits minimal tidal attenuation along its course, effectively reducing the shear stresses characteristic of shallow tidal systems a phenomenon also documented elsewhere along the Amazon coast (Asp et al., 2012; Gomes et al., 2020).

The morphology-hydrodynamics feedback is a key control on coastal system evolution across spatiotemporal scales (Hibma et al., 2004; Dai et al., 2016; Wang et al., 2024). This relationship is particularly pronounced on the Amazon coast, where intense sediment fluxes and strong tidal forcing drive rapid geomorphological changes (Souza e Filho et al., 2023; de Freitas et al., 2025; Santos et al., 2025).

The uniform current velocities observed in the Furo do Muriá channel's mid-reach reflect its stable morphological profile, where depth sustains consistent flow throughout the tidal cycle. Similar patterns were documented by Silva et al. (2023) in the tectonically influenced Mocajuba River estuary. This deep, narrow system configuration creates unique hydrodynamic circulation that fundamentally modifies sediment transport processes (Stigebrandt, 2012; Shan et al., 2019).

The sedimentary pattern of the Furo do Muriá channel reflects significant influence from Amazon River sediment inputs, which enter the system through the Mocajuba estuary. According to Silva et al. (2023), sediment from the Amazon during the rainy season disperses into the middle portion of the Mocajuba estuary, where it connects with the Muriá channel. This seasonal input results in a significant increase in

suspended particulate matter concentrations, particularly during ebb tides when flow direction favors transport from Mocajuba toward Curuçá (Fig. 11 -b).

With regard to sediment transport onto the mangrove tidal flats along Amazonian estuaries (Asp et al., 2016) and tidal channels (Gomes et al., 2020), the results indicate that during spring tides, mangrove areas become flooded, promoting the retention of mud. A significant portion of the Amazon River sediment load is directed toward the eastern sector of the Amazon coast during the rainy season, constituting a crucial factor for the development and evolution of tidal flats and mangrove forests (Nittrouer et al., 1995). These processes represent fundamental mechanisms for the maintenance and progradation of

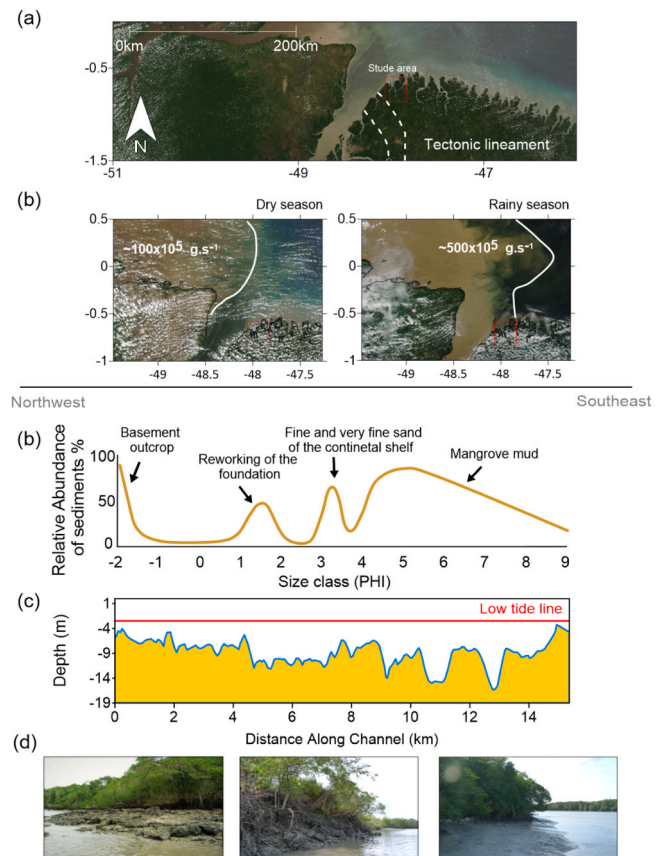


Fig. 11. (a) Amazon Coastal Zone showing the main tectonic lineament; (b) Satellite images illustrating plume dynamics during the dry and rainy seasons; (c) Relative abundance of sediment grain-size fractions in the study area; (d) Longitudinal thalweg depth profiles; and (e) Photographic images of the study area showing geomorphological features such as mangroves, outcrops, and cliff areas.

mangroves along the Amazonian coastline.

