Institute of Biodiversity and Environmental Conservation

The Distribution and Ecology of Land Snails (Mollusca: Gastropoda) in Limestone Habitats of Western Sarawak

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The Distribution and Ecology of Land Snails (Mollusca: Gastropoda) in Limestone Habitats of Western Sarawak

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



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ABSTRACT

Species inventories and ecological studies are fundamental tools for assessing the conservation of limestone-associated species such as land snails. Unfortunately, previous inventories of land snail species in the Bau-Serian limestone area lack a systematic checklist with corresponding illustrations for each species. This study aims to investigate the species composition of land snails in the Bau limestone hill clusters in Sarawak, to measure the estimated species richness and sampling effectiveness between live-caught snails and empty snail shells, and finally to investigate the relationships between land snail species and microhabitats. To fill this knowledge gap, systematic and random sampling for land snails were carried out at eight limestone outcrops. All specimens were sorted, identified to species level, and catalogued. Sampling effectiveness between live snails and empty snail shells was determined using cluster-scale completeness ratios for 135 plots. Species completeness analyses were conducted to extrapolate species richness and inventory for different spatial scales. Cluster analyses were conducted to determine the relationship between the species community and assemblages based on the presence, absence, and abundance data of 17 live-caught land snail species. Associations between land snail species and microhabitats sampled were described using the bipartite weighted network. A total of 122 land snail species, of which 18 are new to science, from 58 genera and 24 families, with photographs of each species. The inventory revealed high completeness of sampling for both empty shells and live-taken snails (> 90%) but species diversity is very low for live snails compared to empty snail shells at hill and cluster scales suggesting that some species may have expired locally. Cluster analysis showed that the land snails assemblages do not correspond to different microhabitats, but rather to locality. The limestone area in Bau has a very high degree of endemism due to the low dispersal ability of the land snails. The soil sample appears to have

very high species richness, but the species composition contains species from different niches and microhabitats. As the limestone hills in Sarawak are threatened by various habitat degradation activities, further inventories are needed to assess the species richness of land snails in limestone hill clusters to identify and conserve high-priority areas for snail conservation in Sarawak.

Keywords: Limestone forest, land snail, inventory, sampling effectiveness, ecology

Taburan dan Ekologi Siput Darat (Mollusca: Gastropoda) dalam Habitat Batu Kapur di Barat Sarawak

ABSTRAK

Inventori spesies dan kajian ekologi adalah alat asas untuk menilai pemuliharaan spesies yang berkaitan dengan batu kapur seperti siput darat. Malangnya, inventori sebelumnya spesies siput darat di kawasan batu kapur Bau-Serian tidak mempunyai senarai semak yang sistematik dengan ilustrasi yang sepadan untuk setiap spesies. Kajian ini bertujuan untuk menyiasat komposisi spesies siput darat di gugusan bukit batu kapur Bau di Sarawak, untuk mengukur anggaran kekayaan spesies dan keberkesanan pensampelan antara siput yang ditangkap hidup dan cengkerang kosong, dan akhirnya untuk menyiasat hubungan antara spesies siput darat dan mikrohabitat. Bagi mengisi jurang pengetahuan ini, persampelan sistematik dan rawak bagi siput darat telah dijalankan di lapan singkapan batu kapur. Semua spesimen telah diisih, dikenal pasti kepada peringkat spesies dan dikatalogkan. Keberkesanan pensampelan antara siput hidup dan cengkerang kosong ditentukan menggunakan nisbah kesempurnaan skala kelompok untuk 135 petak. Analisis kesempurnaan spesies telah dijalankan untuk mengekstrapolasi kekayaan spesies dan inventori untuk skala spatial yang berbeza. Analisis kluster telah dijalankan untuk menentukan hubungan antara komuniti spesies dan himpunan berdasarkan data kehadiran, ketiadaan dan kelimpahan 17 spesies siput darat yang hidup. Hubungan antara spesies siput darat dan mikrohabitat diterangkan menggunakan rangkaian berwajaran dwipartit. Sebanyak 122 spesies siput darat direkod, di mana 18 adalah spesies baharu, daripada 58 genera dan 24 keluarga, dengan gambar bagi setiap spesies. Inventori menunjukkan kesempurnaan pensampelan yang tinggi untuk kedua-dua cengkerang kosong dan siput hidup (>90%) tetapi kepelbagaian spesies adalah sangat rendah untuk siput hidup

berbanding dengan cangkerang kosong di skala bukit dan kluster yang menunjukkan bahawa sesetengah spesies mungkin telah pupus di kawasan tersebut. Analisis kluster menunjukkan bahawa himpunan siput darat tidak sepadan dengan mikrohabitat yang berbeza, tetapi lebih kepada lokaliti. Kawasan batu kapur di Bau mempunyai tahap endemisme yang sangat tinggi kerana keupayaan penyebaran siput darat yang rendah. Sampel tanah kelihatan mempunyai kekayaan spesies yang sangat tinggi, tetapi komposisi siput mengandungi spesies daripada relung dan mikrohabitat yang berbeza. Memandangkan bukit batu kapur di Sarawak diancam oleh pelbagai aktiviti degradasi habitat, inventori selanjutnya diperlukan untuk menilai kekayaan spesies siput darat dalam gugusan bukit batu kapur untuk mengenal pasti dan memulihara kawasan keutamaan tinggi untuk pemuliharaan siput di Sarawak.

