TAXONOMY AND BIOGEOGRAPHY OF THE LAND SNAIL GENUS *ALYCAEUS* (GASTROPODA: ALYCAEINAE) IN PENINSULAR MALAYSIA

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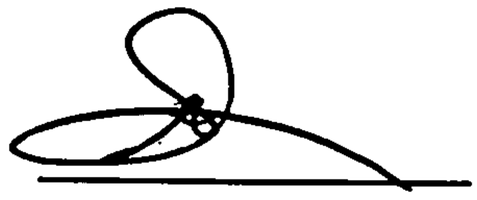

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ABSTRACT

The conservation of tropical limestone karsts is a priority for Malaysia. To assist karst conservation, sound understanding of the taxonomy and biogeography of karst endemic taxa is required. In this study, I used the genus *Alycaeus* as a model taxon for this purpose, focusing on two aspects of the genus: species taxonomy and biogeography. First, on taxonomy: A total of 10 species and one subspecies of *Alycaeus* was recognised in Peninsular Malaysia prior to this study. However, these taxonomic descriptions of *Alycaeus* taxa are based on limited number of examined materials where a whole spectrum of morphological variations were not accounted for and diagnosis were often provided without sufficient comparison between congeners from across the peninsula. I reviewed Peninsular Malaysian *Alycaeus* through the examination of major museum collection lots and literature sources. Based on these examined materials, I utilised a more comprehensive set of shell and operculum characters, as well as living animal colour to describe all *Alycaeus* species in this paper. I also noted their habitat and ecology, as well as updated the distribution of each species. Of the 11 previously described taxa, nine were reconfirmed as present on Peninsular Malaysia (*Alycaeus balingensis, Alycaeus liratulus, Alycaeus thieroti, Alycaeus conformis, Alycaeus gibbosulus, Alycaeus kelantanensis, Alycaeus carinata, Alycaeus perakensis altispirus, Alycaeus perakensis*) and two were confirmed as absent on the peninsula (*Alycaeus jagori, Alycaeus pyramidalis*). A new record of *Alycaeus robeleni* is reported for Peninsular Malaysia. One species, *Chamalycaeus jousseaumei* is confirmed as present on the peninsula and is reassigned to *Alycaeus*. The subspecies *Alycaeus perakensis altispirus* Möllendorff, 1902, is elevated to species. Examined Peninsular Malaysian materials that do not fit previously recognised species are described as new species. A total of 11 new species are proposed (*Alycaeus selangoriensis* Foon and Liew, 2017, *Alycaeus costacrassa* Foon and Liew, 2017, *Alycaeus ikanensis* Foon and Liew, 2017, *Alycaeus alticola* Foon and Liew, 2017, *Alycaeus charasensis* sFoon and Liew, 2017, *Alycaeus kurauensis* Foon and Liew, 2017, *Alycaeus regalis* Foon and Liew, 2017, *Alycaeus virgogravida* Foon and Liew, 2017, *Alycaeus senyumensis* Foon and Liew, 2017, *Alycaeus expansus* Foon and Liew, 2017, *Alycaeus clementsi* Foon and Liew, 2017). Overall, 23 species of *Alycaeus* are now recognised in Peninsular Malaysia. Second, on biogeography: With *Alycaeus* species and their distributions identified, I utilised Geographic Information System tools to study their biogeography across Peninsular Malaysia. First, I examined the role of the Titiwangsa Range as a potential biogeographic barrier for *Alycaeus* species. I found that the Titiwangsa Range appears to be a barrier for limestone rock dwelling *Alycaeus* species while arboreal and rotten log dwelling *Alycaeus* species are either restricted to one side or found on both sides of the Titiwangsa Range. Second, I elucidate and discuss the correlation between hill isolation, hill size and the degree of *Alycaeus* endemism. I found that there is no correlation between hill isolation and *Alycaeus* endemism, while there is a weak correlation between hill size and *Alycaeus* endemism. These findings run

contrary to previous conclusions of land snail community level studies whereby hill isolation and hill size have strong correlations with land snail endemism. Overall, these findings suggest that conservation of limestone karst biodiversity should consider not just endemism patterns at the community level but also at the genus level as well, especially for those genera that are known to be restricted to limestone rock habitats.

