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Habitat preferences in freshwater benthic macroinvertebrates: Algae as substratum and food resource in high mountain rivers from Mexico

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A B S T R A C T

The diversity of benthic macroinvertebrates in lotic systems is closely related to the availability and heterogeneity of habitats. These habitats may be of inorganic origin, such as the rocky substratum associated with the river bed, or organic such as macroscopic algae. The objective of this study was to determinate the importance of five species of algae that differ in their morphological type as a substratum and food resource regarding the associated establishment of macroinvertebrate assemblages taking account the climatic seasonality (warm dry, cool dry and rainy). We then evaluate the differences in macroinvertebrates assemblages with respect to the inorganic substratum by sampling high mountain rivers in central Mexico. The mucilaginous colonies of *Nostoc parmelioides* and *Placoma regulare,* the pseudoparenchymatous bambusiform thallus of *Paralemanea mexicana* and the laminate thallus of *Prasiola mexicana* had the highest densities of macroinvertebrates, represented by the genera *Cricotopus*, *Paramerina*, *Simulium* and Tanytarsini tribe. The relationship between algal morphological type and the richness and diversity of macroinvertebrates was positively related to specific conductivity, total dissolved solids and discharge variables. The dominant taxa associated with the inorganic substratum belonged mainly to the Trichoptera, Diptera and Ephemeroptera orders. Water temperature, discharge and concentration of orthophosphates were the main environmental variables able to explain the diversity of macroinvertebrates on this substratum. The dominance of detritivorous macroinvertebrates in these mountain rivers suggests the contribution of allochthonous organic matter possibly of anthropogenic origin. The assemblages of macroinvertebrates on inorganic substratum did not significantly differ among sites or climatic seasons.

1. Introduction

The diversity of benthic macroinvertebrates inhabiting lotic environments is directly associated with substratum diversity and habitat type (Dewalt et al., 2010). Macroscopic algae, because of the diversity of their physical structures, can increase habitat complexity and heterogeneity (Wellnitz and Ward, 2000; Liston and Trexler, 2005; Walker et al., 2013), can modify the oxygen concentration and availability of nutrients, and can provide refuge against predation (Beauger et al., 2006; Bakker et al., 2016). Studies of interactions between heterotrophic organisms and algae in rivers are scarce, because the impact of herbivory is difficult to quantify, and has been considered of lower magnitude than in terrestrial ecosystems (Wellnitz and Ward, 2000). Nevertheless, these interactions modify the relationships between aquatic communities through changes in their structure and function (Lodge, 1991; Bakker et al., 2016). For example, many species of herbivorous macroinvertebrates that are associated with algae may facilitate algal growth and dispersion of reproductive structures (Caro-Borrero and Carmona, 2016). Other macroinvertebrates, such as shredders and burrowers, promote recycling and nutrient retention by incorporating organic matter into the food chain (Grubaugh et al., 1996). In oligotrophic systems such as high mountain rivers, the heterotrophic community depends largely on algae as a food source.

The diversity of algal morphology (*e.g.* gelatinous, crusty, filamentous, laminar.) can provide substratum for the development of macroinvertebrate larvae that as adults will be an important component of the terrestrial ecosystem (Wellnitz and Ward, 2000; Di Sabatino et al., 2014). Algal structures may alleviate the physical challenges faced by aquatic larvae, such as the mechanical dragging force of current, and difficulty in capturing oxygen and/or food (Grubaugh et al., 1996; Walker et al., 2013; Liston and Trexler, 2005). These features enable algae to support a macroinvertebrate community that differs from the assemblage associated with inorganic substrata.

The composition and stability of inorganic substrata (mainly rocky) depends on hydrogeomorphological and climatological characteristics, which define ecosystems locally and change sporadically. Inorganic

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substrata tend to be more stable that organic mats, since those are subject to diverse pressures of physico-chemical and biological origin that limit their growth and dispersion (Grubaugh et al., 1996). The heterogeneity of inorganic substratum (mainly defined by grain size), also influences the diversity and availability of habitats for benthic organisms and therefore the community structure (Walker et al., 2013; Liston and Trexler, 2015).

Information about the influence of algal mats on the structure of benthic macroinvertebrate communities and their interactions is limited defined by number of published research. This paper presents empirical information on habitat preferences of benthic macroinvertebrates in high mountain rivers. Considering the diversity of algal substrata and their dependence on conditions in the river channel, we hypothesize that throughout the year we will find modifications in percentage cover and morphological types of algae, and that the macroinvertebrate assemblages will respond with structural changes. In contrast, the inorganic substratum will have greater stability, so we expect to find that macroinvertebrate assemblages are more diverse than on algae, and that they are similar in composition among the inorganic sample sites. The main objective of this study was to establish the differences among habitats in high mountain rivers, central Mexico, and to establish the preferences shown by the composition of macroinvertebrate assemblages associated with five species of algae of diverse morphological type and associated with the inorganic substratum.

2. Materials and methods

2.1. Study area

Samples were collected from a segment of the one-to–three-order mountain rivers in the *trans*-Mexican Volcanic Belt, central Mexico (19° 09′- 19° 16′N and 98° 43′- 100° 09′W, Fig. 1). It is an area of intense volcanic activity and marked altitudinal changes, diverse geological composition and abundant streams that originate from a system of mountains (altitude 1800–3200 m) and drain into the coastal plain. In general, these mountainous regions have a temperate sub-humid climate, coniferous forest vegetation and andesitic to basaltic substratum (Ferrusquía, 1993).

