

University of Nebraska - Lincoln

DigitalCommons@University of Nebraska - Lincoln

---

Insecta Mundi

Center for Systematic Entomology, Gainesville,  
Florida

---

11-30-2012

## Phylogeny and systematics of the giant rhinoceros beetles (Scarabaeidae: Dynastini)

J. Mark Rowland

*University of New Mexico*, rowland@unm.edu

Kelly B. Miller

*University of New Mexico - Los Alamos Campus*, kbmiller@unm.edu

Follow this and additional works at: <https://digitalcommons.unl.edu/insectamundi>

---

Rowland, J. Mark and Miller, Kelly B., "Phylogeny and systematics of the giant rhinoceros beetles (Scarabaeidae: Dynastini)" (2012). *Insecta Mundi*. 770.

<https://digitalcommons.unl.edu/insectamundi/770>

This Article is brought to you for free and open access by the Center for Systematic Entomology, Gainesville, Florida at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in Insecta Mundi by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.

# INSECTA MUNDI

A Journal of World Insect Systematics

---

**0263**

Phylogeny and systematics of the giant rhinoceros beetles  
(Scarabaeidae: Dynastini)

J. Mark Rowland  
Department of Biology  
MSC03 2020  
University of New Mexico  
Albuquerque, NM 87131, USA

Kelly B. Miller  
Department of Biology  
Museum of Southwestern Biology  
MSC03 2020  
University of New Mexico  
Albuquerque, NM 87131, USA

Date of Issue: November 30, 2012

J. Mark Rowland and Kelly B. Miller

Phylogeny and systematics of the giant rhinoceros beetles (Scarabaeidae: Dynastini)

*Insecta Mundi* 0263: 1-15

**Published in 2012 by**

Center for Systematic Entomology, Inc.

P. O. Box 141874

Gainesville, FL 32614-1874 USA

<http://www.centerforsystematicentomology.org/>

**Insecta Mundi** is a journal primarily devoted to insect systematics, but articles can be published on any non-marine arthropod. Topics considered for publication include systematics, taxonomy, nomenclature, checklists, faunal works, and natural history. **Insecta Mundi** will not consider works in the applied sciences (i.e. medical entomology, pest control research, etc.), and no longer publishes book reviews or editorials. **Insecta Mundi** publishes original research or discoveries in an inexpensive and timely manner, distributing them free via open access on the internet on the date of publication.

**Insecta Mundi** is referenced or abstracted by several sources including the Zoological Record, CAB Abstracts, etc. **Insecta Mundi** is published irregularly throughout the year, with completed manuscripts assigned an individual number. Manuscripts must be peer reviewed prior to submission, after which they are reviewed by the editorial board to ensure quality. One author of each submitted manuscript must be a current member of the Center for Systematic Entomology. Manuscript preparation guidelines are available at the CSE website.

**Managing editor:** Paul E. Skelley, e-mail: [insectamundi@gmail.com](mailto:insectamundi@gmail.com)

**Production editor:** Michael C. Thomas, Brian Armitage, Ian Stocks

**Editorial board:** J. H. Frank, M. J. Paulsen

**Subject editors:** G.B. Edwards, J. Eger, A. Rasmussen, F. Shockley, G. Steck, Ian Stocks, A. Van Pelt, J. Zaspel

**Spanish editors:** Julieta Brambila, Angélico Asenjo

**Printed copies (ISSN 0749-6737) deposited in libraries of:**

CSIRO, Canberra, ACT, Australia

Museu de Zoologia, São Paulo, Brazil

Agriculture and Agrifood Canada, Ottawa, ON, Canada

The Natural History Museum, London, Great Britain

Muzeum i Instytut Zoologiczny PAN, Warsaw, Poland

National Taiwan University, Taipei, Taiwan

California Academy of Sciences, San Francisco, CA, USA

Florida Department of Agriculture and Consumer Services, Gainesville, FL, USA

Field Museum of Natural History, Chicago, IL, USA

National Museum of Natural History, Smithsonian Institution, Washington, DC, USA

Zoological Institute of Russian Academy of Sciences, Saint-Petersburg, Russia

**Electronic copies (On-Line ISSN 1942-1354, CDROM ISSN 1942-1362) in PDF format:**

Printed CD mailed to all members at end of year.

Florida Virtual Campus: <http://purl.fcla.edu/fcla/insectamundi>

University of Nebraska-Lincoln, Digital Commons: <http://digitalcommons.unl.edu/insectamundi/>

Goethe-Universität, Frankfurt am Main: <http://edocs.ub.uni-frankfurt.de/volltexte/2010/14363/>

**Author instructions** available on the *Insecta Mundi* page at:

<http://www.centerforsystematicentomology.org/insectamundi/>

Copyright held by the author(s). This is an open access article distributed under the terms of the Creative Commons, Attribution Non-Commercial License, which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original author(s) and source are credited. <http://creativecommons.org/licenses/by-nc/3.0/>

## Phylogeny and systematics of the giant rhinoceros beetles (Scarabaeidae: Dynastini)

J. Mark Rowland

Department of Biology

MSC03 2020

University of New Mexico

Albuquerque, NM 87131, USA

rowland@unm.edu

Kelly B. Miller

Department of Biology

Museum of Southwestern Biology

MSC03 2020

University of New Mexico

Albuquerque, NM 87131, USA

kbmiller@unm.edu

**Abstract.** This report contains the first inclusive phylogenetic analysis and taxonomic structure for the genera presently included within the scarabaeid tribe Dynastini. The study was based upon morphological, biogeographic and molecular data and yielded direct support for the recognition of three subtribes in the Dynastini: Dynastina MacLeay, **New Status** (*Dynastes* Kirby, *Augosoma* Burmeister, *Megasoma* Kirby, *Golofa* Hope), Xylotrupina Hope, **New Status** (*Xylotrupes* Hope, *Allomyrina* Arrow, *Trypoxylus* Minck, *Xyloscaptes* Prell) and Chalcosomina Rowland and Miller, **New Subtribe** (*Chalcosoma* Hope, *Haploscapanes* Arrow, *Beckius* Dechambre, *Eupatorus* Burmeister, *Pachyoryctes* Arrow). The results provide indirect but significant support for the origin of the tribe Dynastini to be of an age no later than the early Late Cretaceous. Molecular and morphological evidence suggests that *Eupatorus* as constituted in current taxonomic literature is not monophyletic, and taxonomic alternatives are discussed to address this deficiency. A plausible explanation is also provided for the perplexing use by F. W. Hope of the family-group names Xylotrupidae and Dynastidae.

### Introduction

The remarkable extravagance and variety of male sexual ornaments that have evolved among the giant rhinoceros beetles (tribe Dynastini) have attracted the ardent attention of naturalists for centuries (e.g. Scheuchzer 1732-1737). However, despite this notoriety basic aspects of the biology of this group - which might help reveal how and why such armaments arise and evolve - remain poorly resolved to this day. A conspicuous example is the virtual absence of investigations since Darwinian times that might have focused upon evolutionary relationships among the relatively few genera that compose the Dynastini.

This study attempts to aid such further research by providing the first phylogenetic analyses within the tribe Dynastini (Fig. 1), notwithstanding Rowland (2003). These analyses are based upon morphological, biogeographic and molecular characters from representatives of each of the 13 genera and approximately 70% of the species currently proposed to constitute the tribe. From the results of these analyses we have assembled a relatively robust phylogenetic topology which forms the basis of a first, readily testable taxonomic structure for the tribe - and from which trends in character evolution can be assessed. Further, the phylogenetic analyses provide indirect evidence that suggests a minimum geological age of origin of the tribe. Discussions are also provided concerning enigmatic historical usages of family-group names, as well as present directions for future refinements in the proposed taxonomic system for the tribe Dynastini.

### Methods and Materials

**Taxon sampling.** Ingroup taxa included 20 species representing each genus of the tribe Dynastini (Table 1): *Augosoma* Burmeister, *Golofa* Hope, *Dynastes* Kirby, *Megasoma* Kirby, *Trypoxylus* Minck, *Xyloscaptes*

Prell, *Allomyrina* Arrow, *Xylotrupes* Hope, *Haploscapanes* Arrow, *Chalcosoma* Hope, *Beckius* Dechambre, *Eupatorus* Burmeister, *Pachyoryctes* Arrow. Where possible multiple species are included from genera that contain more than one species to examine monophyly of the genus-groups. Morphological and taxonomic analyses were performed by JMR. Molecular and phylogenetic analyses were performed by KBM.

Outgroup taxa included four species from other tribes and subfamilies within Scarabaeidae (Table 1). The resulting cladograms were rooted with *Polyphylla decemlineata* (Say), a member of the subfamily Melolonthinae.

