Environmental Modelling & Software 89 (2017) 19–30

Contents lists available at ScienceDirect

Environmental Modelling & Software

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

Towards a framework for terrain attribute selection in environmental studies

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A R T I C L E I N F O

Article history:
Received 30 May 2016
Received in revised form
28 November 2016
Accepted 29 November 2016

Keywords:
Bathymetry
Geomorphometry
Surrogacy
Terrain analysis
Terrain attributes
Topography

A B S T R A C T

Terrain attributes (*e.g.* slope, rugosity) derived from digital terrain models are commonly used in environmental studies. The increasing availability of GIS tools that generate those attributes can lead users to select a sub-optimal combination of terrain attributes for their applications. Our objectives were to identify sets of terrain attributes that best capture terrain properties and to assess how they vary with surface complexity. 230 tools from 11 software packages were used to derive terrain attributes from nine surfaces of different topographic complexity levels. Covariation and independence of terrain attributes were explored using three multivariate statistical methods. Distinct groups of correlated terrain attributes were identified, and their importance in describing a surface varied with surface complexity. Terrain attributes were highly covarying and sometimes ambiguously defined within software documentation. We found that a combination of six to seven particular terrain attributes always captures more than 70% of the topographic structure of surfaces.

1. Introduction

Combining georeferenced species data with environmental datasets has become common practice in environmental studies both in the terrestrial (Elith and Leathwick, 2009) and marine realms (Brown et al., 2011). Exploring species-environment relationships is important for habitat mapping, biogeographical classification, conservation, and management (Harris and Baker, 2012). Research in these fields has been fueled by progresses in remote sensing and Geographic Information Systems (GIS), along with the increase in data availability and computing power (Wiersma et al., 2011; Vierod et al., 2014). In parallel, these elements have motivated the development of geomorphometry (Bishop et al., 2012; Zhou and Zhu, 2013), the field that helps quantitatively describe digital terrain models (DTM) using terrain attributes such as slope, orientation or rugosity (Pike, 1995). Terrain attributes have been found to be linked with the distribution of many terrestrial and marine species in different types of environments (*e.g.* forests, agroecosystems, deep-sea, continental shelf) and are now routinely integrated in environmental studies (Bouchet et al., 2015; Lecours et al., 2016a). Other environmental disciplines that make use of terrain attributes include hydrology, soil mapping, vegetation mapping, geomorphology, meteorology and agriculture (Florinsky and Kuryakova, 1996; Florinsky et al., 2002; Lacroix et al., 2002; Hengl and Reuter, 2009; Schwanghart and Heckmann, 2012; Bispo et al., 2016).

Led by the increasing availability of different types of intuitive GIS tools that “automatically” derive terrain attributes from DTMs (Bishop et al., 2012; *e.g.* Klingseisen et al., 2008; Han et al., 2012; Rigol-Sanchez et al., 2015) - either digital elevation (DEM) or bathymetric (DBM) models - ecologists and other GIS users often select a small subset of terrain attributes to perform their analyses. Non-expert GIS users do not always understand the underpinnings of the numerous options available (Bishop and Shroder, 2004; Bouchet et al., 2015), and a lack of guidance can lead them to select an arbitrary and sub-optimal set of terrain attributes. Such selections are often based on the availability and simplicity of the

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http://dx.doi.org/10.1016/j.envsoft.2016.11.027
1364-8152/

GIS tools rather than on statistical grounds or ecological, biological, or geomorphological relevance. An inappropriate selection of terrain attributes can however produce results that do not accurately represent the observed phenomenon, fail to capture the key properties of the terrain relevant to the question or problem, and influence subsequent analysis (*e.g.* species-environment relationship measurements).

A same terrain attribute derived using different algorithms can also produce significantly different outcomes. For instance, Dolan and Lucieer (2014) demonstrated that five different slope algorithms derived from DBMs resulted in different slope surfaces, confirming previous work performed on DEMs (Jones, 1998a) and artificial surfaces (Jones, 1998b). Since the algorithms used by GIS tools are not always made explicit within the software, users are often left with little choice on which one to use and sometimes are not free to decide the details of particular parameters such as the neighbourhood size. These elements, combined with the lack of explicit statements in the ecological literature of algorithms and parameters used for deriving terrain attributes (Dolan and Lucieer, 2014), may lead to misleading and incorrect comparisons of results from different studies. To add to the confusion, geomorphometry is a field recognized for its ambiguous terminology (Bishop et al., 2012), where terrain attributes measuring a same terrain characteristic can be named differently depending on the source or software.

Finally, a poor selection of terrain attributes may cause covariation between variables. Being all derivatives of the same DTM, terrain attributes are likely to covary and induce redundancy in the analysis (Pittman et al., 2009), violating the basic assumptions of many statistical analysis methods used. For instance, Rooper and Zimmermann (2007) calculated a correlation of 0.90 between their measures of slope and rugosity. Assessing covariation between variables is however rarely performed (Graham, 2003), despite being recognized to obscure the influence of individual drivers on a response variable, and to impact statistical models, species distribution models and regression analyses (Hijmans, 2012; Dormann et al., 2013).

