Ecological Indicators 52 (2015) 332–340

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Assessing the impact of gold mining in headwater streams of Eastern Amazonia using Ephemeroptera assemblages and biological traits

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ARTICLE INFO

Article history:
Received 18 September 2014
Received in revised form 9 December 2014
Accepted 11 December 2014

Keywords:
Biological traits
Biomonitoring
Fuzzy-coding
Mayfly
Neotropical rivers
Macroinvertebrates

ABSTRACT

Whilst the biological traits composition of invertebrate assemblages has been successfully used to monitor temperate rivers, it has been seldom tested in tropical areas. We compared the trait composition of Ephemeroptera assemblages (five traits, 21 modalities) in three categories of headwater streams of FG: reference (undisturbed) sites, sites formerly impacted by gold-mining, and sites currently impacted by gold-mining. Differences in macroinvertebrate assemblage according to environmental characteristics and disturbance were evaluated using correspondence analysis and MANOVA. Among the considered traits, food acquisition, respiration and locomotion detected both past and current disturbance associated with gold-mining in headwaters. A fuzzy correspondence analysis showed a significant segregation of currently gold-mined, formerly gold-mined, and reference sites according to species traits. Shifts in trait composition were mostly related to changes in assemblage composition. Interestingly, no significant decline in diversity indices was observed in formerly gold-mined sites compared to the reference sites, 2 years after abandonment, while the taxonomic and trait composition of communities changed at these sites. These results support the case for further fundamental quantification of species traits, and for the inclusion of sensitive, trait-related metrics in upcoming multimetric indices for the assessment of river health.

1. Introduction

Throughout the world, environmental legislation aiming at surveying, managing and protecting freshwater ecosystems relies on biological indicators of ecosystem health (Stoddard et al., 2008; Dos Santos et al., 2011). For instance, regional-national surveys of stream systems provide large volumes of site-specific data on biological communities and the associated physical–chemical environments (e.g., Harris and Silveira, 1999a,b; Paulsen et al., 2008; Mondy et al., 2012). The ecological health of rivers is then defined in terms of deviation from a *reference* state where human impacts are almost null (Bailey et al., 1998). Biological traits of freshwater organisms (e.g., body size, feeding habits, etc.) are potentially more useful than taxonomic structure (species × abundance data) to detect patterns of deviation from reference conditions where different hydroecoregions (areas that differ by geology, climate, vegetation, and species composition) are covered (Bonada et al., 2006), though ecologists traditionally make use of taxa lists (e.g., Bernadet et al., 2013). Whilst species occurrence may have a strong stochastic element and local-regional validity only, traits reflect environmental conditions and may be shared among many species (Southwood, 1988; Statzner et al., 2001). Traits may give greater insight into habitat change (Dolédec et al., 1999; Statzner et al., 2004) and their determination generally requires less taxonomic expertise (Dolédec et al., 2000), so that it can be utilized where limited information is available, and/or for animal groups where taxonomic knowledge is limited.

Most applications of biological traits to bioassessment were developed in the temperate zone, and were based on benthic macroinvertebrates (e.g., Usseglio-Polatera et al., 2000; Gayraud et al., 2003; Statzner et al., 2005; Dolédec et al., 2006). This is owing to the fact that species traits are poorly documented in tropical invertebrates compared, for instance, to the European or North-American ones (Touron-Poncet et al., 2014). To the best of our knowledge, only a few studies used a biological traits approach in tropical rivers (Tomanova, 2007; Tomanova et al., 2008) to assess how macroinvertebrate community functions change along gradients of anthropogenic disturbance. Recent efforts on the taxonomy

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http://dx.doi.org/10.1016/j.ecolind.2014.12.012
1470-160X/

of the South American Ephemeroptera (mayflies) have provided valuable information on the diversity of this insect order in the neotropics (Heckman, 2002; Salles et al., 2004; Domínguez et al., 2006; Chacón et al., 2009), and in addition, Ephemeroptera are recognized as relevant biological indicators, because of their sensitivity to a wide array of disturbance types (Landa and Soldan, 1991; Buffagni, 1997). Their taxonomic richness and/or abundance have notably proven relevant parameters for the design of multimetric indices in temperate (Gabriels et al., 2010) and neotropical (Couceiro et al., 2012; Touron-Poncet et al., 2014) rivers. Ephemeroptera are usually present in all stream types and benthic microhabitats within stream systems (Sowa, 1975), and show high morphological and ecological differentiation among genera (Domínguez et al., 2006). With such ecological characteristics, one may expect that variations in the biological trait combination of Ephemeroptera assemblages effectively account for ecosystem alteration.

