ARTICLE IN PRESS

Environmental Modelling & Software xxx (2017) 1–11

Contents lists available at ScienceDirect

Environmental Modelling & Software

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

Model-based analysis of the relationship between macroinvertebrate traits and environmental river conditions

Marie Anne Eurie Forio [a, b, *], Peter L.M. Goethals [b], Koen Lock [b], Victor Asio [c, d], Marlito Bande [d], Olivier Thas [a, e]

[a] Department of Mathematical Modelling, Statistics and Bioinformatics, Ghent University, Coupure Links 653, B-9000 Gent, Belgium
[b] Laboratory of Environmental Toxicology and Aquatic Ecology, Ghent University, Coupure Links 653, B-9000 Ghent, Belgium
[c] Department of Soil Science, Visayas State University, 6521 Baybay, Leyte, Philippines
[d] Institute of Tropical Ecology and Environmental Management, Visayas State University, 6521 Baybay, Leyte, Philippines
[e] National Institute for Applied Statistics Research Australia (NIASRA), University of Wollongong, Australia

ARTICLE INFO

Article history:
Received 20 February 2017
Received in revised form
8 October 2017
Accepted 9 November 2017
Available online xxx

Keywords:
Negative binomial regression
Feeding strategies
Flow velocity
Tropical island
Generalized linear models
Philippines

ABSTRACT

Aquatic macroinvertebrates, 18 physical-chemical water characteristics and 30 hydromorphological variables were assessed at 85 locations on Leyte island, Philippines. Biological traits derived from literature were linked to the biological samples based on four different trait estimation methods. These data were used to determine the relation with river characteristics using negative binomial regression. At least five feeding habit modalities were associated with conductivity, velocity, pH, temperature, ammonium-N concentrations, and sediment. The various methods of estimating trait abundance differ in determined major patterns and ecological implications. Therefore, the estimation method used should be explicitly described in trait-related papers to avoid misinterpretation. Trait abundance-environment relationships can be linear or non-linear and therefore a careful selection of the functional relationship should be performed. The process of extracting knowledge from data is of paramount importance as relevant ecological insights were extracted providing insights on flow, wastewater and nutrient management in the rivers.

1. Introduction

The traits (characteristics) of an organism (i.e. body size, feeding strategy, locomotion, …) are connected to ecosystem functions (Doledec and Statzner, 2010) and strongly influence ecosystem properties (Hooper et al., 2005). As organisms' traits, such as feeding strategies and habit requirements, are strongly affected by the habitat conditions (Heino, 2005), relating these traits to habitat and environmental characteristics can provide significant insights into the structure and functioning of biological communities (Usseglio-Polatera et al., 2000b). Moreover, the analysis of biological traits provides a better understanding of the mechanism of the organisms' responses (Bolam et al., 2016). Over the past two decades, the number of studies related to aquatic macroinvertebrate traits has been increasingly growing. Most studies focus on the relationship between environmental conditions (natural and disturbed) and the traits of these organisms (Menezes et al., 2010; Schmera et al., 2017). They have also been successfully applied to assess aquatic ecosystems (Bonada et al., 2007b; Dolédec et al., 2011). However, in-depth investigations and documentation on data processing and modelling of aquatic macroinvertebrate traits are lacking.

Recently, various macroinvertebrate trait databases have been developed (Statzner et al., 2007; Schmidt-Kloiber and Hering, 2015; USEPA, 2016). However, the use of these databases has limitations and challenges such as: they are hampered by missing data of some taxa (Violle et al., 2015), scattered information among databases (Poschlod et al., 2003), varying trait coding and differences in trait modalities (classes/categories) among databases (Usseglio-Polatera et al., 2000b) and few databases available for taxa found in the tropics. Thus, appropriate measures should be taken when using these databases. In a number of studies, traits have been allocated to each taxon from these databases, but the estimation of trait abundance has not been thoroughly investigated yet.

* Corresponding author. Department of Mathematical Modelling, Statistics and Bioinformatics, Ghent University, Coupure Links 653, B-9000 Gent, Belgium.
E-mail address: marie.forio@ugent.be (M.A.E. Forio).

https://doi.org/10.1016/j.envsoft.2017.11.025
1364-8152/

Various modelling techniques have been used for modelling and analysing macroinvertebrate traits. The chosen approach is usually driven by the purpose of the study, the nature of the data and the acceptability to the end-user of the model (Mouton et al., 2009; Forio et al., 2017b). Mondy et al. (2016) applied calibrated boosted regression tree models to predict community tolerance using multiple biological traits with their individual responses to specific stressors. Statistical models such as logistic regression (Richards et al., 1997), zero-inflated Poisson regression (Boets et al., 2013) and various multivariate analysis methods (Bremner et al., 2006; Feld and Hering, 2007) were used to relate environmental conditions and macroinvertebrate traits. These relationships can be linear, non-linear or skewed unimodal. However, these assumptions are uncritically considered in statistical procedures (Austin, 2002).