Selecting a suitable set of independent variables, including terrain attributes, is essential to ensure robust analyses and increase reliability of results in environmental studies (King and Jackson, 1999). A theoretical and operational framework to geomorphometric analysis is still to be defined (Pike, 1995), and “the use of quantitative geomorphological knowledge must be revisited in an analytical framework” (Bishop et al., 2012, p.6). This paper bridges geomorphometry and environmental studies by proposing an operational framework that addresses the common issue of terrain attribute selection in environmental applications like ecology. It aims to identify combinations of available terrain attributes that minimize covariation between attributes and optimize the information given on the characteristics of a terrain. The specific objectives are to 1) explore existing GIS software to compute available local terrain attributes, 2) identify groups of local terrain attributes that represent unique morphological terrain characteristics, 3) and explore the relationship between the importance of these groups and terrain complexity.

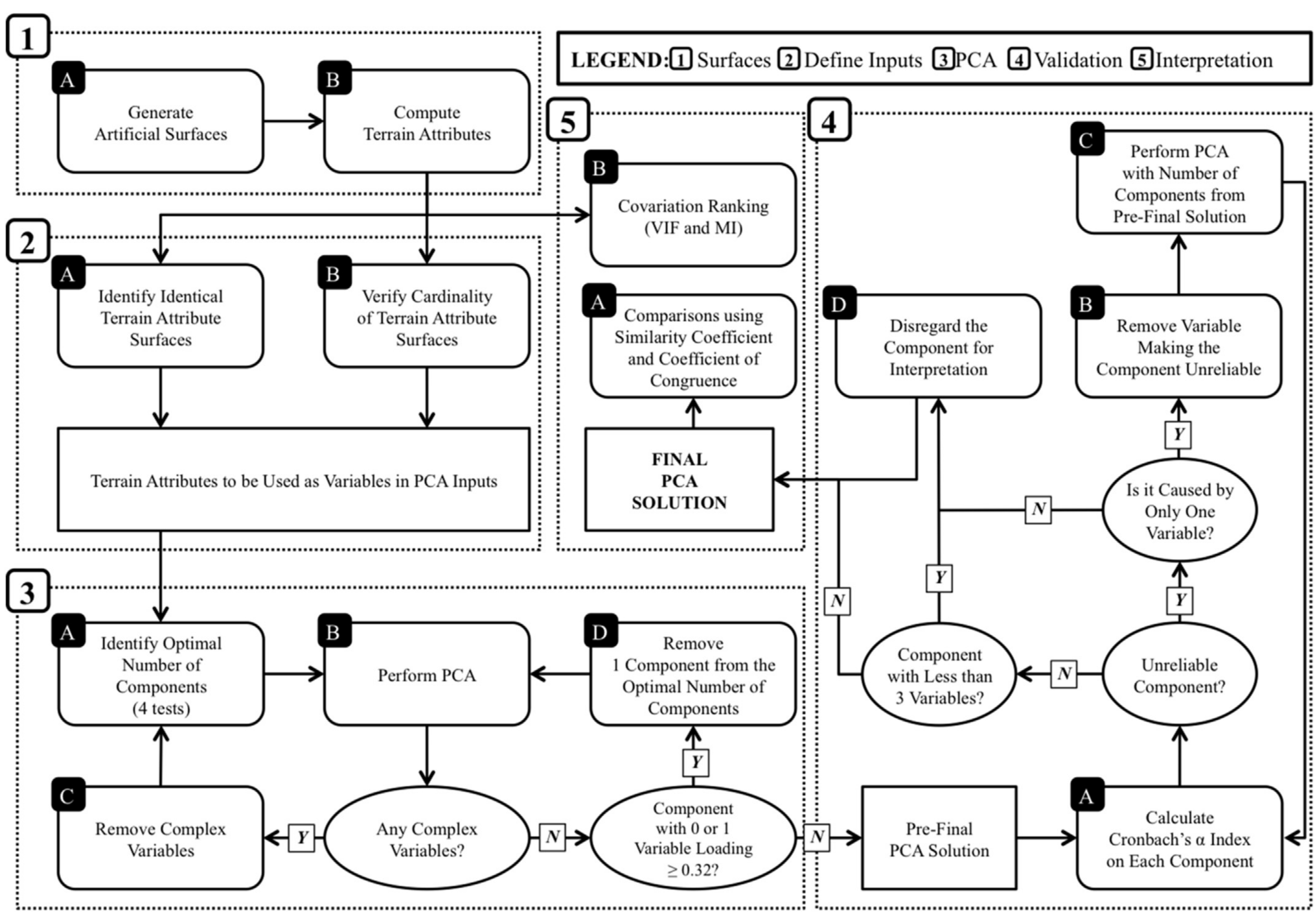

Fig. 1. Conceptual model of the analysis performed on each artificial surface.