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Integrative taxonomy in the *Liolaemus fitzingerii* complex (Squamata: Liolaemini) based on morphological analyses and niche modeling

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Abstract

It has long been considered sufficient a single method or only a descriptive diagnosis to propose a new species. Recently, many works have proposed new theoretical paradigms to consider multiple sources of evidence to support the hypothesis of new taxa within an integrative approach. Despite this, many new described species continue to be merely descriptive and without any reproducible statistical analysis to support these descriptions. We tested whether five species described as members of a species complex of the lizard genus *Liolaemus* from Patagonia, can be differentiated based on classical morphometric analyses and ecological niche modeling. Individuals were sampled from their type localities. Our results showed that the univariate tests and Principal Component Analyses (PCA) were more accurate to differentiate species compared to the Linear Discriminant Analyses (LDA). However, there were almost no morphometric differences between two of the analyzed species. Major differences were found in bioclimatic variables of four of the species through Maxent ENMs and PCA using the original worldclim variables. Our results partially support the hypothesis that species can be differentiated by classical morphometric analyses, and found a strong support for the hypothesis that these taxa can be differentiated through their bioclimatic niches. These two approaches based on repeatable statistical basis, can supplement qualitative descriptive diagnoses of new species of the genus *Liolaemus*.

Key words: ecological niche modeling, integrative taxonomy, lizards, morphology, operational criteria, species' limits

Introduction

One of the major challenges systematists and taxonomists face when describing new taxa is to clearly advocate a species concept and implement associated delimitation methods, which implies a strong theoretical background as well as a variety of analytical methods. Several contributions have been written concerning species definition (e.g., de Queiroz 2005, 2007; Camargo & Sites 2013) and de Queiroz (1998) listed numerous species concepts; currently most evolutionary biologists agree that species are separately evolving lineages of populations or metapopulations (de Queiroz 2007; Padial *et al.* 2010). An important aspect to consider is the operational criteria used to delimit species (Sites & Marshall 2004), which is one of the main focus of discussion among systematists, because scientists give priority to different operational criteria depending on their working systems (de Queiroz 2007; Yeates *et al.* 2011). The species concept and operational criteria used for delimiting species (whether it is explicit or not), have a major impact on systematic and taxonomic arrangements (Sites & Crandall 1997), and also have a great impact on conservation and management strategies, especially for groups with a large number of species (Camargo *et al.* 2010).

Integrative taxonomy (Dayrat 2005) is currently the working paradigm that provides the best theoretical basis for hypothesizing new species, implementing more than one line of evidence. This framework is described as the science that is intended to delineate the units of the diversity of life from multiple and complementary perspectives, such as phylogeography, comparative morphology, population genetics, ecology, development, behavior, etc. (Dayrat 2005). The main theoretical concept is to employ more than one line of evidence to hypothesize new taxa (e.g., Schlick-Steiner *et al.* 2010) and three alternative protocols have been proposed: integration by accumulation, by congruence and by consensus, and each of them has advantages and disadvantages to delimit species (Padial *et*

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