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The impact of channel capture on estuarine hydro-morphodynamics and water quality in the Amazon delta

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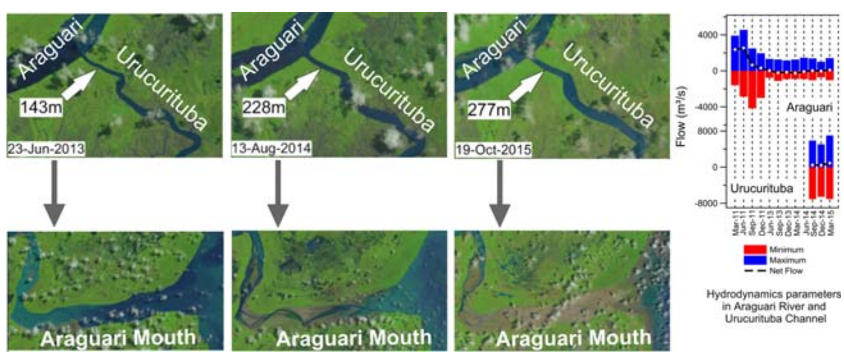
HIGHLIGHTS

- Natural diversion connected Araguari River to Amazon River in Eastern Amazon.
- Up to 98% in flowrate reduction to lower estuary and flow direction inversion.
- Flowrate reduction to estuary causes accelerated siltation process in river mouth.
- Water quality changed downstream and not affected upstream river diversion.
- Future studies are necessary to evaluate impacts to water communities.

GRAPHICAL ABSTRACT



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ABSTRACT

Due to progressive erosion of the new Urucurituba Channel, the Amazon River has recently captured almost all discharge from the lower Araguari River (Amapá-AP, Brazil), which previously flowed directly to the Atlantic Ocean. These recent geomorphological changes have caused strong impacts on the landscape and hydrodynamic patterns near the Araguari River mouth, especially the alteration of the riverine drainage system and its water quality. Landsat images were used to assess the estuarine landscape morphodynamic, particularly the expansion of the Urucurituba Channel, 80 km from the Araguari River mouth, chronicling its connection to the Amazon River. The results suggest that the Urucurituba developed by headward migration across the Amazon delta; this is perhaps the first observation of estuarine distributary network development by headward channel erosion. The rate of Urucurituba Channel width increase has been ≈5 m/month since 2011, increasing drainage capacity of the channel. We also collected in situ hydrodynamic measurements and analyzed 17 water quality parameters. Having 2011 as baseline, the flowrate of Araguari River has been diverted by up to 98% through Urucurituba Channel, with substantial changes in net discharge recorded at 3 monitoring stations. Statistically significant differences in water quality ($p < 0.05$) were observed between 2011 and 2015, associated with the change in the

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flow pattern. Estuarine salinity and solids concentrations have increased. Overall, we demonstrate changes in landscape, hydrodynamics and water quality of the lower Araguari River.

1. Introduction

Disturbances in the dynamic equilibrium of estuarine or fluvial-marine ecosystems are often caused by changes in the drainage system of the associated watershed. These changes include the creation of new deltas (Mertzanis and Mertzanis, 2013), an increased susceptibility to saline contamination (Das et al., 2012; Li et al., 2015), geomorphological changes in the river mouth (Petts and Gurnell, 2005; Kolker et al., 2012), reduced flood duration (Jolly, 1996) and changes in flora (Restrepo and Kettner, 2012). Likewise, biota and landscape ecology, including primary productivity and ecosystem services, are also affected by these changes (Kimmerer, 2002).

Estuaries present biomes with the highest value per hectare for environmental services, i.e., they provided on average US$ 28,916/ha in 2011 (Costanza et al., 2014). Estuarine rivers are responsible for important environmental services, particularly water quality, water availability, biodiversity maintenance and food production (Dias et al., 2016; Dodds et al., 2013). Changes occurring throughout the watershed have direct consequences to these environmental services. For instance, in the Araguari River region of Brazil (the object of the present study), Dias et al. (2016) estimated that ≈US$ 4003/fisherman/year is provided to artisanal fishing by estuaries due to environmental services located on the Amapá coast, highlighting the socioeconomic importance of these biomes. For these reasons, the natural richness and benefits of these ecosystems should be monitored and managed. Likewise, knowledge on hydrological dynamics of the watershed must be generated and provided to decision-makers responsible for water resources and biodiversity conservation (Dias et al., 2016).

