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Effects of urbanization on stream benthic invertebrate communities in Central Amazon

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ABSTRACT

Urbanization and its physical and chemical effects on aquatic environments influence invertebrate communities negatively. Yet, it is not clear how urbanization affects inter-annual variation of invertebrate assemblages in streams. We 1) evaluated urbanization effects on the ecological conditions (biotic and abiotic) of streams in Manaus and 2) analyzed invertebrate community variation over time (between 2003 and 2010). Data on abiotic variables and invertebrates from 2003 were obtained from a previous study. In 2010 we sampled abiotic variables and invertebrate communities in the same low-order urban streams sampled in 2003 ($n = 40$). We recorded high values of total nitrogen, total phosphorous, deforestation, total impervious area (TIA), water temperature, pH, and electrical conductivity in the most urbanized streams, as compared to the least-impacted ones. In contrast, the least-impacted streams had high dissolved oxygen concentrations. Water quality was poorer in 2010 than in 2003: oxygen concentration was lower and total nitrogen, total phosphorous, deforestation, and TIA significantly higher in 2010. We recorded higher inter-annual variation of abiotic variables in the most-impacted streams as compared to the least-impacted streams. EPT (%, Ephemeroptera, Plecoptera, and Trichoptera) and richness metrics decreased with urbanization. On the other hand, % OP (percent of Oligochaeta and Psychodidae) increased with urbanization. Observed and EPT richness and% OP increased between 2003 and 2010. On the other hand, rarefied richness decreased between years. Increases of observed and EPT richness between 2003 and 2010 were related to low inter-annual variability in streams conditions; however, differences of% OP and rarefied richness were not related to inter-annual variability in environmental conditions. The degree of urbanization did not explain the magnitude of the within-stream difference of invertebrate communities between 2003 and 2010. The increased effects of urbanization represented by the abiotic variables sampled and the reduction of invertebrate richness and increased dominance of tolerant taxa indicate that public policy is not enough to protect or mitigate human impacts on the urban water systems under study.

1. Introduction

Urbanization is a major threat to aquatic ecosystems (Ramírez et al., 2009; Wallace et al., 2013 Wallace et al., 2013) and developed countries have adopted various policies to reduce the impacts on these ecosystems (Booth et al., 2004). In developing countries, however, urban population growth has often not been accompanied by efficient public policies, resulting in degradation of aquatic ecosystems (Ramírez et al., 2009; Couceiro and Hamada, 2011 Couceiro and Hamada, 2011). In urban areas, the main impacts on aquatic environments has been related to the decrease of soil permeability, removal of riparian vegetation and to the increase of domestic and industrial wastewater input (Paul and Meyer, 2001; Walsh et al., 2005; Fig. 1).

Decrease in soil permeability increases superficial runoff and may increase the input of contaminants to streams (e.g., organic compounds and heavy metals, Schueler, 1994; Walsh et al., 2005). This pollutant input causes changes in physical and chemical water

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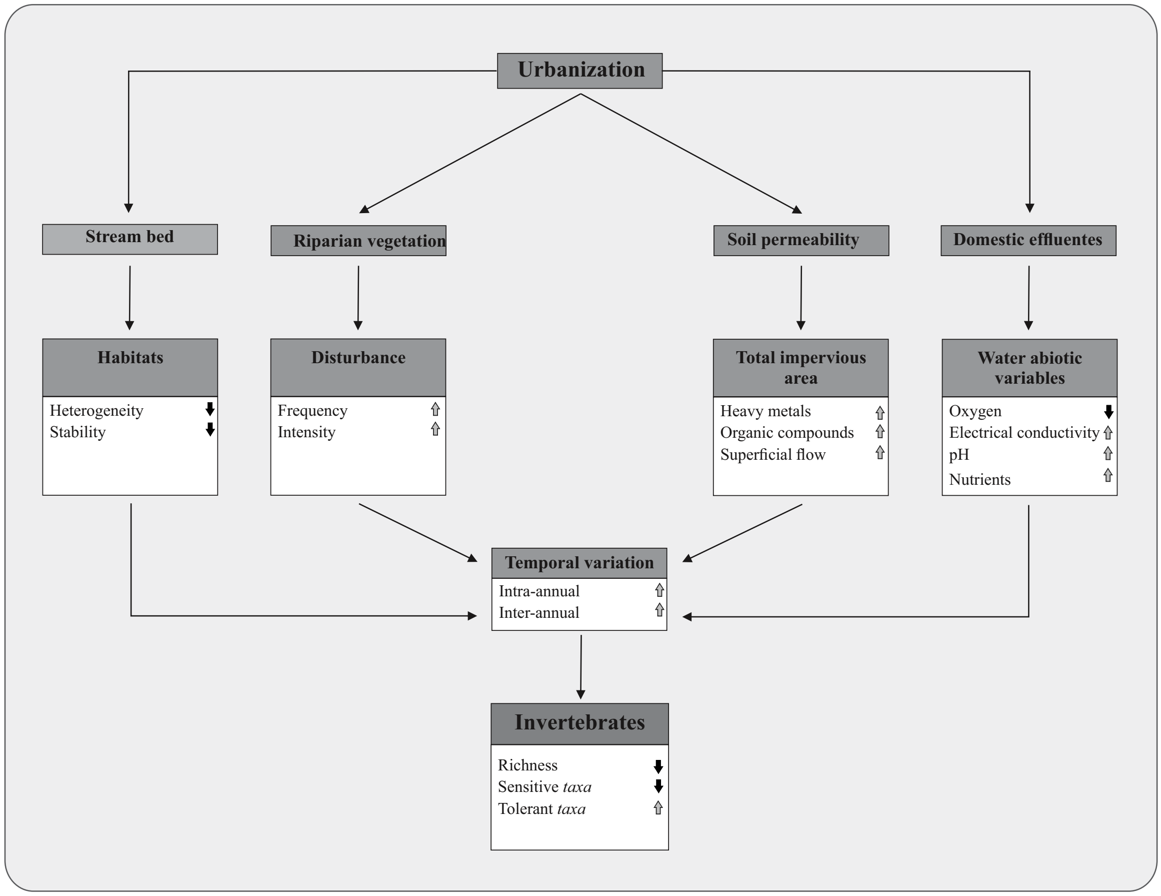