2.2. Physical and chemical analysis

Samples were collected on one to three occasions in each of the seven rivers between April 2015 and March 2016, during the rainy (R; June-November), cool dry (DC; December-February) and warm dry (WD; March-May) seasons (see Table 1). Water temperature, specific conductivity and pH were recorded *in situ* with a Hanna multi-sensor (HI 991300, California, USA). Oxygen saturation was recorded with an oxygen meter (YSI-85, YSI, Ohio, USA). Sampling locations located at the upstream were selected according to the ecological status, between good and excellent to avoid erroneous results dependent on environmental degradation and not on the type of substratum. samples of water (500 ml) were filtered *in situ* through 0.45 μm and 0.22 μm filter membranes (Millipore, Massachusetts, USA) and collected in sterile polypropylene bottles for the physicochemical analysis, according to the criteria established in APHA (2005). Samples were stored at 4 °C and two replicates were analyzed in the laboratory within 24 h of collection. The nutrient analyses were adapted from Standard Methods for the Examination of Water and Wastewater (APHA, 1999) and used a DR 3900 laboratory Spectrophotometer (Hach, Loveland, Colorado). Dissolved inorganic nitrogen (DIN) was calculated as the sum of the three inorganic nitrogen forms in water. NH_4–N was measured colorimetrically by the Nessler method (detection limit 0.1 mg l^{-1}), reading the absorbance at 425 nm. When values were close to the detection limits, the salicylate method was used (detection limit 0.01 mg l^{-1}), read at 655 nm. NO_3–N was measured colorimetrically by a modification of the cadmium reduction method, using gentisic acid instead of 1-naphthylamine (detection limit 0.5 mg l^{-1}) and reading absorbance at 500 nm. The low-range method (up to 0.5 mg l^{-1}) is an expanded modification of the former that employs a chromotropic acid indicator (detection limit 0.05 mg l^{-1}) reading at the same wavelength. NO_2–N was determined colorimetrically with chromotropic and sulfanilic acids as indicators (detection limit 0.01 mg l^{-1}) and reading absorbance at 500 nm. PO_4–P was estimated colorimetrically with a modification of the molybdenum blue procedure, provided by Phos Ver 3 (detection limit 0.01 mg l^{-1}), reading absorbance at 890 nm.

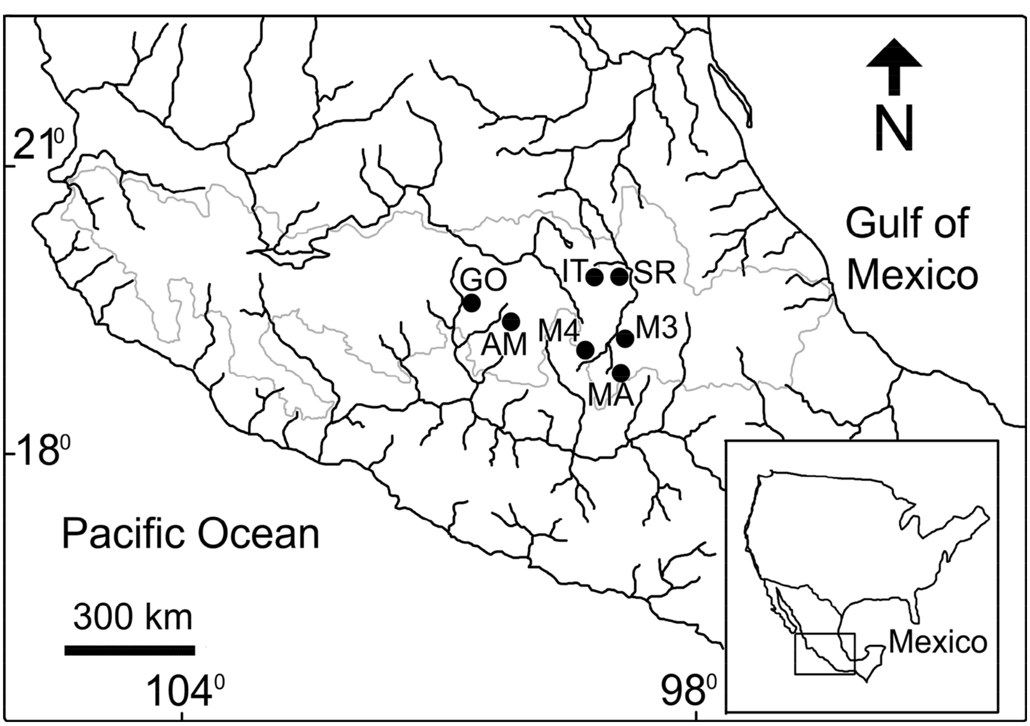

Fig. 1. Location of sampling sites in the Mexican Volcanic Belt (grey line): Amanalco (AM), Gonzalez spring (GO), La Magdalena 3rd dinamo (M3), La Magdalena 4th dinamo (M4), Monte Alegre (MA), San Rafael (SR) and Presa Iturbide spring (IT).