Although analysis and modelling of macroinvertebrate traits have been applied in temperate aquatic systems (Statzner et al., 2005; Bonada et al., 2007a; Boets et al., 2013), it has been only occasionally studied in tropical and sub-tropical regions. To date, only limited studies applied functional traits to assess water integrity in neotropical streams (Tomanova et al., 2008; Dedieu et al., 2015; Tupinambas et al., 2016), Cameroonian (Tchakonte et al., 2015) and Iranian (Aazami et al., 2015) rivers. The trait-based analysis is scarcely explored in the tropical regions.

Thus, we ascertain answers to the questions on whether the abundances of macroinvertebrate traits are associated linearly or non-linearly (e.g. quadratic) to a gradient of an environmental variable and what is the effect of the different methods of allocating trait abundances on the response functions. This study, therefore, aims to determine how the abundance of macroinvertebrate traits (particularly the feeding strategies) evolve across the gradient of an environmental variable on a tropical island. Furthermore, the effect of different methods of allocating trait abundances on the response functions is investigated. Hence, a case study on the Leyte island, Philippines is presented. We applied negative binomial regressions to model the abundance of each feeding strategy (modalities/categories) of aquatic macroinvertebrate as a function of each environmental condition (physical, chemical and hydromorphological variables). The discovered ecological insights are then translated into water management.

2. Material and methods

The overall phases implemented in this study is presented in Fig. 1. Each step is described in detail in the proceeding sections.

2.1. Study area

The Leyte island is the eighth largest island in the Philippines and has a surface area of 7368 km^2 (Fig. 2). The island is irregular in shape and has mountains in the centre of which the highest reaches 1349 m. A complex system of short streams drains from the mountains to the coasts (Pletcher, 2015). The climate of the island is characterized by a relatively high temperature (24–33 °C), high humidity and abundant rainfall (average annual rainfall of 2100–4500 mm) (Forio et al., 2017a).

Human activities within the island include crop cultivation, industry, quarrying, urbanization and aquaculture. The crops cultivated are rice, coconut, corn (maize), abaca, tobacco, bananas, pineapple and sugarcane. Manganese deposits, sandstone and limestone are quarried in the north-west. Additionally, industrial plants such as coconut oil mills, a copper smelting plant, a phosphate fertilizer and ethyl alcohol production plants are operating on the island. A geothermal production field is also located in the west of the island (Forio et al., 2017a).

2.2. Data collection

Aquatic macroinvertebrates were sampled on the island at 85 different locations. The sampling campaign was conducted during the dry season (April-May, 2015). Macroinvertebrates were monitored through kick sampling with a standard handnet (conical net with a frame size of 20 × 30 cm and a mesh size of 500 μm) as described by Gabriels et al. (2010). For each sampling site, a 10–20 m stretch was sampled for 5 min. Sampling effort was proportionally distributed across all aquatic habitats present at the sampling site, including bed substrates (stones, sand or mud), macrophytes (floating, submerged, emerging) and other floating or submerged natural and artificial substrates. All the collected material was transferred to buckets with covers. Afterwards, the samples were sieved and organisms were sorted alive in the laboratory. Macroinvertebrates were identified to the family level.

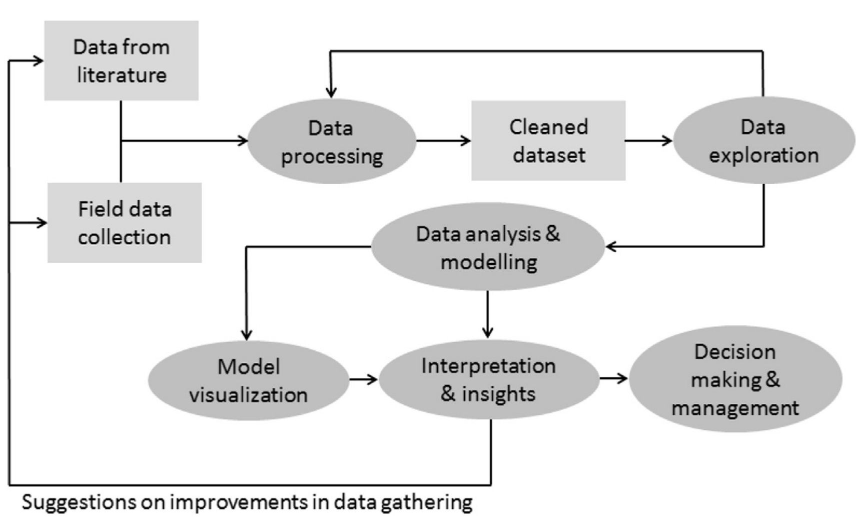

Fig. 1. Overall schematic diagram of the method implemented in this study (adapted from O'Neil and Schutt (2014)).