ABSTRAK

TAXONOMI DAN BIOGEOGRAFI SIPUT DARAT GENUS ALYCAEUS (GASTROPODA: ALYCAEINAE) DI SEMENANJUNG MALAYSIA

Pemuliharaan kars tropika adalah keutamaan konservasi bagi Malaysia. Untuk membantu pemuliharaan kars, pemahaman yang baik tentang taksonomi dan biogeografi taxa kars endemik adalah diperlukan. Dalam kajian ini, saya menggunakan genus Alycaeus sebagai takson model untuk tujuan ini, dengan memberi tumpuan kepada dua aspek genus tersebut: taksonomi spesies dan biogeografi. Pertama, mengenai taksonomi: Sebanyak 10 spesies dan satu subspesies Alycaeus diiktiraf di Semenanjung Malaysia sebelum kajian ini. Deskripsi taksonomi Alycaeus adalah berdasarkan bahan yang diperiksa di mana bilanganya adalah terhad dan spektrum variasi morfologi tidak dikirakan dan diagnosis sering disediakan tanpa perbandingan yang mencukupi dari seluruh Semenanjung Malaysia. Saya mengkaji Alycaeus Semenanjung Malaysia melalui pemeriksaan koleksi besar muzium-muzium khusus dan sumber-sumber kesusasteraan. Berdasarkan bahan-bahan yang diperiksa ini, saya menggunakan satu set lengkap cangkerang dan operculum, serta warna haiwan yang hidup untuk mendiagnosiskan semua spesies Alycaeus dalam tesis ini. Saya juga memperhatikan habitat dan ekologi mereka, serta mengemas kini pengagihan setiap spesies. Daripada 11 taxa yang telah diiktiraf sebelum ini, sembilan taxa telah dikesahkan semula sebagai wujud di Semenanjung Malaysia (Alycaeus balingensis, Alycaeus liratulus, Alycaeus thieroti, Alycaeus conformis, Alycaeus gibbosulus, Alycaeus kelantanensis, Alycaeus carinata, Alycaeus perakensis altispirus dan Alycaeus perakensis) manakala dua taxa disahkan sebagai tidak wujud di Semenanjung Malaysia (Alycaeus jagori dan Alycaeus pyramidalis). Rekod baru Alycaeus robeleni dilaporkan wujud di Semenanjung Malaysia. Satu spesies, Chamalycaeus jousseaumei disahkan sebagai wujud di Semenanjung Malaysia dan dipindahkan semula ke genus Alycaeus. Subspesies Alycaeus perakensis altispirus Möllendorff, 1902, dinaikkan ke tahap spesies. Bahan-bahan Semenanjung Malaysia yang diperiksa yang tidak sesuai dengan spesies yang diiktiraf terdahulu dideskripsikan sebagai spesies baru. Sebanyak 11 spesies baru dicadangkan (Alycaeus selangoriensis Foon dan Liew, 2017, Alycaeus costacrassa Foon dan Liew, 2017, Alycaeus ikanensis Foon dan Liew, 2017, Alycaeus alticola Foon dan Liew, 2017, Alycaeus charasensis Foon dan Liew, 2017, Alycaeus kurauensis Foon dan Liew, 2017, Alycaeus regalis Foon dan Liew, 2017, Alycaeus virgogravida Foon dan Liew, 2017, Alycaeus senyumensis Foon dan Liew, 2017, Alycaeus expansus Foon dan Liew, 2017, Alycaeus clementsi Foon dan Liew, 2017) Secara keseluruhan, 23 spesies Alycaeus kini diiktiraf di Semenanjung Malaysia. Kedua, mengenai biogeografi: Dengan pengenalpastian spesies Alycaeus dan taburan

mereka, saya menggunakan alat Sistem Maklumat Geografi untuk mengkaji biogeografi mereka di seluruh Semenanjung Malaysia. Pertama, saya mengenal pasti peranan Banjaran Titiwangsa sebagai halangan biogeografi untuk spesis-spesis Alycaeus. Kajian saya mendapati Banjaran Titiwangsa adalah halangan untuk spesies-spesies Alycaeus yang berhabitat batu kapur manakala spesies-spesies yang berhabitat arboreal dan kayu reput boleh didapati di salah satu belah atau kedua-dua belah kawasan di sekitar Banjaran Titiwangsa. Kedua, saya meninjau dan membincangkan korelasi antara pengasingan bukit, saiz bukit dan tahap endemisme Alycaeus. Kajian saya mendapati tiada korelasi antara pengasingan bukit dan tahap endemisme Alycaeus manakala korelasi lemah telah dijumpai antara saiz bukit dan tahap endemisme Alycaeus. Penemuan ini bertentangan dengan kesimpulan kajian-kajian terdahulu yang berfokus pada tahap komuniti siput darat, di mana pengasingan bukit dan saiz bukit didapati berkorelasi kuat dengan tahap endemisme siput darat. Secara keseluruhanya, penemuan kajian saya bercadangkan bahawa pemuliharaan biodiversiti kars harus mempertimbangkan bukan sahaja corak endemisme pada tahap komuniti tetapi juga pada tahap genus terutamanya untuk genus-genus yang berhabitat batu kapur.

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ANSP – Academy of Natural Sciences of Drexel University, Philadelphia, United States of America.

BOR/MOL – *BORNEENSIS* Malacology Collection, Institute for Tropical Biology and Conservation, Universiti Malaysia Sabah, Kota Kinabalu, Malaysia.

HUJ – National Mollusc Collection of the Hebrew University of Jerusalem, Jerusalem, Israel.

H/W – Private collection of Jens and Christa Hemmen, Wiesbaden, Germany.

km – kilometres

km² – kilometres-squared

mm – millilitres

MNHN – Museum National d'Histoire Naturelle, Paris, France.

NHM – The Natural History Museum, London, United Kingdom.

NHMUK – When citing registered specimens from The Natural History Museum, London.

RMNH – Naturalis Biodiversity Center (formerly Rijksmuseum van Natuurlijke Historie), Leiden, the Netherlands.

SMF – Forschungsinstitut und Naturmuseum Senckenberg, Frankfurt am Main, Germany.

ZMA – Naturalis Biodiversity Center (formerly Zoological Museum of Amsterdam), Leiden, the Netherlands.

ZRC – Zoological Reference Collection, Lee Kong Chian Natural History Museum, National University of Singapore, Singapore.

LIST OF APPENDICES

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