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Diversity and community structure of rapids-dwelling fishes of the Xingu River: Implications for conservation amid large-scale hydroelectric development

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ABSTRACT

A recent boom in hydroelectric development in the world's most diverse tropical river basins is currently threatening aquatic biodiversity on an unprecedented scale. Among the most controversial of these projects is the Belo Monte Hydroelectric Complex (BMHC) on the Xingu River, the Amazon's largest clear-water tributary. The design of the BMHC creates three distinctly altered segments: a flooded section upstream of the main dam, a middle section between the dam and the main powerhouse that will be dewatered, and a downstream section subject to flow alteration from powerhouse discharge. This region of the Xingu is notable for an extensive series of rapids known as the Volta Grande that hosts exceptional levels of endemic aquatic biodiversity; yet, patterns of temporal and spatial variation in community composition within this highly threatened habitat are not well documented. We surveyed fish assemblages within rapids in the three segments impacted by the BMHC prior to hydrologic alteration, and tested for differences in assemblage structure between segments and seasons. Fish species richness varied only slightly between segments, but there were significant differences in assemblage structure between segments and seasons. Most of the species thought to be highly dependent on rapids habitat, including several species listed as threatened in Brazil, were either restricted to or much more abundant within the upstream and middle segments. Our analysis identified the middle section of the Volta Grande as critically important for the conservation of this diverse, endemic fish fauna. Additional research is urgently needed to determine dam operations that may optimize energy production with an environmental flow regime that conserves the river's unique habitat and biodiversity.

1. Introduction

Hydrologic alteration of rivers is widespread, with nearly two-thirds of the world's large rivers impacted by dams (Nilsson et al., 2005). Dams represent one of the greatest threats to aquatic biodiversity worldwide (Vörösmarty et al., 2010); their impacts on flow dynamics and river connectivity cause biotic homogenization, promote invasion of exotic species, favor generalist over specialist species, and increase extinction risk for endemic taxa (Johnson et al., 2008; Liermann et al., 2012; Rahel, 2000). Until recently, highly diverse tropical rivers had few large dams (Liermann et al., 2012), but a boom in hydroelectric development in the world's great tropical river basins is now threatening aquatic biodiversity on an unprecedented scale (Winemiller et al., 2016; Zarfl et al., 2015).

The Amazon Basin holds the highest concentration of aquatic biodiversity on the planet, with 2411 described fish species (roughly 16% of global freshwater fish diversity), at least 1089 endemic species, and ongoing discovery of new species (Reis et al., 2016). Currently, 416 dams are operational or under construction within the basin and an additional 334 have been proposed (Winemiller et al., 2016), which together would leave only three free-flowing Amazon tributaries within the next few decades (Castello and Macedo, 2016; Fearnside, 2006).

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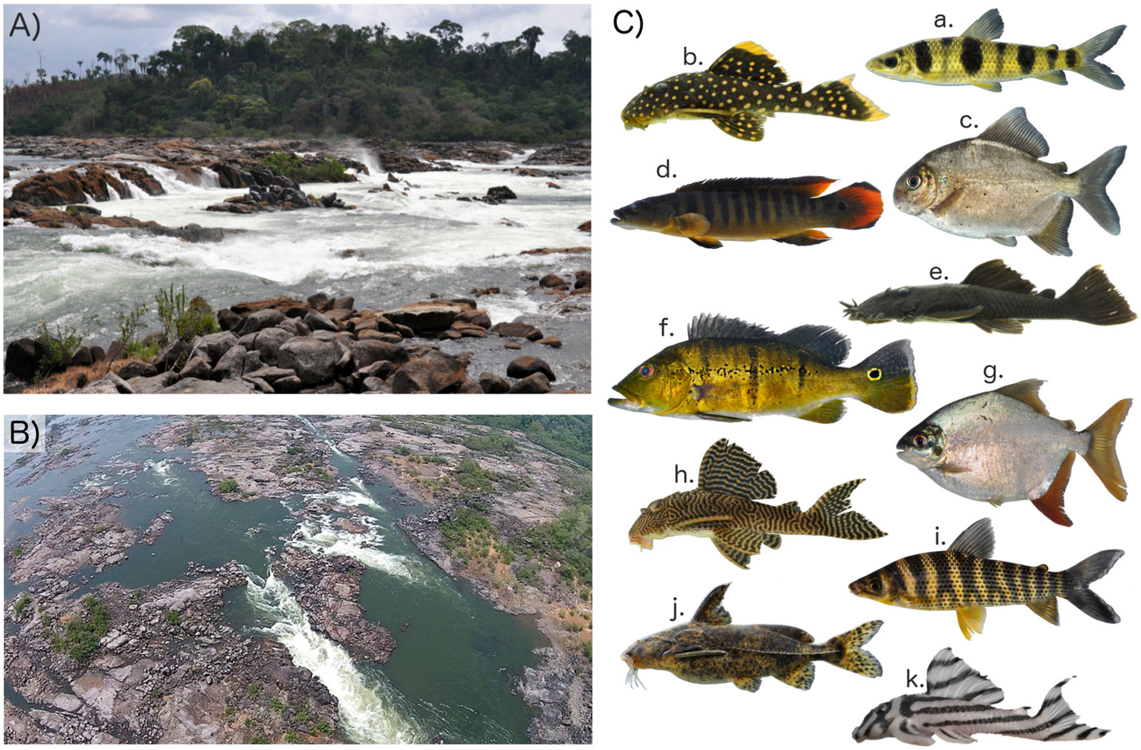