In addition to the specimens employed in the phylogenetic analyses, the following taxa were examined for development of the descriptions of the subtribes and the key to the subtribes and genera: *Allomyrina pfeifferi* (Redtenbacher), *Augosoma centaurus* (Fabricius), *Beckius beccarii* (Gestro), *Chalcosoma atlas* (Linné), *C. caucasus* (Fabricius), *C. mollenkampii* (Kolbe), *Dynastes granti* Horn, *D. hercules* (Linné), *D. neptunus* (Quensel), *D. satanas* (Moser), *D. tityus* (Linné), *Eupatorus birmanicus* Arrow, *E. gracilicornis* Arrow, *E. hardwickei* (Hope), *E. siamensis* (Laporte), *Golofa aegeon* (Drury), *G. argentinus* Arrow, *G. clavigera* (Linné), *G. cochlearis* Ohaus, *G. costaricensis* Bates, *G. eacus* Burmeister, *G. imperialis* Thomson, *G. minuta* Sternberg, *G. pelagon* Burmeister, *G. pizarro* Hope, *G. porteri* Hope, *G. pusilla* Arrow, *G. spatha* Dechambre, *G. tersander* (Burmeister), *G. unicolor* (Bates), *G. xiximeca* Moron, *Haploscapanes barbarossa* (Fabricius), *Megasoma acteon* (Linné), *M. anubis* (Chevrolat), *M. cedrosa* Hardy, *M. elephas* (Fabricius), *M. gyas* (Herbst), *M. joergenseni* (Bruch), *M. mars* (Reiche), *M. occidentalis* Bolívar, Jiménez et Martínez, *M. pachecoi* Cartwright, *M. punctulatum* Cartwright, *M. sleeperi* Hardy, *M. thersites* LeConte, *M. vogti* Cartwright, *Oryctes rhinoceros* (Linné), *Pachyoryctes solidus* Arrow, *Trypoxylus dichotomus* (Linné), *Xyloscaptes davidis* (Deyrolle et Fairmaire), *Xylotrupes australicus* Thomson, *X. beckeri* Schaufuss, *X. carinulus* Rowland, *X. clinias* Schaufuss, *X. damarensis* Rowland, *X. falcatus* Minck, *X. gideon* (Linné), *X. inarmatus* Sternberg, *X. lorquini* Schaufuss, *X. macleayi* Montrouzier, *X. meridionalis* Prell, *X. mniszewski* Thomson, *X. pachycera* Rowland, *X. pauliani* Silvestre, *X. philippinensis* Endrödi, *X. pubescens* Waterhouse, *X. siamensis* Minck, *X. sumatrensis* Minck, *X. tadoana* Rowland, *X. telemachos* Rowland, *X. ulysses* (Guérin-Ménéville).

Voucher specimens used in the molecular analyses are deposited in the JM Rowland Collection (JMRC) or the Museum of Southwestern Biology, University of New Mexico (MSBA, K.B. Miller curator) and bear labels with the indicated identifying codes (Table 1).

**Morphological data.** Morphological characters were assembled from published sources (Arrow 1908, 1911, 1925, 1937, 1944, 1951; Burmeister 1847; Endrödi 1947, 1951, 1957, 1976, 1985; Hope 1837; Janssens 1949; Lacordaire 1856; Latreille, 1829; Minck 1920; Rowland 2003, 2011) and from direct examination of specimens contained in the JMRC. The latter characters were employed for the descriptions of the subtribes, the key to the subtribes and genera of the Dynastini, and the phylogenetic analyses presented in Figures 1 and 2. The key is diagnostic for male specimens that fully express the secondary sexual characters, and is largely synoptic. The systematic account conforms to the format of Smith (2006) and Bouchard et al. (2011), and the nomenclatural actions are in accord with ICZN (1999).

Morphological characters and states as coded for the phylogenetic analysis are listed as follows, and their distribution among studied taxa is given in Table 2.

1. Mandible incisors: 0, adenticulate; 1, denticulate.
2. Cephalic horn apex (male): 0, acuminate; 1, bifurcate.
3. Lateral cephalic horn armature (male): 0, absent; 1, present.
4. Dorsal cephalic horn armature (male): 0, absent; 1, present.
5. Mesal pronotal horn (male): 0, absent; 1, present.
6. Mesal pronotal horn apex (male): 0, acuminate; 1, bifurcate.
7. Mesal pronotal dense pilosity (male): 0, absent; 1, present.
8. Mesal pronotal accessory horns (male): 0, absent; 1, present.
9. Lateral pronotal horns (male): 0, absent; 1, present.
10. Anterior ventrolateral pronotal apices (male): 0, not developed as horns; 1, developed as horns.
11. Prothoracic legs: 0, essentially sexually monomorphic; 1, decidedly sexually dimorphic.
12. Protibia: 0, tridentate; 1, quadridentate.

13. Paramere dorsal interdigitating teeth: 0, absent; 1, present.
14. Paramere distolateral contours: 0, converging inward; 1, parallel or diverging outward.
15. Paramere apex setation: 0, absent or short and inconspicuous; 1, long and conspicuous.
16. Rasplae: 0, essentially a simple chagrin of flexible filaments; 1, chagrin includes sclerotized spines or indurated patches.
17. Dorsal integument color: 0, dark reddish brown; 1, tan to orangish yellow or greenish yellow to bluish gray with irregular dark spots.

**DNA sequences.** Methods for DNA extraction, amplification and sequencing closely followed Miller et al. (2007, 2009). DNA was extracted using the Qiagen DNEasy kit (Valencia, California, USA) and the animal tissue protocol. In most cases, thoracic muscle tissue was removed and extracted. In some cases other tissues were extracted.

Four genes were sequenced for analysis, *cytochrome c oxidase II* (COII), *16S rRNA* (16S), *histone III* (H3) and *arginine kinase* (ArgKin). Individual gene fragments are missing for some taxa (Table 1). Primers used for both amplification and sequences were derived from several sources (Table 3). Amplification of COII, 16S and H3 required typical amplification conditions (35 cycles of denaturing: 95°C 1min., annealing: 40-50°C 1 min., elongation: 72°C 1min.). Arginine kinase required nested reamplification with one amplification run using AK168F and AK939R (Table 3) and amplification from this product using nested primers, AK183F and AK933R (Table 3), using the above conditions with sequencing from this final product. Fragments were PCR amplified using TaKaRa Ex Taq (Takara Bio Inc., Otsu, Shiga, Japan) on an Eppendorf Mastercycler ep gradient S Thermal Cycler (Eppendorf, Hamburg, Germany) and visualized by gel electrophoresis. Fragment purification was done using ExoSAP-IT (USB-Affymetrix, Cleveland, Ohio, USA) and cycle-sequenced using ABI Prism Big Dye (ver. 3.1, Fairfax, Virginia, USA) with the same primers as those used in amplification. Sequencing reaction products were purified using Sephadex G-50 Fine or Medium (GE Healthcare, Uppsala, Sweden) and sequenced with an ABI 3130xl Genetic analyzer (Molecular Biology Facility, UNM). Fragments were sequenced in both directions and sequences were edited using Sequencher (Genecodes 1999).

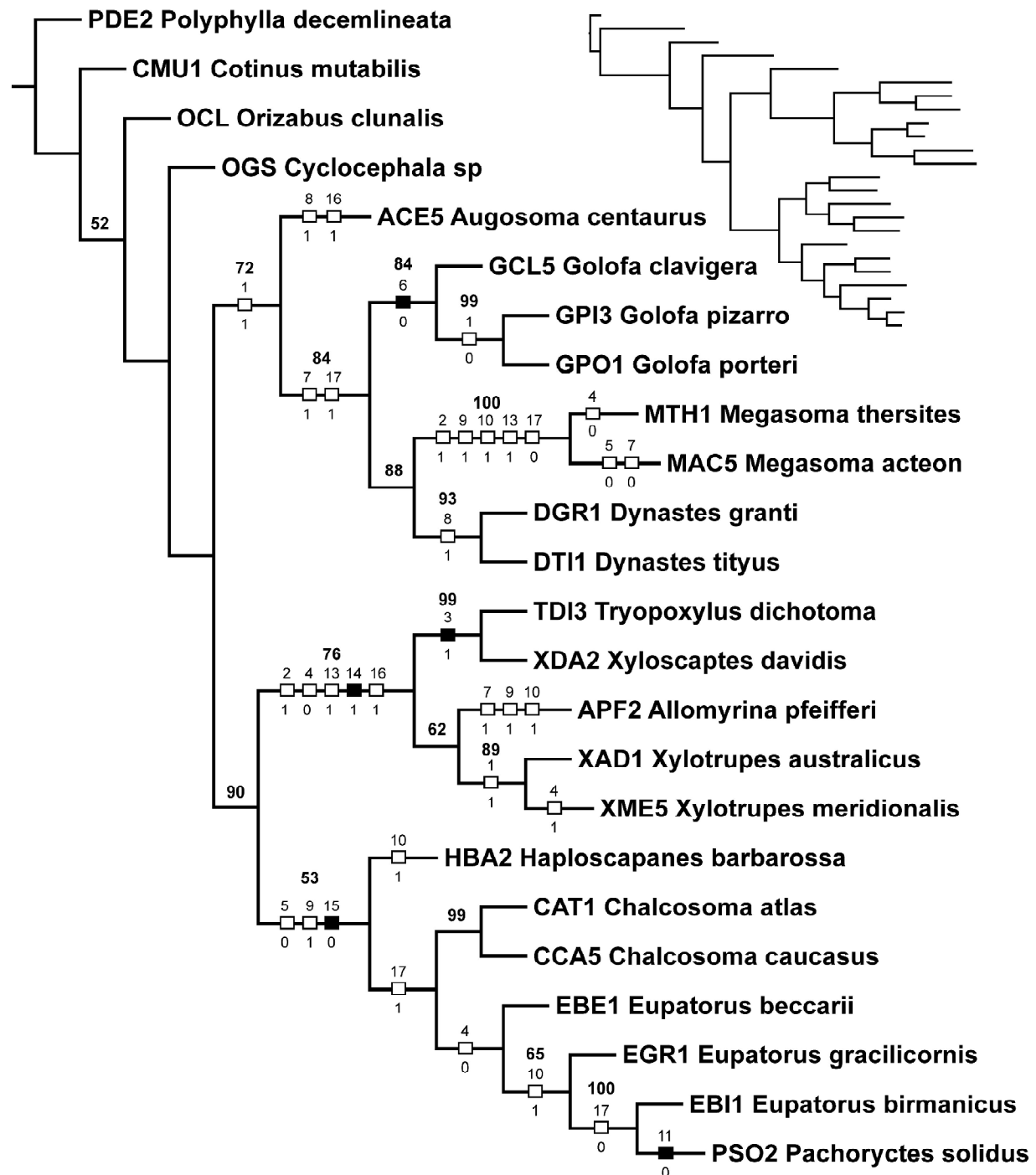
**Analysis.** Alignment of COI, H3 and ArgKin was straightforward since these markers are length-invariant and were aligned based on conservation of codon reading frame. Alignment of 16S was done using the program Muscle (Edgar 2004) using the default settings. Gaps in the aligned region were treated as missing data.

