



Assessing the extent and relative risk of aquatic stressors on stream macroinvertebrate assemblages in the neotropical savanna

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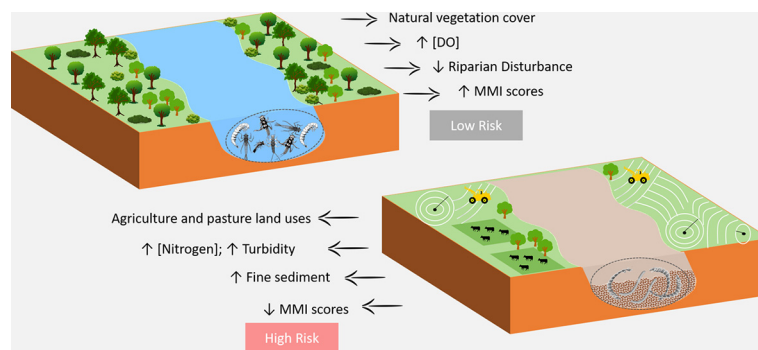
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HIGHLIGHTS

- Aquatic ecosystems are among the most threatened worldwide.
- The extent and relative risks of stressors to biological condition were assessed.
- We used a probabilistic survey design to obtain estimates of relative risk and extent.
- Excess fine sediments posed the greatest risk to biological condition.
- To improve biological condition, management practice should consider both RR and RE.

GRAPHICAL ABSTRACT



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ABSTRACT

Freshwater ecosystems are among the most threatened by human activities, influencing losses of biodiversity. To efficiently address management practices to conserve and restore those ecosystems it is important to correctly identify and quantify the severity and magnitude of anthropogenic stressors degrading freshwater biota. In this study we assessed seven stressors describing poor water quality, physical habitat alteration, and land use by means of the relative risk (RR) and relative extent (RE) approach. The RR measures the co-occurrence probability of high stressor condition and poor biological condition. The RE measures the proportion of stream length in the region in high stressor condition. To obtain accurate estimations of RR and RE we used a probabilistic survey design to select a representative sample of perennial, wadeable and accessible streams within four hydrologic units in the neotropical savanna. Results were evaluated at two spatial scales: local – within each of the four hydrologic units, and regional – all four units combined. From 143 randomly selected sites we inferred our results to a target population of 9466 km of streams. Regionally, we found turbidity, % fine sediments and % agriculture as key stressors associated with poor biological condition. At the local scale, we also found that % pasture and total nitrogen were key stressors of biological condition, but their extent was relatively small. By evaluating both RR and RE we conclude that reducing excess sedimentation on streambeds should be the most effective means of improving biological condition over the region. That finding should guide decision makers and land managers to better focus their efforts and resources on improving biological condition of savanna streams.

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1. Introduction

Freshwater ecosystems are among the most threatened ones, facing a long history of exploitation of their resources to meet human-needs (Dudgeon, 2010; Dudgeon et al., 2006; Nieto et al., 2017; Revenga et al., 2005). Intense human pressures on these ecosystems from water pollution, sedimentation, habitat degradation, flow regulation, overfishing, and alien species invasion are among the main causes of biodiversity losses (Dudgeon, 2010; Vörösmarty et al., 2010). Because of the extents and intensities of such stressors, application of available environmental assessment methods are urgently need to improve the management, conservation, and rehabilitation of aquatic resources (Buss et al., 2015; Helson and Williams, 2013; Ruaro and Gubiani, 2013). In particular, it is essential to identify and focus on managing the major stressors directly or indirectly impairing freshwater ecosystems. In addition, it is critical to employ biologically based approaches for assessing stream condition because of the ability of biological indicators to integrate and detect multiple stressors in aquatic environments (Hughes et al., 2000; Karr, 1981; Moya et al., 2011).

In the United States (US), the relative risk (RR) and relative extent (RE) approaches have been used by the Environmental Protection Agency (EPA) to report on the regional and national condition of wadeable streams, boatable rivers, lakes, and wetlands (Angradi et al., 2011; Paulsen et al., 2008; USEPA, 2016a, 2016b, 2016c). The foundation of this approach is its ability to provide quantifiable associations between key stressors of concern and biological responses (Van Sickle et al., 2006; Van Sickle and Paulsen, 2008). RR describes the probability of good versus poor biological condition given the presence/absence of low versus high stressor condition. RE provides the magnitude of which the high stressor condition was found within a region. It should be noted that the RR and RE approaches are based on discrete measures (good and poor classes) rather than continuous variables. As such, they provide risk estimates that are easily interpreted and familiar to broad audiences (Van Sickle et al., 2006; Van Sickle and Paulsen, 2008). In addition, the RR and RE approaches help decision makers focus regulation, rehabilitation, and mitigation efforts on the stressors most strongly associated with poor biological condition (Hughes et al., 2000).

