Zootaxa 3980 (1): 106–126
www.mapress.com/zootaxa/

Article

ISSN 1175-5326 (print edition)
ZOOTAXA
ISSN 1175-5334 (online edition)

http://dx.doi.org/10.11646/zootaxa.3980.1.6
http://zoobank.org/urn:lsid:zoobank.org:pub:11EF386F-0773-4D85-AD52-6BEAE440205A

The systematics and independent evolution of cave ecomorphology in distantly related clades of Bent-toed Geckos (Genus *Cyrtodactylus* Gray, 1827) from the Mekong Delta and islands in the Gulf of Thailand

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Abstract

An integrative taxonomic analysis of the distantly related *Cyrtodactylus condorensis* and *intermedius* species complexes of the Mekong Delta revealed that *C. paradoxus* is a junior synonym of *C. condorensis* and that *C. thochuensis* is a junior synonym of *C. leegrismeri.* Additionally, the analysis revealed that a cave-dwelling ecomorpholgy has evolved independently early on in the evolution of both complexes (represented by *C. hontreensis* in the *intermedius* complex and *C. grismeri* and *C. eisenmani* in the *condorensis* complex) and cave ecomorphs exist in sympatry—but not syntopy—with general scansorial ecomorphs. Multiple, recent, cyclical, glacioeustatic driven changes in sea levels across the Sunda Shelf are hypothesized to account for the evolution and distribution of the widely separated, conspecific insular populations of *C. condorensis* and *C. leegrismeri.* The independent evolution of cave ecomorphology is proposed to have been driven by competition avoidance. Habitat islands across the Mekong Delta are an important source of endemism and in need of protection.

Key words: ecomorphology, *Cyrtodactylus,* habitat islands, Mekong Delta, Vietnam, systematics

Introduction

The notion that an animal's form is somehow related to the way that animal functions in its environment goes back as far as the teachings of Aristotle although it was Darwin's clarity on "adaptation" that formally centralized these concepts. Studying the relationships between adaptation and the environment began to flourish in a number of fields (Wainwright & Reilly 1994) but it was not until Van der Klaauw (1948) coined the term "ecological morphology" (= ecomorphology) that a more formalized subdiscipline emerged that was focused on studying the relationship between organismal morphology and life history. We now know that ecomorphology is best studied in large, monophyletic groups where repeated "experiments" have happened independently over time in different lineages on the same phylogenetic tree (Losos 2009), thus enabling researchers to decipher between morphological similarities based on common ancestry versus those generated independently by similar selection pressures in similar environments on a similar body plan and genetic constitution.

The monophyletic Asian/Melanesian gekkonid genus *Cyrtodactylus* is well-suited for studying the evolution of ecomorphology in that its high diversity (~ 200 species [www.reptile-batabase.org]) manifests a broad spectrum of body shapes, sizes, ecological preferences, and life histories (Grismer 2011; Oliver *et al.* 2014). Some of this morphological diversity is intimately related to adapting to particular microhabitats wherein each ecomorph bears a particular suite of characters that aligns it with a particular life style in a particular environment. For example, cryptic, obligate, arboreal species such as *Cyrtodactylus elok* Dring and *C. durio* Grismer, Anuar, Quah, Muin, Chan, Grismer, and Ahmad have short limbs with wide, proximal, subdigital, lamellar pads or webbing; prehensile tails; and color patterns that mimic bark or leaves (Grismer 2011:391–398). Whereas species such as *C. astrum*

 Accepted by A. Bauer: 18 May 2015; published: 26 Jun. 2015