The phylogeny was estimated using a combined equal-weights parsimony analysis using the program NONA (Goloboff 1995) as implemented by WinClada (Nixon 2002) using the heuristic command settings “hold 10000”, “mult\*100”, “hold/40” and “multiple TBR + TBR”. Support for branches was measured using bootstrap values. These were calculated with NONA and WinClada using 1000 replications, 10 search reps, 1 starting tree per rep, “don’t do max\*(TBR)”, and save the consensus of each replication.

We recognize that at least some of the morphological characters may not be independent (Rowland 2003). To explore the effect of inclusion of morphological character on the resulting cladogram, we also ran the analysis with only the combined molecular data using the same commands as above.

## Results

The parsimony analysis resulted in a fully resolved cladogram (Fig. 1, length = 4216, CI = 40, RI = 47). Dynastini is monophyletic, though with relatively low support (bs<50), and since only a few outgroups were included, broader conclusions about the monophyly of the group are not here warranted. Within Dynastini, support for most groupings is relatively strong. Two larger monophyletic groups within the tribe are indicated. One includes the African genus *Augosoma*, sister to a clade including the New World genera *Golofa*, *Dynastes* and *Megasoma*, each of which is monophyletic with strong support (bs>85 in each case). Within this group, *Dynastes* and *Megasoma* are sister to each other with strong support (bs=88) and *Golofa* is sister to that clade, also with good support (bs=84). The other large monophyletic group includes all the Palearctic and Oriental genera (bs=90). Within this group, there are two additional larger clades. The first (bs=76) includes *Trypoxylus*, *Xyloscaptes*, *Allomyrina* and a monophyletic



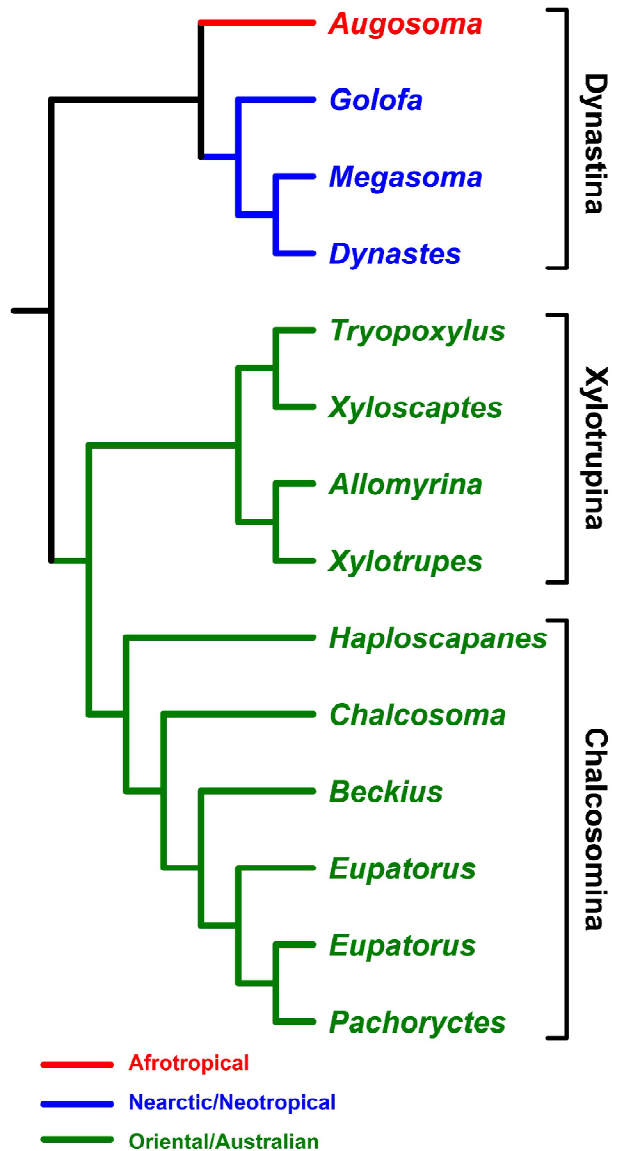
**Figure 1.** Single most parsimonious cladogram resulting from analysis of morphological and molecular data (16S, COII, H3 and arginine kinase) for Dynastini with morphological character state transformations mapped using "fast" (ACCTRAN) optimization in WinClada. Numbers immediately above hashmarks are morphological character numbers. Numbers below hashmarks are character state numbers derived on that branch. Numbers in bold above branches are bootstrap support values. Inset branching diagram is single most parsimonious cladogram from analysis of all data with branch lengths proportionate to number of character state transformations mapped using "fast" optimization.

(bs=89) *Xylotrupes*. The second, more weakly supported clade (bs=53) includes the genera *Haploscapanes*, a monophyletic (bs=99) *Chalcosoma*, *Beckius*, *Eupatorus* and *Pachoryctes* nested within *Eupatorus* Burmeister. Analysis of the combined molecular data alone (without including morphology) resulted in exactly the same topology.

## Discussion

Based upon the results of the phylogenetic analyses we propose recognition of three well-supported subtribes, the African and New World clade Dynastina and two Old World clades, Xylotrupina and the new subtribe Chalcosomina (Fig. 2). Further, our analyses found that the west African genus *Augosoma* is sister to the clade containing the American genera *Dynastes*, *Megasoma* and *Golofa* (Figs. 1, 2). This evidence supports the origin of the tribe Dynastini as no later than the early Late Cretaceous, when the South American and African continental tectonic plates separated and thus initiated the vicariant differentiation of their respective biotas (Wegener 1929; Reymont 1969; Berggren and Hollister 1978; Moullade and Guérin 1982). This proposed geologic age of origin of the tribe Dynastini is not inconsistent with the direct, though limited evidence documented in the fossil record of Mesozoic scarabaeid beetles (Krell 2000).

Hope (1837, 1845a, 1845b) and Burmeister (1847) present formal and informal taxonomic treatments regarding the Dynastini. Here we examine these treatments for the inferences they might contain regarding these authors' concepts of the relationships among the genera of this tribe. Hope (1837, 1845b) recognized MacLeay's family Dynastidae, and in Hope (1845a) he created the apparent additional family Xylotrupidae, but he did so, perplexingly, in order to accommodate the new genus *Dipelicus*, a pentodontine. One might infer from the latter that either Hope (1845a) perceived *Xylotrupes* to be more closely allied morphologically to *Dipelicus* than it is to *Dynastes*, which seems unlikely; or that Hope wrote Xylotrupidae, but should rather have written Xyloryctidae, which seems quite likely from the following evidence. Hope (1837) introduced the new genus *Xyloryctes* at the head of six new pentodontine genera. Then Hope (1845a) introduced the additional new pentodontine genus *Dipelicus*, but enigmatically created the family Xylotrupidae to contain that new genus. Darren Mann obtained the F. W. Hope archives at Oxford University Museum which contain Hope's manuscript notes from the historical period in question. These revealed that, other than *Xylotrupes*, all of the recognised genera that Hope listed in his notes under Xylotrupidae are oryctines or pentodontines: *Oryctes*, *Oryctoderus*, *Cheiroplatys*, *Tetradosata*(?), *Apothrix*(?) and *Phileurus depressus* - which is a junior synonym of the pentodontine *Semanopterus subcostatus* Laporte (Endrödi 1985: 416-417). Moreover, Hope did not list *Xyloryctes* among these, but did list *Xylotrupes*, and under the latter are listed five trivial names: *juba*, *latipes*, *curtus*, *porcellus*, *ixion* - all of which are names of pentodontines, and none of which



**Figure 2.** Summary phylogeny of Dynastini genera, distribution and classification based on results of combined phylogenetic analyses.



**Table 1.** Taxa and specimens used in phylogenetic analysis of Dynastini. JMRC = JM Rowland Collection, MSBA = Museum of Southwestern Biology, University of New Mexico.

