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Deforestation facilitates widespread stream habitat and flow alteration in the Brazilian Amazon

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ABSTRACT

Stream flows and connectivity have been impacted by road crossings and other changes in land use worldwide, with potential negative impacts for aquatic biodiversity. We investigated how pervasive stream flow, habitat, and connectivity alteration is predicted to be in tributaries of the Brazilian Amazon, represented through stream impoundments. We mapped impoundments associated with roads or agricultural land use across the Amazon's Curuá-Una basin and identified landscape factors correlated with each type of impoundment. Impoundments were widespread, and deforestation and the land use changes it facilitated was the driving factor underlying their creation. We found, on average, one impoundment per 7.5 stream kilometers, or 3 km^2, of deforested land, a concentration significantly higher than in areas of native forest, which had an average of one impoundment per 117 stream kilometers or 100 km^2. Continuing to slow deforestation and agricultural conversion would reduce new agricultural impoundments and conditions facilitating soil erosion and subsequent impoundments at road-stream crossings. If Brazil's Forest Code can be effectively enforced, it could contribute substantially to slowing down deforestation and restoring areas already affected. There is an additional need for incentives for sustainable agricultural practices that directly reduce impacts to streams and remove in-stream cattle water impoundments. These possible solutions to address stream alterations would be strengthened by regulatory oversight for watershed management in the Amazon basin through implementation of existing Brazilian water laws, which could provide the groundwork for better valuing aquatic resources in the world's largest freshwater ecosystem.

1. Introduction

Connectivity and flows in smaller tributaries have been impacted by road crossings and other changes in land use worldwide (Januchowski-Hartley et al., 2013; Macedo et al., 2013; Park et al., 2008; Stein et al., 2002). Changes in stream flow regimes resulting from changes in connectivity can affect aquatic biodiversity by altering physical habitat structure and the amount, temperature, and timing of flows to which native species have adapted (Bunn and Arthington, 2002; Poff and Hart, 2002). Dams and road crossings also impede longitudinal hydrological connectivity, disrupting fish migrations and altering sediment distribution and benthic invertebrate communities (Agostinho et al., 2016; Mantel et al., 2010; Warren and Pardew, 1998).

Impacts to freshwater systems are of particular concern in the Amazon River basin, the world's largest, with the most diverse fish fauna on Earth (Junk et al., 2007; Salati and Vose, 1984). Threats here include deforestation, dams, pollution from agriculture and mining, and overharvesting of timber and fish (Castello et al., 2013). Major deforestation in the Brazilian Amazon began in 1970 with construction of the Transamazon Highway (Fearnside, 2005) and intensified as cattle ranching expanded along unofficial spur roads that were initially used for timber extraction, partly through cattle ranching expansion. Deforestation rates have declined by 70% since 2005 (Nepstad et al., 2014) but are still high; 5831 km^2 were cleared in 2015 (INPE, 2015).

Roads and associated occupation have facilitated alteration of stream flow, temperature, and habitat in Brazil's eastern Amazon. Stream impoundments created to support cattle ranching in the Xingu watershed resulted in elevated stream temperatures extending at least 2.4 km downstream (Macedo et al., 2013). In the Marapanim watershed, impoundments caused by road crossings had lower fish species richness and trophic group diversity than associated upstream and downstream reaches, along with altered physical structure, increased water temperature, lower dissolved oxygen and invasive plant species (Lourenço Brejão, 2011). Amazon region soils are especially prone to erosion following road construction and agricultural conversion, potentially contributing to stream sedimentation and altered flows (Laurance et al., 2009; Salati and Vose, 1984).

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Deforestation in Brazil's Amazon is being addressed through national Forest Code policy, agriculture supply-chain programs, and other incentive-based initiatives (Nepstad et al., 2014; Soares-Filho et al., 2014). The New Forest Code, approved in 2012, created the Program for Environmental Compliance [Programa de Regularização Ambiental] (PRA), which aims to promote restoration of private lands that must be legally set aside for conservation, including riparian areas. However, PRA implementation has been slow and the protection and restoration of degraded areas is far from being a reality. Specific impacts on aquatic systems have received much less attention, and water laws and their enforcement are weak in structure and implementation (Castello and Macedo, 2016; Elabras Veiga and Magrini, 2013).

We investigated how pervasive stream flow, habitat, and connectivity alteration is predicted to be in small tributaries of the Brazilian Amazon, as well as landscape-scale correlates of these changes. Previous studies indicated that impoundments occur in the region, however it remains unknown how widespread this issue is and what the full range of potential causes may be. Our analysis focused on the Curuá-Una River basin, which has experienced road construction and deforestation typical of the developing Amazon. First, we estimated the prevalence of impoundments associated with road-stream crossings and agricultural activities. Second, we described how overall stream connectivity is potentially affected by the identified impoundments. We used stream impoundments as evidence of stream habitat and flow alterations because they can be detected over a large area. Third, we identified landscape factors correlated with each type of impoundment. Finally, we discuss how existing policies and programs could help to address stream alterations by impoundments and additional approaches that could further advance stream habitat protection and restoration.