During flood tides, increased SSC concentrations are primarily driven by bed sediment resuspension. This process is most intense in the shallower portions of the channel, where reduced cross-sectional areas enhance near-bed shear velocities and mobilize consolidated sediments (Asp et al., 2012; Gomes et al., 2020).

Spatial analysis of channel morphology and sediment characteristics (Fig. 11-c and d) reveals that the largest cross-sectional areas occur in the southwestern sector adjacent to the Mocajuba estuary, with a progressive reduction toward the northwestern portion (near the Curuçá estuary). This morphological trend is associated with greater sandy sediment input from flood and ebb deltas in the Curuçá estuary bay, which promote sediment accumulation and redistribution in the northwestern channel segment (Ranieri & El-Robrini, 2012).

The combined assessment of morphology and sedimentary processes indicates that the Furo do Muriá channel experiences slower infilling compared to shallow tidal flat channels, reflecting greater geomorphological stability, a characteristic feature of structurally controlled systems. Gomes et al. (2020) emphasize that shallow, high-connectivity channels exhibit sediment transport convergence that drives rapid sedimentation in central channel portions, ultimately promoting channel closure. In contrast, deep channels like Furo do Muriá, lack this effect, as their morphology prevents significant sediment convergence, maintaining long-term hydro-sedimentary stability.

This structural and hydrodynamic configuration results in distinct sedimentary dynamics, where Amazon-derived inputs interact with local resuspension processes, while the channel's depth and morphology mitigate infilling rates highlighting the critical role of inherited tectonic controls in shaping coastal sediment pathways.

6. Conclusions

The Furo do Muriá channel represents a unique geomorphological entity within Amazonian coastal systems, distinguished by its attenuated tidal asymmetry and exceptional sediment dynamics. Its considerable depth and tectonic inheritance effectively constrain tidal distortion processes, limiting significant hydrodynamic variations to transitional spring-neap tide conditions. This stability stands in marked contrast to the dynamic equilibrium of shallow, high-connectivity tidal channels, where frequent sediment resuspension and deposition drive morphological instability.

The channel's structural framework maintains its characteristic deep, narrow morphology, which sustains uninterrupted hydrodynamic circulation throughout the tidal cycle. This configuration produces two critical effects: i) substantial reduction of bed shear stresses, and ii) minimization of sediment transport convergence - both key factors that typically promote rapid infilling and instability in shallower systems. The channel's role as a conduit between the Mocajuba and Curuçá estuaries facilitates seasonal import of Amazon-derived particulate matter, introducing a distinct rainy-season signature to the system's sediment composition and dynamics.

This integrated analysis establishes the Muriá Channel as an exemplary model of structural control in coastal geomorphology, where tectonic inheritance governs persistent channel morphology, atypical hydro-sedimentary regimes and long-term geomorphic stability. These findings fundamentally reshape our understanding of Amazonian coastal evolution by demonstrating how structural antecedents and channel depth modulate system behavior. The study highlights the necessity of incorporating geological framework analysis into predictive models of coastal morphodynamics, particularly in complex, sediment-rich environments like the Amazon margin.

CRediT authorship contribution statement

Vando J.C. Gomes: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology,

Investigation, Formal analysis, Data curation, Conceptualization. **Clauber S. Galvão dos Reis:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis. **Talita Naiff Robert:** Writing – original draft, Methodology, Investigation, Formal analysis. **Nils E. Asp:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Ariane M.M. Silva:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis. **Eduardo Siegle:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis. **Pedro Paulo de Freitas:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Formal analysis.

Declaration of Competing Interest

The authors also declare that there is no conflict of interest.

All authors agree with the publication.

Being an innovative study and in the Amazon region

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Data availability

Data will be made available on request.

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