Genus	Species	Code	Voucher deposition	Extracted tissue (see footnotes)	GenBank # (COII/16S/H3/ArgKin)
<b>Outgroup</b>					
<i>Polyphylla</i>	<i>decemlineata</i>	KBMC-PDE2	JMRC	1	-/JX994048/-/JX994005
<i>Cotinus</i>	<i>mutabilis</i>	KBMC-CMU1	JMRC	1	JX994068/JX994045/JX994025/JX994004
<i>Orizabus</i>	<i>clunalis</i>	KBMC-OCL1	JMRC	1	JX994069/JX994046/-/-
<i>Cyclocephala</i>	sp.	KBMC-OGS	MSBA	2	JX994070/JX994047/-/-
<b>Ingroup</b>					
<i>Allomyrina</i>	<i>pfeifferi</i>	KBMC-APF2	JMRC	1	JX994049/JX994026/JX994006/JX993994
<i>Augosoma</i>	<i>centaurus</i>	KBMC-ACE5	JMRC	3	JX994050/JX994027/JX994007/JX993995
<i>Beckius</i>	<i>beccarii</i>	KBMC-EBE1	JMRC	2	JX994055/JX994032/JX994012/-
<i>Chalcosoma</i>	<i>atlas</i>	KBMC-CAT1	JMRC	2	JX994051/JX994028/JX994008/-
<i>Chalcosoma</i>	<i>caucasus</i>	KBMC-CCA5	JMRC	3	JX994052/JX994029/JX994009/JX993996
<i>Dynastes</i>	<i>granti</i>	KBMC-DGR1	JMRC	1	JX994053/JX994030/JX994010/JX993997
<i>Dynastes</i>	<i>tityus</i>	KBMC-DT11	JMRC	1	JX994054/JX994031/JX994011/-
<i>Eupatorus</i>	<i>birmanicus</i>	KBMC-EBI1	JMRC	2	JX994056/JX994033/JX994013/-
<i>Eupatorus</i>	<i>gracilicornis</i>	KBMC-EGR1	JMRC	2	JX994071/-/-/-
<i>Golofa</i>	<i>clavigera</i>	KBMC-GCL5	JMRC	3	JX994057/JX994034/JX994014/JX993998
<i>Golofa</i>	<i>pizarro</i>	KBMC-GPI3	JMRC	3	JX994058/JX994035/JX994015/-
<i>Golofa</i>	<i>porteri</i>	KBMC-GPO1	JMRC	3	JX994059/JX994036/JX994016/-
<i>Haploscapanes</i>	<i>barbarossa</i>	KBMC-HBA2	JMRC	1	JX994060/JX994037/JX994017/JX993999
<i>Megasoma</i>	<i>acteon</i>	KBMC-MAC5	JMRC	3	JX994061/JX994038/JX994018/JX994000
<i>Megasoma</i>	<i>thersites</i>	KBMC-MTH1	JMRC	2	JX994062/JX994039/JX994019/-
<i>Pachyoryctes</i>	<i>solidus</i>	KBMC-PSO2	JMRC	2	JX994063/JX994040/JX994020/-
<i>Trypoxylus</i>	<i>dichotom</i>	KBMC-TDI3	JMRC	3	JX994064/JX994041/JX994021/-
<i>Xyloscaptus</i>	<i>davidis</i>	KBMC-XDA2	JMRC	1	JX994065/JX994042/JX994022/JX994001
<i>Xylotrupes</i>	<i>australicus</i>	KBMC-XAD1	JMRC	1	JX994066/JX994043/JX994023/JX994002
<i>Xylotrupes</i>	<i>meridionalis</i>	KBMC-XME5	JMRC	1	JX994067/JX994044/JX994024/JX994003

<sup>1</sup>Collected as live adults, then frozen or placed in EtOH, and muscle tissue dissected into absolute EtOH.

<sup>2</sup>Muscle tissue isolated from dead, dried adults, muscle tissue dissected dry into sealable vials.

<sup>3</sup>Procured as frozen larvae, muscle tissue dissected into absolute EtOH.

have otherwise ever been associated with *Xylotrupes* or are now associated with Dynastini. The latter evidence thus is strong that Hope simply mistakenly used the names Xylotrupidae and *Xylotrupes* in the above publications and manuscript notes where he should have used the names Xyloryctidae and *Xyloryctes*. Darren Mann provided the following additional supportive insights regarding Hope's heretofore perplexing use of the family name Xylotrupidae: "*I have been through some of Hope's archives and found the name Xylotrupidae in his own hand, although in the same notebook, on three separate occasions. This usage included several genera beneath, Oryctes, Xylotrupes, etc. So my guess would be that he wanted to create a new 'group name' for the genus Dipelicus and just lost track of what was Xyloryctes and Xylotrupes more a lapsus memoriae than a lapsus calami.*" Moreover, the several foregoing facts suggest that considerable caution should be used in inferring Hope's concepts of relationships among the genera of the Dynastini by his use of the family names Dynastidae (Hope 1837, 1845b) and Xylotrupidae (Hope 1845a). Regarding formal nomenclature, whether or not Hope (1845a) mistakenly used the name Xylotrupidae rather than Xyloryctidae does not affect the status of the name Xylotrupidae according to the ICZN (pers. comm. Andrew Smith).

Burmeister (1847) segregated Dynastidae into the two informal categories "*Dynastidae lasiopygi*" containing *Golofa*, *Theogenes* and *Dynastes*; and "*Dynastidae liparopygi*" containing *Augosoma*, *Xylotrupes*, *Eupatorus*, *Chalcosoma* and *Megasoma*; and of which he wrote: [p. 246] "*Dynastidae liparopygi. Sie bewohnen die westliche halbkugel und zerfallen in drei natürliche Gattungen.*"; and [pp. 262-263]

**Table 2.** Taxa and morphological character states coded for phylogenetic analysis of Dynastini. Morphological characters and code states are described in the Materials and Methods on pp. 2-3.

	000000000	11111111
	123456789	01234567
<i>Augosoma centaurus</i>	100111010	01000110
<i>Golofa clavigera</i>	100110100	01000101
<i>Golofa pizarro</i>	000110100	01000101
<i>Golofa porteri</i>	000110100	01000101
<i>Dynastes granti</i>	100111110	01000101
<i>Dynastes tityus</i>	100111110	01000101
<i>Megasoma thersites</i>	110011101	11010100
<i>Megasoma actaeon</i>	11010-001	11010100
<i>Trypoxylus dichotom</i>	011011000	01011110
<i>Xyloscaptes davidis</i>	011011000	01011110
<i>Allomyrina pfeifferi</i>	010011101	11011110
<i>Xylotrupes australicus darwinia</i>	110011000	01011110
<i>Xylotrupes meridionalis</i>	110111000	01011110
<i>Haploscapanes barbarossa</i>	00010-001	11000000
<i>Chalcosoma atlas</i>	00010-001	01000001
<i>Chalcosoma caucasus</i>	00010-001	01000001
<i>Beckius beccarii</i>	00000-001	01000001
<i>Eupatorus gracilicornis</i>	00000-001	11000001
<i>Eupatorus birmanicus</i>	00000-001	11000000
<i>Pachyoryctes solidus</i>	00000-001	10000000

“*Dynastidae lasiopygi*. Man kann nach der Bildung der Unterkiefer, mit denen der übrige Körperbau ganz in Harmonie bleibt, noch zwei natürliche Unterabtheilungen feststellen.” Burmeister thus considered *Dynastidae lasiopygi* and *Dynastidae liparopygi* as natural groupings (pers. comm. Joachim Willers).

Arrow (1908) revised the genus *Eupatorus* to contain *E. hardwickei*, *E. gracilicornis*, *E. beccarii*, *E. birmanicus* and *E. siamensis* by synonymizing *Alcidosoma* which Laporte (1867) had created for *A. siamensis*. This arrangement was followed in Endrödi (1976, 1985). However, our results indicate that under this concept *Eupatorus* is not monophyletic because *Pachyoryctes solidus* is nested among *Eupatorus* species (Fig. 1). That is, *E. gracilicornis* is sister to the clade containing *E. birmanicus* and *Pachyoryctes solidus*, and the latter three species form a clade that is sister to *B. beccarii*. To improve the classification with respect to the latter, we follow Dechambre (1992) in which *E. beccarii* was transferred to *Beckius* Dechambre. Our morphological and biogeographic observations are consistent with this approach, as are the notations, if not the actions, of Arrow (1908), Gestro (1876), Laporte (1867), Endrödi (1976) and Dechambre (1992). Further, we compared non-type specimens of *E. siamensis*, *E. birmanicus*, *E. hardwickei* and *E. gracilicornis* and found that *E. siamensis* and *E. birmanicus* are similar in the following respects: 1) they have dorsal pronotal horns which are larger than the basolateral horns, 2) their pronotal integument is rugose and without well-defined pits and 3) they are not known to express tan-colored individuals. Arrow (1908) found *E. siamensis* and *E. birmanicus* to have “curiously different sexual armature c [but] which are so closely alike in all other respects.” We found that *E. hardwickei* and *E. gracilicornis* differ from *E. siamensis* and *E. birmanicus* in having: 1) dorsal pronotal horns that are smaller than the basolateral horns, 2) polished pronotal integument with well-defined pits and 3) predominately tan-colored individuals. Further, in spite of Arrow (1908) placing *P. solidus* in its own monotypic genus relative to *E. siamensis* and *E. birmanicus*, these three species display a pattern of character states from which it is not difficult to imagine that *P. solidus* could be sister to one and not both *E. siamensis* or *E. birmanicus*: *P. solidus* is compressed lengthwise in general body proportions compared to *E. siamensis* and *E. birmanicus*; the pronotal dorsolateral horns are strong in *E. siamensis* and *E. birmanicus*, weak in *P. solidus*; pronotal anterolateral apices are strong horns in *E. siamensis* and *E. birmanicus*, weak horns in *P. solidus*; proleg sexual dimorphism is strong in *E. siamensis* and *E. birmanicus*, weak in *P. solidus*; mandible incisors are blunt and distinctly laterally lobed in *E. siamensis* and *E. birmanicus*,