Accurate estimations of RR and RE can be obtained by randomly sampling sites (Van Sickle and Paulsen, 2008). The use of probabilistic survey designs is strongly recommended for site selection in regional stream condition assessments for several reasons (Dobbie and Negus, 2013; Herlihy et al., 2000; Olsen and Peck, 2008; Stevens and Olsen, 2004). 1) This design ensures representativeness over the surveyed region where physical, chemical and biological characteristics reflect ecological condition (Herlihy et al., 2008, 2000). 2) It is a cost-effective tool that allows confident and precise inferences to vast geographic areas and thousands of stream kilometers with a minimum number of sites (Paulsen et al., 2008). 3) Such a design allows statistical estimations over the stream length of the entire target population of interest, not only the sampled sites (Herlihy et al., 2000). 4) This randomized approach avoids biased conclusions inherent when convenience-based sampling site selection is used in ecological assessment studies (Dobbie et al., 2008; Dobbie and Negus, 2013; Jiménez-Valencia et al., 2014). 5) A probability site-selection design is far more cost-effective for regional ecological studies and assessments than a stratified-random design where the number of potential strata, and therefore the sampling costs, are typically very large and the statistical inferences are very complex (Stevens and Olsen, 2004).

A well-designed monitoring program provides reliable, credible, and valid inferences regarding environmental questions of concern (Dobbie and Negus, 2013; Paulsen et al., 2008). However, the practice is still neglected in Brazil and most other South American countries (Jiménez-Valencia et al., 2014; Macedo et al., 2014b), where biodiversity is high (Barlow et al., 2016; Brook et al., 2006; Myers et al., 2000) and widespread environmental changes are rapidly occurring (Barlow et al., 2016; Brook et al., 2006; Hernández et al., 2016; Vörösmarty

et al., 2010). There is an urgent need to improve methods of selecting sites to achieve high quality data that support improved management practices to protect and rehabilitate streams. This is especially the case for the neotropical savanna, a highly threatened biome, suffering from rapid natural cover replacement and pasture and crop expansion (Hunke et al., 2015; Ratter et al., 1997; Strassburg et al., 2017).

Therefore, the goal of our study was to evaluate the extent of stressors and their risk to biological condition. To achieve our objective, we used a probabilistic survey design to estimate total stream length of a target population of wadeable, perennial and accessible streams and estimate non-target situations of dry, inaccessible, non-wadeable streams and map errors in our frame length. We used a macroinvertebrate multimetric index developed for savanna streams as a measure of biological condition (Silva et al., 2017) and stressors describing physical habitat degradation, poor water quality, and land uses. We assessed results at two scales: local (within each of four hydrologic units) and regional (all four hydrologic units combined).

2. Methodology

2.1. Study area

We defined our sample frame as the stream network in the drainage area within 35 km upstream of the limits of four major hydropower reservoirs: Nova Ponte, Volta Grande, São Simão (Paraná River Basin) and Três Marias (São Francisco River Basin) (Fig. 1). Sampling occurred during the dry season in each hydrologic unit in subsequent years from 2009 to 2012. Dry season sampling facilitates data collection, and the more constant discharges during this time reduces the effect of flash floods. Also, available aquatic habitats are more distinct, macroinvertebrate assemblage structure is more stable, and crew safety hazards and road access difficulties are minimized during the dry season (Hughes and Peck, 2008; Plafkin et al., 1989). This geographic area covered a total of 45,180 km², with land uses and cover characterized by agricultural cash crops, charcoal production, grazing, and urbanization (Macedo et al., 2014a). Climate is described as humid tropical savanna, with a dry season from May to September, precipitation averaging from 800 to 2000 mm, and air temperature averaging between 18 and 28 °C (Ratter et al., 1997).

2.2. Survey design and sampling sites

Sites were selected based on a probabilistic survey design in each of the four areas (hereafter hydrologic units, sensu Ferreira et al., 2017; Firmiano et al., 2017; Seaber et al., 1987). This site selection procedure is based on the first one used by the US-EPA in the Environmental Monitoring and Assessment Program for the Mid-Atlantic Highlands Streams Assessment (Herlihy et al., 2000) and refined in subsequent regional and national stream monitoring programs (Olsen and Peck, 2008; Paulsen et al., 2008; Stoddard et al., 2005). The approach consists of the establishment of a sample frame in a 1:100,000 scale digitized map where we sorted sites by means of a randomized, systematic, spatially balanced criterion (Herlihy et al., 2000; Olsen and Peck, 2008; Stevens and Olsen, 2004).

Our survey design allowed us to obtain an even distribution of sites over the geographic location (Herlihy et al., 2000; Stevens and Olsen, 2004). Probability sampling provides reliable population estimates from a representative set of sample sites in the surveyed region. However, the distribution of sites from the probability sampling design mirrors that in the sampling frame; there will be lots of sample sites with commonly occurring (intermediate) conditions but rare conditions will have few if any sample sites depending on their rarity (Karr and Chu, 1999; Stoddard et al., 2008). As such, minimally disturbed sites (e.g., preserved areas) or highly degraded sites (e.g., urban areas) are rare in our sample, as our study area is highly dominated by agriculture and pasture (Callisto et al., 2014). Therefore, to ensure a gradient of

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