Fig. 1. Examples of the habitat (A, B) and fishes (C) characteristic of the Middle Xingu River. Species shown are: a) *Leporinus maculatus* (Anostomidae), b) *Baryancistrus xanthellus* (Loricariidae), c) *Ossubtus xinguense* (Serrasalmidae), d) *Crenicichla* sp. (Cichlidae), e) *Ancistrus ranunculus* (Loricariidae), f) *Cichla melaniae* (Cichlidae), g) *Tometes kranponhah* (Serrasalmidae), h) *Hypancistrus* sp. (Loricariidae), i) *Leporinus fasciatus* (Anostomidae), j) *Rhinodoras* sp. (Doradidae) and k) *Hypancistrus zebra* (Loricariidae).

Existing dams in the Amazon are concentrated in the Tocantins, Tapajós, Xingu, and other tributaries draining ancient granitic shields, which contain more than twice as many endemic species compared to tributaries draining younger Andean regions (Castello and Macedo, 2016). In addition to the higher concentration of dams in these tributaries, site selection for development projects generally targets areas with high-gradient reaches due to their large hydropower potential. Unfortunately, these same areas often harbor exceptional aquatic diversity.

The Xingu River is the largest clearwater tributary of the Amazon, and contains a unique segment known as the Volta Grande: a 130 km stretch of rapids and anastomosing channels flowing over the crystalline bedrock of the Brazilian Shield (Fig. 1A & B). The river's strong seasonality, steep gradient, and complex geomorphology, with numerous braided channels ranging in width from several meters to several kilometers, create substantial habitat heterogeneity that contributes to the maintenance of a globally unique fish fauna (Fig. 1C). Because the Xingu Basin does not follow a gradual transition from high-gradient to low-gradient conditions (Camargo et al., 2004; Sabaj Pérez, 2015), assemblage structure may be influenced more by discrete barriers such as rapids and waterfalls than gradual changes (Balon and Stewart, 1983; Ibanez et al., 2007; Lujan et al., 2013). Surveys of fish diversity within the basin have identified the Volta Grande as a region of particularly high diversity and endemism (Camargo et al., 2004), though distributional limits of species within the Volta Grande and adjacent reaches remain largely unknown. Recent surveys in this area have collected over 450 species of fishes in 48 families (Sabaj Pérez, 2015), many of which are highly adapted to life within rapids (Zuanon, 1999). Of the 63 species known to be endemic to the Xingu Basin (Winemiller et al., 2016), at least 26 are known only from the large rapids complex in the Volta Grande region (Sabaj Peréz et al., unpublished). Although demographic and distribution data for many species are lacking, and taxonomic descriptions are ongoing, several species have already been listed as threatened in Brazil (National Red List, 2016), including the critically endangered *Hypancistrus zebra* (zebra pleco; Fig. 1C-k), endangered *Teleocichla centisquama*, and vulnerable *Ossubtus xinguense* (eagle-beaked pacu; Fig. 1C-c).

The same factors that promote the tremendous aquatic diversity of the Xingu's Volta Grande also contribute to the hydropower potential of the region, making the middle Xingu the focus of one of the most controversial development projects in the Amazon: the Belo Monte Hydroelectric Complex (BMHC). A massive engineering project, the BMHC is projected to have an installed capacity of 11,233 MW (3rd largest in the world). Initial proposals in 1975 received considerable backlash due to plans for a series of five separate reservoirs within indigenous territories (Fearnside, 2006). After intense debate, a redesigned proposal emerged in 2002 focusing on only the dams within the Xingu's Volta Grande region (Fearnside, 2006; Sabaj Pérez, 2015). Unlike traditional designs that place the powerhouse at the foot of the dam, the new design would take advantage of a large elevation gradient by diverting water through a series of man-made canals to a powerhouse nearly 90 m below. While the new design reduces the size of the reservoirs on nearby indigenous territories, it has the added impacts of dewatering a significant portion of the Volta Grande between the diversion dam and the main powerhouse and flooding hundreds of square-kilometers of forest. Despite continued controversy, accusations of political corruption, and significant cost overruns (Lees et al., 2016; Sabaj Pérez, 2015), the Brazilian Environmental Authority authorized the operation of the BMHC on November 24, 2015. The reservoirs are currently filled and the facility has been generating power commercially since April 20, 2016. As of publication, eight turbines are currently online and full operation is expected by 2019 (Portal Brasil, 2016).

Direct impacts of river impoundments are well documented and the BMHC will cause significant and predictable changes to aquatic habitat, resulting in three distinctly altered stretches. Upstream of the diversion