**Table 3.** Primers used for amplification and sequencing of gene fragments for Dynastini specimens.

Gene	Primer	Direction	Sequence (5'-3')
16S	16S <sup>1</sup>	For	CGCCTGTTTATCAAAAACAT
	16S <sup>2</sup>	Rev	CTCCGGTTTGAACCTCAGATCA
COII	9b <sup>2</sup>	Rev	GTACTTGCTTTCAGTCATCTWATG
	F-luc <sup>2</sup>	For	TCTAATATGGCAGATTAGTGC
	R-lys <sup>2</sup>	Rev	GAGACCAGTACTTGCTTTCAGTCATC
	Eflá <sup>3</sup> Cho10 <sup>3</sup>	Rev	ACRGCVACKGTYTGHCKCATGTC
	For <sup>3</sup>	For	GGYGACAAYGTTGGTTTYAAY
H3	Haf <sup>4</sup>	For	ATGGCTCGTACCAAGCAGACGGC
	Har <sup>4</sup>	Rev	ATATCCTTGGGCATGATGGTGAC
	AK168F <sup>5</sup>	For	CAGGTTTGGARAAACACGAYTCYGG
ArgKin	AK939R <sup>5</sup>	Rev	GCCNCCYTCRCYTCRGTGTGYTC
	AK183F <sup>5</sup>	For	GATTCTGGAGTCGGNATYTAYGCNCCYGAYGC
	AK933R <sup>5</sup>	Rev	CCCTCAGCYTCRGTGTGYTCNCCRCG

<sup>1</sup>Simon et al. (1994); <sup>2</sup>Whiting (2002); <sup>3</sup>Danforth et al. (1999); <sup>4</sup>Colgan et al. (1998); <sup>5</sup>Wild and Maddison (2008).

sharp and indistinctly laterally lobed in *P. solidus*; prosternal apex is broadly acuminate and orthogonal in *E. birmanicus*, truncate and reflected inward in *E. siamensis* and *P. solidus*; anterodorsal margin of phallobase is sharply defined with midline furrow extending to margin in *E. birmanicus* and *P. solidus*, less defined in *E. siamensis* and midline furrow vague, not extending to margin; paramere blades are short in *E. birmanicus* and *P. solidus*, long and attenuate in *E. siamensis*; paramere orifice is wide and round in *E. birmanicus* and *P. solidus*, narrow and elliptical in *E. siamensis*. It is indeed notable that the male of *P. solidus* has much reduced pronotal armature compared to *siamensis* and *birmanicus*, but it is also observed that the largest males of *P. solidus* have a similar pronotal armature to the small males of *E. siamensis*. Moreover, large males of *P. solidus* appear to express the pronotal armature phenotype typical of the subordinate males of ancestral lineages of *Eupatorus*. This seems also to parallel the expression in *P. solidus* of an essentially female proleg phenotype. Relatively rapid phylogenetic switching between and among such intraspecific alternative developmental phenotypes within conditionally polymorphic lineages appears to be commonplace in the Dynastini (Rowland 2003) and other groups of scarabaeid beetles (Rowland and Emlen 2009), and these phylogenetic events can produce considerable difficulties for the taxonomists of affected groups (West-Eberhard 2003). Thus, the questions regarding *Eupatorus* framed above might best be addressed with robust phylogenetic methods including molecular analyses that incorporate all of the taxa concerned, and consulting the necessary type specimens. According to Endrödi (1976) the type of *A. siamensis* is lost, however Endrödi designated a neotype which he deposited in “meiner Sammlung”, and which is now possibly in the Hungarian Natural History Museum, Budapest. Endrödi (1976) further reported that the type specimen of *E. birmanicus* is in The Natural History Museum, London, as is the type of *E. gracilicornis* and the lectotype of *P. solidus*. The type of *Dynastes hardwickei* is in the Oxford University Museum.

## Systematics

### Tribe DYNASTINI MacLeay, 1819

Original spelling and citation: Dynastidae MacLeay, 1819: 64

Type genus: *Dynastes* MacLeay, 1819: 22

### Subtribe DYNASTINA MacLeay, 1819, NEW STATUS

Original spelling and citation: Dynastidae MacLeay, 1819: 64

Type genus: *Dynastes* MacLeay, 1819: 22

Synonym: Megasominae Swainson, 1840: 210 [stem *Megasomat*-]. Type genus: *Megasoma* Kirby, 1825.

Family-group name attributed to Imhoff (1856) in A. B. T. Smith (2006: 175); incorrect original stem formation, not in prevailing usage.

Type genus: *Megasoma* Kirby, 1825: 566

**Subtribe XYLOTRUPINA Hope, 1845, NEW STATUS**

Original spelling and citation: Xylotrupidae, Hope 1845: 7

Type genus: *Xylotrupes* Hope, 1837: ix

**Subtribe CHALCOSOMINA, NEW SUBTRIBE**

Original spelling and citation: Chalcosomina Rowland and Miller, 2012

Type genus: *Chalcosoma* Hope, 1837: 86

**Tribe DYNASTINI MacLeay**

**Description.** Endrödi (1985) constitutes the most recent comprehensive taxonomic review of the Dynastinae, in which he provides the following morphological description of the Dynastini relative to the other tribes of the subfamily: “*This tribe includes the biggest species of the whole family Melolonthidae. Most species display very strong sexual dimorphism. Horns of males often very long, head and pronotum [horns] in females usually almost absent. Fore legs of males mostly longer than in females. Also elytra in many species different: in male smooth, in female strongly sculptured. Mandibles mostly incised on apex, outer side straight or lobed. Antennae 10-jointed, club in both sexes short. Form of prosternal process highly variable. Propygidium either with or without a stridulatory area. Claw-joint of anterior tarsi strongly thickened only in Dynastes neptunus Quensel and D. satanas Moser; apex of basal-joint of hind tarsi rarely spiniformly produced.*”

**Subtribe DYNASTINA MacLeay**

**Included genera.** *Augosoma* Burmeister, *Golofa* Hope, *Dynastes* Kirby, *Megasoma* Kirby.

**Description.** **Clypeus mesal margin:** deeply emarginate in *Augosoma*, entire to slightly emarginate in *Dynastes*, widely emarginate in *Megasoma* and slightly emarginate in *Golofa*. **Male cephalic horn apex:** Acuminate in *Augosoma*, *Dynastes* and *Golofa*, bifurcate in *Megasoma*. **Male cephalic horn armature:** Denticulate in *Augosoma*, *Dynastes* and some *Golofa*, adenticulate in *Megasoma* and some *Golofa*, serrate in most *Golofa*; armature is dorsal in all genera. **Male cephalic horn length in longest-horned species:** Long in all genera. **Male cephalic horn length of shortest-horned species:** Long in *Augosoma*, medium in *Dynastes*, short in *Megasoma* and *Golofa*. **Female frons:** Tuberculate and lateral in position in *Augosoma* and *Megasoma*, tuberculate and mesal in position in *Dynastes* and *Golofa*; tubercles large in *Augosoma* and *Megasoma* and small in *Dynastes* and *Golofa*. **Mandible incisor:** Denticulate in *Augosoma*, *Dynastes*, *Megasoma* and some *Golofa*, adenticulate in other *Golofa*; denticles asymmetrical and dominant denticle mesal in *Augosoma*, *Dynastes* and *Megasoma*, lateral in *Golofa*. **Maxillary lacinia:** Denticles mesally directed, usually number one to three in *Augosoma*, *Dynastes* and *Megasoma*, and four or more in most *Golofa*. **Dorsal pronotum of major males:** With single mesal horn or boss in *Augosoma*, *Dynastes*, *Megasoma* and most *Golofa*, and simply convex in some *Golofa*. **Mesal pronotal horns apex:** Apically bifurcate in *Augosoma*, *Dynastes* (even if inconsistently or minutely so), *Megasoma* and some *Golofa*, and apically acuminate in other *Golofa*. **Mesal pronotum dense pilosity:** Absent in *Augosoma*, present in *Dynastes*, *Megasoma* and *Golofa*. **Mesal pronotal accessory horns:** Paired lateral accessory horns present in *Augosoma* and most *Dynastes*, accessory horns absent in *Megasoma*, *Golofa* and one species of *Dynastes*. **Male anterior ventrolateral pronotal apices:** Not developed as horns in *Augosoma*, *Dynastes* and *Golofa*, developed as horns in *Megasoma*. **Male pronotal horn length of longest-horned species:** Long in *Augosoma*, *Dynastes* and *Golofa*, medium in *Megasoma*. **Male pronotal horn length of shortest-horned species:** Long in *Augosoma*, medium in *Dynastes*, absent in *Megasoma* and *Golofa*. **Pronotal architecture of female:** Vaguely complex in *Augosoma*, simply convex in *Dynastes*, *Megasoma* and *Golofa*. **Pronotal integument of male:** With some anastomosing sculpture in *Augosoma*, other genera without anastomosing sculpture. **Pronotal integument of female:** With considerable anastomosing sculpture in *Augosoma* and *Dynastes*,