Fig. 1. Conceptual model of urbanization effects on invertebrates in aquatic ecosystems.

characteristics, especially due to increased turbidity, electrical conductivity, nutrient concentration and decreased dissolved oxygen (Wenger et al., 2009).

Riparian vegetation removal can result in increased bank erosion and, consequently, in the siltation of stream beds (Couceiro et al., 2010). Lack of canopy allows more light and results in increased water temperature, which decreases oxygen availability (Paul and Meyer, 2001; Callisto et al., 2012). In addition, riparian vegetation removal reduces the input of allochthonous organic matter in aquatic ecosystems and results in the decrease of habitats and food availability for organisms that depend on this resource (Sanchez-Arguello et al., 2010).

Domestic sewage pollution results in high nitrogen and phosphorus concentrations in streams, due to inputs of human wastes and detergents (Halstead et al., 2014). Increase of nutrients in aquatic systems favors high abundance and activities of micro-organisms (e.g., coliform bacteria and nitrifying bacteria) and results in high respiration and reduced dissolved oxygen (Walsh et al., 2005; Rosa et al., 2014).

Urbanization generally affects aquatic organisms negatively, particularly invertebrates due to their limited mobility, sensitivity to habitat quality and dependence on allochthonous resources (Rosenberg and Resh, 1993). Thus, urbanization often results in a decrease in species richness by exclusion of sensitive taxa to environmental changes and an increase in abundance of taxa tolerant to impacts (Couceiro et al., 2007a, 2012; Feio et al., 2013; see Fig. 1).

The natural variation of fauna over time has a key role in the development of biomonitoring programs as it can mask the effects of environmental impacts (Mazor et al., 2009; Álvarez-Cabria et al., 2010). The relationship between inter-annual variation of communities and gradients of natural or anthropogenic impacts is not always linear. Reference streams that have high stability, heterogeneous habitats and low variation of abiotic variables over time, generally have communities with low inter-annual variability (Robinson et al., 2000; Mykrä et al., 2011). Thus, one could expect less annual variation of invertebrate fauna in reference streams as compared to impacted streams (Maul et al., 2004; Feio et al., 2010, 2015); however, this does not always occur. Huttunen et al. (2012) recorded similar temporal faunal variation in reference and human-disturbed sites in two catchments in Finland. This low variability of invertebrate communities in impacted streams was due to the simplified assemblage composed of only a few tolerant species in a homogenous stream habitat.

Tropical forests have been losing area to pasture and agriculture and, to a lesser degree, to growing cities. Although the area occupied by cities is far smaller than that of pasture and agriculture, the impacts caused by cities tend to be much more severe. Cities in developing countries tend to grow by occupation of the peripheral areas or by following roads (Laurance et al., 2001; Cohen, 2004). In most cases this growth occurs in a disorderly fashion by occupation of public or private areas, and the new neighborhoods have poor sanitary facilities. Consequently, streams in these areas are profoundly impacted due to deforestation and organic enrichment by domestic effluents (Couceiro et al., 2007a,b). After populations establish themselves in the newly occupied areas, it is expected that political pressure will drive urban improvements such as collection of domestic wastewater and establishment of green areas. Accordingly, one could expect an improvement of stream conditions and, consequently, a partial restoration of the original biota. However, stream conditions may deteriorate even more if population density in new neighborhoods continues to increase and this is coupled with absence of public policies to mitigate the impacts.