2. Methods

2.1. Study area

We analyzed the 3.2-million ha Curuá-Una River basin, located between the Tapajós and Xingu River basins (Fig. 1). The Curuá-Una River flows into the Amazon River downstream of Santarém, Brazil. The native vegetation is tropical moist forest, average daily temperature is 26 °C, and average yearly rainfall is 1900 mm. Elevation ranges from sea level to 500 m. The basin has experienced development patterns typical of eastern Amazonia (Fig. 1), particularly in the 1970s, when a federal strategy of Amazon occupation led to creation of small farmer settlements and construction of two federal highways. This facilitated expansion of secondary and unofficial roads and favored deforestation associated with land speculation, logging, and cattle ranching. Since the early 2000s, agriculture in parts of the basin shifted to soybean production (Morton et al., 2006).

2.2. Impoundment prevalence and stream connectivity

We mapped stream impoundments across the Curuá-Una basin, with a focus on road-stream intersections and agricultural areas, places where small in-stream impoundments have been noted previously. Impoundments have occurred unintentionally as a result of poor road construction and intentionally to support agricultural operations and subsistence (Lourenço Brejão, 2011; Macedo et al., 2013). We first mapped all water bodies and then identified potential impoundments as those water bodies located within 50-m upstream of a road crossing or within 10-m on either side of streams located in deforested areas.

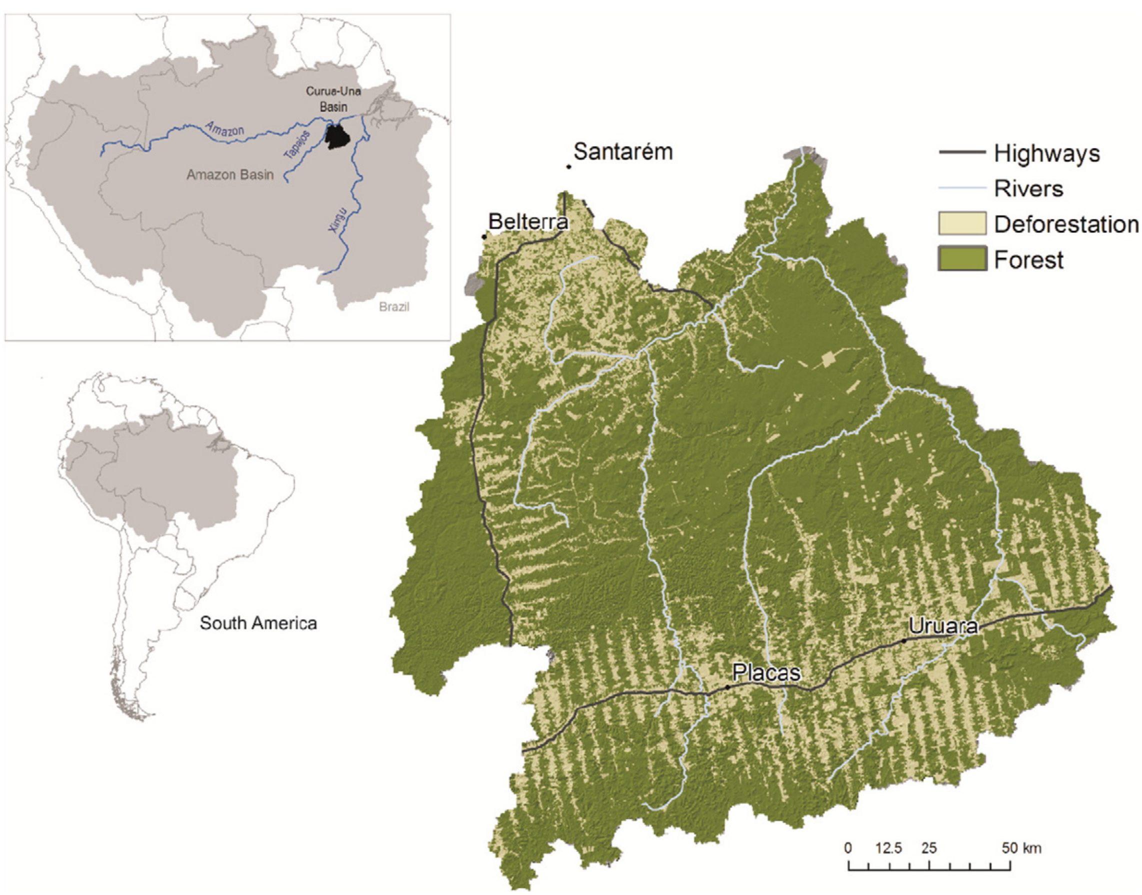

Fig. 1. The Curuá-Una basin is located in the eastern Amazon basin of Brazil, where road construction has facilitated widespread deforestation by enabling access and settlements.