with little or no anastomosing sculpture in *Megasoma* and *Golofa*. **Prolegs:** Sexually dimorphic in *Augosoma*, *Dynastes* and some *Megasoma* and *Golofa*; sexually monomorphic in some small *Megasoma* and *Golofa*. **Elytra of female:** Dorsal integument essentially as in male in *Augosoma* and *Megasoma* and some *Dynastes* and *Golofa*, significantly different from male in some *Dynastes* and *Golofa*. **Dorsal integument color:** Uniformly dark red/brown/black in *Augosoma*, some *Dynastes* and *Megasoma*, colored in some *Dynastes* and *Golofa*. **Dorsal pilosity:** No species conspicuously hirsute in *Augosoma* and *Dynastes*, one species conspicuously hirsute in *Golofa*, several species conspicuously hirsute in *Megasoma*. **Paramere dorsal conjunction:** Without interdigitating teeth in *Augosoma*, *Dynastes* and *Golofa*, with interdigitating teeth in *Megasoma*. **Paramere apex:** Lateral contours converging inward. **Paramere apex setation:** Long and conspicuous. **Raspulae:** With enlarged, sclerotized plate in *Augosoma* and spines in some *Golofa*, without such structures in *Dynastes*, *Megasoma* and most *Golofa*.

### Subtribe XYLOTRUPINA Hope

**Included genera.** *Allomyrina* Arrow, *Xylotrupes* Hope, *Trypoxylus* Minck, *Xyloscapes* Prell.

**Description. Clypeus mesal margin:** Slightly emarginate in *Allomyrina*, deeply emarginate in *Xylotrupes*, widely emarginate in *Trypoxylus*, entire in *Xyloscapes*. **Male cephalic horn apex:** Bifurcate in all genera. **Male cephalic horn armature:** Adenticulate in *Allomyrina* and some *Xylotrupes*, denticulate in *Trypoxylus*, *Xyloscapes* and other *Xylotrupes*; denticles dorsal in some *Xylotrupes*, lateral in *Trypoxylus* and *Xyloscapes*. **Male cephalic horn length of longest-horned species:** Medium in *Allomyrina* and *Xyloscapes*, long in *Xylotrupes* and *Trypoxylus*. **Male cephalic horn length of shortest-horned species:** Medium in *Allomyrina*, *Trypoxylus* and *Xyloscapes*, short in *Xylotrupes*. **Female frons:** Tuberculate with small tubercles in all genera; position mesal in *Allomyrina*, lateral in *Xylotrupes*, with both mesal and lateral tubercles in *Trypoxylus* and *Xyloscapes*. **Mandible incisor:** Adenticulate in *Allomyrina*, *Trypoxylus*, *Xyloscapes* and *Xylotrupes florensis*, denticulate in other *Xylotrupes*; mostly asymmetrical and laterally dominant. **Maxilla lacinia:** Denticulate in all genera; denticles directed mesally, numbering four or more in *Allomyrina* and *Xylotrupes*, and three or less in *Trypoxylus* and *Xyloscapes*. **Dorsal pronotum of major males:** With single mesal horn in all genera except *Xylotrupes inarmatus*. **Mesal pronotal horns apex:** Apically bifurcate in all genera except *Xylotrupes inarmatus*. **Mesal pronotum dense pilosity:** Present only in *Allomyrina*. **Mesal pronotal accessory horns:** Present only in *Xylotrupes florensis*. **Male anterior ventrolateral pronotal apices:** Developed as horns only in *Allomyrina*. **Male pronotal horn length of longest-horned species:** Short in *Allomyrina* and *Trypoxylus*, medium in *Xyloscapes*, long in *Xylotrupes*. **Male pronotal horn length of shortest-horned species:** Short in *Allomyrina* and *Trypoxylus*, medium in *Xyloscapes*, absent in *Xylotrupes inarmatus*. **Pronotal architecture of female:** Complex in *Allomyrina*, *Trypoxylus* and *Xyloscapes*, simply convex in *Xylotrupes*; architecture vague in *Allomyrina*, pronounced in *Trypoxylus* and *Xyloscapes*. **Pronotal integument of male:** No anastomosing sculpture in any genus. **Pronotal integument of female:** Considerable anastomosing sculpture in *Allomyrina*, little anastomosing sculpture in *Xylotrupes*, *Trypoxylus* and *Xyloscapes*. **Prolegs:** Sexually dimorphic in all genera. **Elytra of female:** Dorsal integument significantly different from male in *Trypoxylus*, essentially the same as in male in *Allomyrina*, *Xylotrupes* and *Xyloscapes*. **Dorsal integument color:** Uniformly dark red/brown/black in all genera. **Dorsal pilosity:** Not conspicuous in *Trypoxylus* and *Xyloscapes*, conspicuous in *Allomyrina* and *Xylotrupes pubescens*. **Paramere dorsal conjunction:** With interdigitating teeth in all genera; teeth strong, dominant tooth evaginates from left side into right side in *Allomyrina*, *Xylotrupes* and *Trypoxylus*; teeth weak, dominant tooth evaginates from right side into left side in *Xyloscapes*. **Paramere apex:** Lateral contours parallel or diverging outward. **Paramere apex setation:** Long and conspicuous. **Raspulae:** With enlarged, sclerotized spines in all genera.

**Subtribe CHALCOSOMINA, New Subtribe**

**Included genera.** *Haploscapanes* Arrow, *Chalcosoma* Hope, *Beckius* Dechambre, *Eupatorus* Burmeister, *Pachyoryctes* Arrow.

**Description.** **Clypeus mesal margin:** Slightly emarginate in *Haploscapanes*, deeply emarginate in other genera. **Male cephalic horn apex:** Acuminate in all genera. **Male cephalic horn armature:** Adenticulate in some *Haploscapanes*, some *Chalcosoma* and all *Beckius*, *Eupatorus* and *Pachyoryctes*; denticulate in some *Haploscapanes* and some *Chalcosoma*. **Male cephalic horn length of longest-horned species:** Medium in *Haploscapanes*, long in other genera. **Male cephalic horn length of shortest-horned species:** Short in *Haploscapanes*, medium in *Eupatorus*, and long in *Chalcosoma*, *Beckius* and *Pachyoryctes*. **Female frons:** Atuberculate in *Chalcosoma*, tuberculate in other genera; tubercle mesal and large in *Pachyoryctes*, lateral and large in other genera. **Mandible incisor:** Adenticulate in all genera. **Maxillary lacinia:** Adenticulate in *Haploscapanes*, denticulate in other genera; denticles directed apically and mesally in *Beckius* and *Eupatorus*, mesally in *Chalcosoma* and apically in *Pachyoryctes*; denticles number less than four in *Chalcosoma*, four or more in *Beckius* and *Eupatorus*. **Dorsal pronotum of major males:** With paired horns, bosses or carinae that vary from mesal to lateral, except *Haploscapanes barbarossa* and *H. enermis* in which the dorsal pronotum is simply convex. **Mesal pronotum dense pilosity:** Absent in all genera. **Male anteroventrolateral pronotal apices:** Horns absent in *Haploscapanes*, *Chalcosoma* and *Beckius*, equivocal in *Pachyoryctes*, developed *Eupatorus*. **Male pronotal horn length of longest-horned species:** Short in *Haploscapanes* and *Pachyoryctes*, medium in *Eupatorus*, long in *Chalcosoma* and *Beckius*. **Male pronotal horn length of shortest-horned species:** Absent in *Haploscapanes*, short in *Chalcosoma*, *Eupatorus* and *Pachyoryctes*, long in *Beckius*. **Pronotal architecture of female:** Not seen in *Pachyoryctes*, in other genera simply convex. **Pronotal integument of male:** No anastomosing sculpture in *Chalcosoma*, *Eupatorus* and *Pachyoryctes*, some anastomosing sculpture in *Haploscapanes* and *Beckius*. **Pronotal integument of female:** Considerable anastomosing sculpture in *Haploscapanes*, *Chalcosoma*, *Beckius*, *Eupatorus* and not seen in *Pachyoryctes*. **Prolegs:** Sexually monomorphic in *Pachyoryctes*, sexually dimorphic in other genera. **Elytra of female:** Integument significantly different from male in *Chalcosoma*, essentially same as in male in *Haploscapanes*, *Beckius* and *Eupatorus*, not seen in *Pachyoryctes*. **Dorsal integument color:** Uniformly dark red/brown/black in *Haploscapanes* and *Pachyoryctes*, colored in *Chalcosoma*, *Beckius* and *Eupatorus*. **Dorsal pilosity:** No genera with conspicuously hirsute species. **Paramere dorsal conjunction:** Without interdigitating teeth in all genera. **Paramere apex:** Lateral contours converging inward. **Paramere apex setation:** Nearly absent, or short and inconspicuous. **Raspular complex:** Without enlarged, sclerotized spines in all genera.