The aim of this study was to assess the extent of shifts in the biological trait composition of Ephemeroptera assemblages along a gradient of disturbance associated with gold-mining in French Guiana (FG), East-Amazonia. Gold is the most significant mineral resource in the Guiana Shield (FG, Guyana and Surinam) (Hammond et al., 2007). After the prospection of large rivers, gold industries are now focusing on smaller inland streams (Cleary, 1990; Hammond et al., 2007). Small streams represent 80% of all running waters in FG and exhibit high ecological quality; some if not most of them have never been impacted by any human activity. Sediment discharges related to gold-mining activities are known to largely exceed those generated by other land-use changes, such as deforestation or road-building (Bruijnzeel, 1993; Krishnaswamy et al., 2006) and this type of disturbance certainly has harsh impact on the river biota in the Guiana shield where smalls streams naturally exhibit low levels of suspended materials (Hammond et al., 2007). In light of recent economic development, our ability to identify relevant reference conditions (e.g., community traits, ecological functions) and effectively rate ecosystem health will undoubtedly contribute to the success of future management actions. Assuming that environmental conditions strongly constraint Ephemeroptera assemblages (Hanquet et al., 2004), we hypothesized that (i) streams with similar habitat conditions host Ephemeroptera assemblages with similar combinations of traits, and (ii) anthropogenic disturbance generates broad shifts in ecological functions as species with certain traits are eliminated or replaced by species with other traits. In order to test these predictions, data on the Ephemeroptera assemblages were collected in 19 headwater streams of FG (abundance matrix for 35 genera), then five biological traits were described for the first time using a fuzzy-coding method (trait matrix). Matrix multiplication and a fuzzy-coding analysis were used to weight traits by taxa abundance, and to investigate the spatial distribution of trait combinations in relation to the extent of anthropogenic impacts generated by gold mining.

2. Materials and methods

2.1. Study area and sampling sites

This study was conducted in FG, East Amazonia, from October to December 2012. The climate is tropical moist with 3000–3400 mm of yearly precipitation mainly distributed over 280 days. There is a major drop in rainfall (dry season) between September and December and another shorter and more irregular dry period in March. The maximum monthly temperature averages 33.5 °C (32.1–35.8 °C), and the monthly minimum averages 20.3 °C (19.7–21 °C). The sampled streams had a water depth <1 m and a stream width <10 m, and were located in the upstream part of the river continuum. Larger streams and rivers were not considered in the study in order to focus on comparable ecosystems.

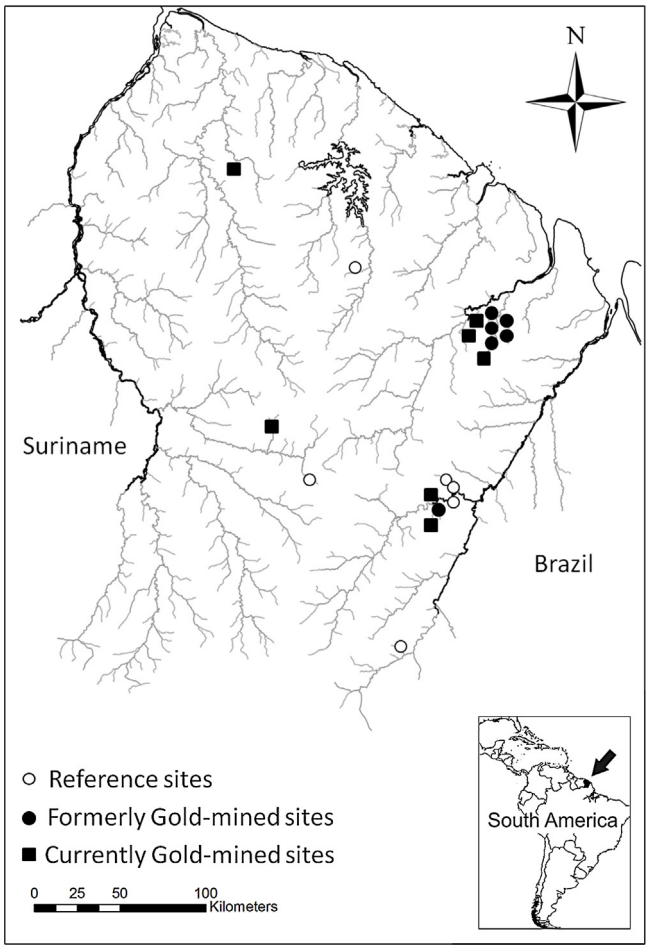

Fig. 1. Distribution of 19 sampling sites in French Guiana.

Nineteen sampling sites were sampled over 19 headwater streams belonging to FG's main river basins. Sites were mostly located on the northern part of FG, an area covered by dense rainforest and without road networks (Fig. 1). The sites were sampled during the dry season (September–December) in 2012. Six sites were defined as not subjected to anthropogenic impacts (Reference sites). Impacted sites were currently ($n = 7$) or formerly ($n = 6$) subjected to gold-mining. Gold mining activity had stopped 2 years before sampling at the formerly gold-mined sites. The mining activities considered in this study refer to so-called "illegal" mining, i.e., small-scale traditional (or artisanal) mining which occurs in most South American countries (Hammond et al., 2007). These illegal activities involve small groups of workers (around a hundred people) who settle on small and remote forest streams (Hinton et al., 2003).

2.2. Physical–chemical variables

The length of a site was defined as 10 times its width, and transects were established each 5 m along this length, for subsequent habitat measures. Stream flow (cm s^{-1}) and the percentage composition of organic and mineral substrate types were determined on a 1 m^2 area every meter along each transect. Mean stream flow at a site was the mean of all point measurements. The substrate types included: % litter, % submerged roots on the banks, % macrophytes, % woody debris, % sand (particle size <2 mm), % gravel (2–25 mm), % coarse substratum (>25 mm). Silt deposit being scarce naturally