The lower Araguari River is a large body of water with an annual average discharge rate (Q) > 1000 m^3/s. Until very recently it flowed freely from its headwaters in Tumucumaque Mountain (protected area) through the Amazon delta directly to the Atlantic Ocean. During the last 10 years, however, its estuarine drainage network has been constantly changing (Fig. 1). Most impressively, Araguari flow has largely been captured by the Amazon River via the new Urucurituba Channel (Fig. 1). The Urucurituba, located approximately 80 km upstream from the mouth of the Araguari, has recently cut through the Amazon delta, and now extends >30 km from the right bank of the Araguari to the left bank of the Amazon River. As will be demonstrated below, the Urucuritiba developed by headward erosion through the Amazon delta floodplain. Two processes have previously been identified for creation of distributary channels in a delta (Jerolmack and Swenson, 2007): mouth bar deposition leads to local channel bifurcation at the delta front (Edmonds and Slingerland, 2007; Jiménez-Robles et al. 2016), while avulsion due to deposition within main distributary channels can lead to adoption of new channels and abandonment of old channels (Slingerland and Smith, 2004; Hood, 2010; Ganti et al., 2016). However, to the best of our knowledge, no previous study has identified channel capture (also known as piracy) due to progressive headward erosion of a connecting channel as a process for distributary network development within a delta.

There are several possible contributing causes for the recent creation of the Urucurituba: a) the natural dynamics of the Amazon estuary and its interactions with the Araguari fluvial-marine zone; b) the implementation of hydroelectric power plants (HPP) in the upper Araguari River (Cunha et al., 2013; Santos et al., 2014); and c) extensive water buffalo (*Bubalus bubalis*) cattle production, which could have initiated and induced the branching and formation of small channels and creeks that grew into larger channels.

The Amazon basin is the biggest river system in the world (6,100,000 km^2). The Amazon River discharged 178,000 ± 65,000 m^3/s of water from 2000 to 2012 (Ward et al., 2016); its discharge is equivalent to about 16–18% of the planet's freshwater flow (Latrubesse et al., 2017). 1000 Mt. yr^{-1} of sediment are discharged into the Atlantic Ocean, particularly in the coastline of Amapá state, Brazil, located along the northern (left) border of the Amazon estuary (Fig. 1B) (Latrubesse et al., 2017). Finally, spring tidal ranges at the mouth of the Amazon River reach >6 m (Gensac et al., 2016). This powerful

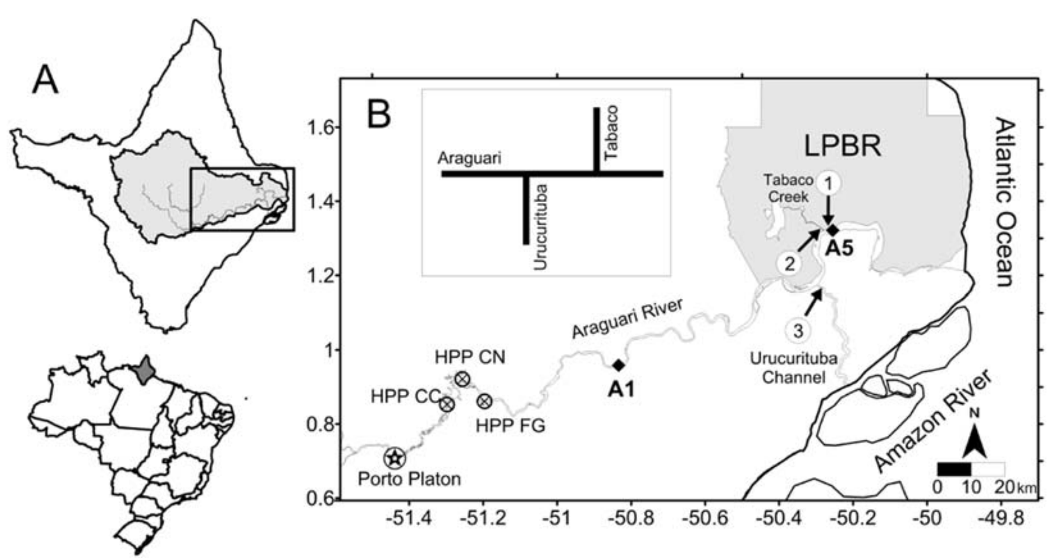

Fig. 1. Study area. (A) Araguari River watershed (in grey) in the Amapá state. (B) Araguari River mid and lower course, Urucurituba Channel and Tabaco creek. Highlighted: Lago Piratuba Biological Reserve (LPBR), water quality sampling points A1(upstream – 0° 58.513′N/50° 48.552′W) and A5 (downstream – 1° 19.361′N/50° 15.938′W), Porto Platon flowmeter gauge station and Hydropower Plants (HPP) Ferreira Gomes (FG), Coaracy Nunes (CN) and Cachoeira Caldeirão (CC). Black arrows indicate sections where net discharges were measured: (1) Araguari River; (2) Tabaco creek (Main Tributary in this stretch) and (3) Urucurituba Channel.