**Key to subtribes and genera of Dynastini**

The key is based on the morphology of males that fully express the secondary sexual traits.

1. Apex of cephalic horn acuminate (*Augosoma*, *Dynastes*, *Golofa*, *Haploscapanes*, *Eupatorus*, *Beckius*, *Pachyoryctes*, *Chalcosoma*) or bifurcate (*Allomyrina*, *Xylotrupes*, *Trypoxylus*, *Xyloscaptes*, *Megasoma*); if acuminate then pronotum has a medial horn (*Augosoma*, *Dynastes*, *Golofa*) or is essentially hornless (female-like *Golofa*); if essentially hornless then anterolateral pronotal integument is immaculate to punctate (*Golofa*), never cristate and distinctly anastomosing (as in *Haploscapanes*), and mandibular incisors are bidentate (with rare exceptions); lateral contours of paramere apex converging inward (Dynastina) or parallel to diverging outward (Xylotrupina) ..... **2 (Dynastina MacLeay and Xylotrupina Hope)**
- Apex of cephalic horn acuminate (*Haploscapanes*, *Eupatorus*, *Beckius*, *Pachyoryctes*, *Chalcosoma*); pronotum without a medial horn (*Haploscapanes*, *Eupatorus*, *Beckius*, *Pachyoryctes*, *Chalcosoma*). or with paired more or less medial horns (*C. mollenkampii*, *E. birmanicus*), or with more or less lateral horns (*C. atlas*, *C. caucasicus*, *Beckius*, all other *Eupatorus*), or with

- horn-like transverse lateral carinae (*Pachyoryctes*); if pronotum is essentially female-like, without obvious male ornaments, then anterolateral pronotal integument is anastomosing and cristate (*Haploscapanes barbarossa*, *H. inermis*); lateral contours of paramere apex converging inward (except *Beckius*) and apex setation absent or nearly so; mandibular incisors adenticulate ..... **9 (Chalcosomina, new subtribe)**
- 2(1). Cephalic horn apex acuminate (*Augosoma*, *Dynastes*, *Golofa*) or bifurcate (*Megasoma*); if bifurcate then mandibular incisor denticles diverge strongly, usually at least 45°; mesal pronotal horn or boss present (*Augosoma*, *Dynastes*, most *Megasoma*, most *Golofa*) or absent (female-like *Megasoma* and *Golofa*); if horn or boss absent then mandibular incisor denticles diverge strongly as above (*Megasoma*) and paramere blades are on a similar plane as or below that of paramere orifice (*Megasoma*, *Golofa*); pronotal medial horn or medial boss usually with dense ventral pilosity; lateral contours of paramere apex converging inward; Africa, America ..... **3 (Dynastina MacLeay)**
- Cephalic horn bifurcate; mandibular incisor adenticulate (*Trypoxylus*, *Xyloscapes*, *Allomyrina*, *Xylotrupes florensis*) or denticulate and denticles diverge at most 30° (other *Xylotrupes*); pronotal horn lacking dense pilosity (*Xylotrupes*, *Trypoxylus*, *Xyloscapes*) except when entire dorsal surface of body is densely hirsute (*Allomyrina*); lateral contours of paramere apex parallel or diverging outward; Asia ..... **6 (Xylotrupina Hope)**
- 3(2). Pronotum with ventrolateral undercut carinae; mesal pronotal horn without ventral dense pilosity; anterolateral pronotal integument with anastomosing, cristate sculpture; Africa ..... **Augosoma Burmeister**
- Pronotum without such ventrolateral carinae; mesal pronotal horn usually with ventral dense pilosity; anterolateral pronotal integument without anastomosing, cristate sculpture ..... **4**
- 4(3). Cephalic horn apex bifurcated to form two lateral tines; mandibular incisor denticles usually diverge at least 45°; anterior margin of clypeus broadly emarginate, forming two widely separated denticles; America ..... **Megasoma Kirby**
- Cephalic horn apex acuminate; mandibular incisor denticles diverge at most 30°; anterior margin of clypeus narrowly emarginate or not emarginate **5**
- 5(4). Relative size of mandibular incisor denticles subequal; when a pronotal horn present then angle between posterior pronotal margin and apex of pronotal horn at least 30° (may be up to 80°); in species with pronotal horn, cephalic horn has weakly to strongly serrated lateral margins; cephalic horn rarely with multiple medial denticles (*G. eacus*, *G. spatha*); pronotal horn without laterally paired accessory horns; America ..... **Golofa Hope**
- Relative size of mandibular incisor denticles varies from strongly positive to strongly negative; angle between posterior pronotal margin and apex of pronotal horn at most 10°; cephalic horn without serrated dorsolateral margins; with one or more dorsomedial denticles (often weak or obscure in *D. tityus*); pronotal horn with laterally paired accessory horns (except *D. satanas*); America c ..... **Dynastes Kirby**
- 6(2). Plane of paramere blades strongly angled toward paramere orifice, or parameres with strong frontal notch (*X. florensis*); with two strongly sclerotized raspulae of similar structure, or if only one raspula then basal metatarsomere dorsally strongly acuminate (*X. florensis*); pronotal horn with basolateral carinae [obscure in small taxa] or, rarely, basolateral denticles (*X. florensis*); pronotal horn apex extends beyond cephalic horn apex in large species; Asia ..... **Xylotrupes Hope**
- Plane of paramere blades essentially same as or below that of paramere orifice; with at least one sclerotized raspular spine, if two spines then they are grossly dissimilar in structure; pronotal horn without basolateral carinae or denticles; pronotal horn apex never extends to cephalic horn apex ..... **7**

- 7(6). Small species, at most 40mm in total length; dorsal integument heavily hirsute; protarsal claws distinctly asymmetrical; Asia ..... **Allomyrina Arrow**  
 — Large species, at least 50mm and up to 85mm in total length; dorsal integument nearly immaculate or finely hirsute; protarsal claws symmetrical or essentially so ..... **8**
- 8(7). Cephalic horn very long (~ 25mm), apex divided into four lateral tines; pronotal horn short, narrow; Asia ..... **Trypoxylus Minck**  
 — Cephalic horn of moderate length (~ 15mm), apex bifurcated into two lateral tines and with two lateral denticles at midlength; pronotal horn stout, short; Asia ..... **Xyloscaptes Prell**
- 9(1). Pronotum with one pair of dorsolateral horns and a basomedial horn directed horizontally over base of cephalic horn; Asia ..... **Chalcosoma Hope**  
 — Pronotum without horns or with one or two pairs of horns, but without a basomedial horn directed over base of cephalic horn ..... **10**
- 10(9). Anterior margin of clypeus nearly entire, not forming denticles; pronotum simply convex (*H. inermis*), or with one pair of lateral bosses or incipient horns (*H. barbarossa*), or with well-developed lateral horns (*H. australicus*); anterior and basolateral pronotal integument with strong, anastomosing, cristate sculpture; dorsal integument uniformly colored, pronotum and elytra reddish brown; Asia ..... **Haploscapanes Arrow**  
 — Anterior margin of clypeus strongly and narrowly emarginate, forming two conspicuous denticles; pronotum with one pair of dorsolateral horns (*Beckius*), or dorsolateral carinae (*Pachyoryctes*), or with two pairs of horns (*E. gracilicornis*, *E. siamensis*, *E. birmanicus*, most *E. hardwickei*), or one pair of basolateral horns (some *E. hardwickei*); anterior and basolateral pronotal integument sparsely punctate, without anastomosing, cristate basolateral sculpture; dorsal integument bicolored, pronotum black or nearly so, elytra reddish brown to yellowish orange ..... **11**
- 11(10). Pronotum with a pair of transverse dorsolateral carinae; prothoracic legs essentially sexually monomorphic; elytra dark reddish brown; Asia ..... **Pachyoryctes Arrow**  
 — Pronotum with one or two pairs of lateral horns; prothoracic legs decidedly sexually dimorphic; elytra yellowish orange or reddish brown ..... **12**
- 12(11). Pronotum with two pairs of horns; Asia .....  
       **Eupatorus Burmeister** (*E. gracilicornis*, *E. birmanicus*, *E. siamensis*, most *E. hardwickei*)  
 — Pronotum with one pair of horns ..... **13**
- 13(12). Pronotal horns basolateral; lateral contours of paramere apex converging inward; Asia .....  
       ..... **Eupatorus Burmeister** (Himalayan *E. hardwickei*)  
 — Pronotal horns dorsolateral and with marginal spines; lateral contours of paramere apex diverging outward, nearly circular; Asia ..... **Beckius Dechambre**

## Acknowledgments

We thank Heidy Hopkins and Hans Weeks for their considerable efforts in sequencing many challenging specimens. Specimens and associated data were provided by Gavin Dally, Dan Sundberg, Justin Schofer, Jen-Pan Huang, Carl Wilhelm, William Wallin, Seul-Ma-Ro Hwang, Beverly Adams, Thomas Moisi, Daniel Fagre-Garcia, Hu Wei, Charles Dewhurst, Wayne Hsu, Joaquim Willers and Edward Riley. Critical logistic support was provided by Prathapan Divakaran. Chris Marshall, Jiri Zidek and Paul Skelley reviewed the manuscript and provided valued advice. Marty Schlabach researched ancient literature at Cornell University Library. Darren Mann explored the F. W. Hope archives at Oxford University Museum. Joaquim Willers provided advice on the work of H. Burmeister. Andrew Smith provided advice on nomenclature. Portions of this project were funded by United States National Science Foundation grant #DEB-0845984 (K. B. Miller, PI).



## Literature Cited

- Arrow, G. J. 1908.** A contribution to the classification of the coleopterous family Dynastidae. Transactions of the Entomological Society of London 2: 321-358.
- Arrow, G. J. 1911.** Notes on the coleopterous subfamily Dynastinae with descriptions of new genera and species. Annals and Magazine of Natural History (8) 8:151-176.
- Arrow, G. J. 1925.** The fauna of British India including Ceylon and Burma. Coleoptera Lamellicornia (Cetoniinae and Dynastinae). Taylor & Francis; London. 322 p.
- Arrow, G. J. 1937.** Systematic notes on beetles of the subfamily Dynastinae with descriptions of a few species in the British Museum collection. Transactions of the Royal Entomological Society of London 86: 35-58.
- Arrow, G. J. 1944.** Polymorphism in giant beetles. Proceedings of the Zoological Society of London (A) 113: 113-116, 1 pl.
- Arrow, G. J. 1951.** Horned beetles – A study of the fantastic in nature. W. Junk Publishers; The Hague. 154p.
- Berggren, W. A., and C. D. Hollister. 1978.** Paleogeography, paleobiogeography and the history of circulation in the Atlantic Ocean. In: W. W. Hay (ed.). Society of Economic Paleontologists and Mineralogists, Special Publication 20:126-186.
- Bouchard, P., Y. Bousquet, A. E. Davies, M. A. Alonso-Zarazaga, J. F. Lawrence, C. H. C. Lyal, A. F. Newton, C. A. M. Reid, M. Schmitt, S. A. Slipinski, and A. B. T. Smith. 2011.** Family-group names in Coleoptera (Insecta). ZooKeys 88: 1-972.
- Burmeister, H. 1847.** Handbuch der Entomologie, Fünfter Band. Enslin; Berlin. 584 p.
- Colgan, D. J., A. McLauchlan, G. D. F. Wilson, S. P. Livingston, G. D. Edgecombe, J. Macaranas, G. Cassis, and M. R. Gray. 1998.** Histone H3 and U2 snRNA DNA sequences and arthropod molecular evolution. Australian Journal of Zoology 46: 419-437.
- Danforth, B. N., H. Sauquet, and L. Packer. 1999.** Phylogeny of the bee genus *Halictus* (Hymenoptera: Halictidae) based on parsimony and likelihood analyses of nuclear EF-1alpha sequence data. Molecular Phylogenetics and Evolution 13: 605-618.
- Dechambre, R. P. 1992.** Le statut generic de '*Eupatorus*' *beccarii* (Gestro) (Col. Dynastidae). Bulletin de la Société Sciences Nat, Suppl. No. 75, 76: 25-26.
- Edgar, R. C. 2004.** MUSCLE: multiple sequence alignment with high accuracy and highthroughput. Nucleic Acids Research 32: 1792-1797.
- Endrödi, S. 1947.** Über die Gattung *Dynastes* Kirby. Folia Entomologica Hungarica (N. S.) 2:54-59.
- Endrödi, S. 1951.** Über die Gattung *Xylotrupes*. Acta Biologica Academiae Scientiarum Hungaricae 2: 239-253.
- Endrödi, S. 1957.** Zur Kenntnis der Dynastinen. Revision der Dynastiden-Materialien des Zool. Forschungsinstitut u. Museums A. Koenig, Bonner Zoologischer Beiträge 1(8): 64-70.
- Endrödi, S. 1976.** Monographie der Dynastinae (Coleoptera) 6. Tribus Dynastini. Acta Zoologica Academiae Scientiarum Hungaricae 22: 217-269.
- Endrödi, S. 1985.** The Dynastinae of the World. W. Junk Publishers; The Hague. 800 p.
- Genecodes. 1999.** Sequencher. Genecodes; Ann Arbor, Michigan.
- Gestro, R. 1876.** Diagnosi di alcune nuove specie di Coleotteri raccolte nella regione Austro-Malese dei Signori Dottore O. Beccari, L. M. Albertis e A. A. Bruijn. Annali del Museo Civico di Storia Naturale di Genova 8: 512-524.
- Goloboff, P. 1995.** NONA. Published by the author; Tucumán, Argentina.
- Hope, F. W. 1837.** The coleopterists manual, containing the lamellicorn insects of Linneus and Fabricius. Henry G. Bohn; London. 121 p.
- Hope, F. W. 1845a.** On the entomology of China, with descriptions of the new species sent to England by Dr. Cantor from Chusan and Canton. Transactions of the Entomological Society of London 4: 4-17.
- Hope, F. W. 1845b.** Descriptions of new species of Coleoptera, from the Kasyah Hills, near the boundary of Assam, in the East Indies, lately received from Dr. Cantor. Transactions of the Royal Entomological Society of London 4(1): 73-77.

- ICZN (International Commission on Zoological Nomenclature). 1999.** International Code of Zoological Nomenclature. Fourth Edition. The International Trust for Zoological Nomenclature; London. 306 p.
- Janssens, A. 1949.** Contribution à l'étude des coléoptères lamellicornes. Bulletin de la Institut Royal des Sciences Naturelles de Belgique 25(15): 1-30.
- Krell, F.-T. 2000.** The fossil record of Mesozoic and Tertiary Scarabaeoidea (Coleoptera: Polyphaga). Invertebrate Taxonomy 14: 871-905.
- Lacordaire, T. 1856.** Histoire naturelle des insectes. Genera des coléoptères. Tome troisième. Roret; Paris. 594 p.
- Laporte, F. 1867.** Note sur un nouveau genre de Dynastide (Alcidiosoma). Revue et Magazin de Zoologie (2) 19: 113-115.
- Latreille, P. A. 1829.** Les crustacés, les arachnides et les insectes distribués en familles naturelles. Tome premier. Deterville Libraire; Paris. 584 p.
- Miller, K. B., J. Bergsten, and M. F. Whiting. 2007.** Phylogeny and classification of diving beetles in the tribe Cybistrini (Coleoptera, Dytiscidae, Dytiscinae). Zoologica Scripta 36: 41-59.
- Miller, K. B., J. Bergsten, and M. F. Whiting. 2009.** The phylogeny and classification of the tribe Hydraticini Sharp (Coleoptera: Dytiscidae). Zoologica Scripta 38: 591-615.
- Minck, P. 1920.** Beitrag zur Kenntnis der Dynastiden. 10. Asiatische Xylotrupiden. Archiv für Naturgeschichte 84A: 194-221.
- Moullade, M., and S. Guérin. 1982.** Le problème des relations de l'Atlantique Sud et de l'Atlantique Central au Crétacé moyen: Nouvelles données microfauniques d'après les forages. Bulletin de la Société Géologique de France 24: 511-517.
- Nixon, K. C. 2002.** WinClada. Published by the author; Ithaca, New York.
- Reyment, R. A. 1969.** Ammonite biostratigraphy, continental drift and oscillatory transgressions. Nature 224: 67-69.
- Rowland, J. M. 2003.** Male horn dimorphism, phylogeny and systematics of rhinoceros beetles of the genus *Xylotrupes* (Scarabaeidae: Coleoptera). Australian Journal of Zoology 51: 213-258.
- Rowland, J. M. 2011.** Notes on nomenclature in *Xylotrupes* Hope (Scarabaeidae: Dynastinae: Dynastini). Insecta Mundi 0176: 1-10.
- Scheuchzer, J. J. 1732-1737.** Physique Sacrée, ou Histoire-naturelle de la Bible. Pierre Schenck; Amsterdam, 8 vols.
- Simon, C., F. Frati, A. Beckenbach, B. Crespi, H. Liu, and P. Flook. 1994.** Evolution, weighting, and phylogenetic utility of mitochondrial gene sequences and a compilation of conserved polymerase chain reaction primers. Annals of the Entomological Society of America 87: 651-701.
- Smith, A. B. T. 2006.** A review of the family-group names for the superfamily Scarabaeoidea (Coleoptera) with corrections to nomenclature and a current classification. Coleopterists Society Monograph No. 5: 144-204.
- Wegener, A. 1929.** Die Entstehung der Kontinente und Ozeane. Vieweg; Braunschweig, Germany. 231p.
- West-Eberhard, M. J. 2003.** Developmental plasticity and evolution. Oxford University Press; New York. 794 p.
- Whiting, M. F. 2002.** Mecoptera is paraphyletic: multiple genes and phylogeny of Mecoptera and Siphonaptera. Zoologica Scripta 31: 93-104.
- Wild, A., and D. R. Maddison. 2008.** Evaluating nuclear protein-coding genes for phylogenetic utility in beetles. Molecular Phylogenetics and Evolution 48: 877-891.

Received August 29, 2012; Accepted October 12, 2012