Kata kunci: *Hutan batu kapur, siput darat, inventori, keberkesanan pensampelan, ekologi*

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LIST OF ABBREVIATIONS

*	Land snail specimens in ME Collection not collected in the present survey
C1	Bau Limestone Hill Clusters
C1H1	part of mykarst-336 Gunung Doya (= Bukit Sokwang)
C1H2	mykarst-329 Gunung Kapor
C1H3	mykarst-333 Gunung Lobang Angin
CGS	Centre for Graduate Studies
IBEC	Institute of Biodiversity and Environmental Conservation
ITBC	Institute for Tropical Biology and Conservation
ME	Mohammad Effendi Private Collection
MZU	Zoological Museum of Universiti Malaysia Sarawak
S1	Site 1
S2	Site 2
S3	Site 3
UMS	Universiti Malaysia Sabah
UNIMAS	Universiti Malaysia Sarawak

CHAPTER 1

INTRODUCTION

1.1 Study Background

Borneo is recognized as one of the world's biodiversity hotspots (Myers et al., 2000). A diverse number species of flora and fauna are found in various types of Malaysian forests, which comprise lowland forests, montane forests, and mangrove forests. In addition to these commonly known forest types, there are also small areas of swamp forest, heath forest, and forest on limestone. Although the total area for several hundreds of limestone hills in Borneo represents less than 0.1% of the land of Peninsular Malaysia (Liew et al., 2021a), the forest on limestone hills supports a significant portion of biodiversity.

The ecological and evolutionary processes that govern the biodiversity patterns and richness of these fragmented, isolated, and majority small patches of limestone forests are similar to the process that acts on oceanic islands' biodiversity. These limestone hills constitute Carbon Carbonate ($CaCO_3$) and thus the forest on or around the hills grows on alkali soil (high pH). This patchy alkali forest is surrounded by forest that grows on more acidic soils (low pH). The surrounding acidic forest acts as an effective barrier for organism dispersal, especially for some plants and snails because many of these organisms are adapted specifically to live in high-pH limestone forests (Berry, 1963; Vermeulen & Whitten, 1998).

Hence, limestone forest resembles islands, harbouring a large number of endemic species, each with unique evolutionary history in this isolated limestone forest (Schilthuizen, 2004; Clements et al., 2006). This biodiversity importance of limestone forests is often overlooked because of the general impression that it has often had very thin and patchy forest

cover due to the thin soil and has no charismatic vertebrate fauna. The biodiversity of the majority of the limestone hills is still under exploration. To illustrate this, a search in the literature reveals that 22 out of 66 new animal species (33%) that were described in the year 2014 from Peninsular Malaysia were collected from limestone forests (Bursey et al., 2014a; 2014b; Dang et al., 2014; Grismer et al., 2014a; 2014b; 2014c; 2014d; 2014e; 2014f; 2014g; Jaloszynski, 2014; Liew et al., 2014; Matzui et al., 2014; Mutafchiev et al., 2014; Ng & Schubart, 2014; Ng et al., 2014; Ochi & Kon, 2014; Onn et al., 2014a; 2014b; 2014c; Schawaller, 2014; Siriboon et al., 2014; Sutcharit et al., 2014; Tanasevitch, 2014; Takaoka et al., 2014a; 2014b; 2014c; Takeuchi, 2014; Turillazzi et al., 2014; Vermeulen & Marzuki, 2014; Victoria & Lin, 2014; Ya'cob et al., 2014; Yoshizawa et al., 2015).

Bornean limestone forests are under threat of degradation of the surrounding forest and irreversible destruction due to quarrying activities (Vermeulen, 1994; Schilthuizen et al., 2005). *Plectostoma scaphilum* (van Benthem-Jutting, 1952), a Diplommatinid snail from Bukit Panching, Kuantan, Pahang has been declared extinct due to habitat destruction (Liew et al., 2014; Liew, 2015). In Borneo, there are at least two karst-dependent species that were probably extinct due to habitat destruction (Vermeulen, 1994; Schilthuizen, 2004). Hence, it is important to protect these hills that support these high-endemic species. However, it is not feasible to protect all limestone hills of Borneo. Thus, certain criteria need to be applied to prioritize the conservation and protection of some of those important limestone forests.

The most conventional criteria in prioritization of conservation areas are to protect the areas with high biodiversity and a high number of endemic species. Although now always been explained explicitly, the high biodiversity and endemic species reflected the unique and rich evolutionary history of the area. Each of the several hundred limestone hills in Borneo

has different physical and geographical characteristics in terms of the degree of isolation, size, and geological history (Hutchison, 2005; Hall, 1998; 2009). Understanding the community ecology and biological evolutionary history of these limestone hills/clusters could help us to prioritize the conservation efforts to protect these small, neglected, and vulnerable limestone hills that have high biodiversity values.

However, it is not possible to study all different taxa groups of organisms to obtain a picture of the evolutionary history of limestone hills. Because of these, calcicole organisms that obligate to limestone hills are a promising surrogate species for other taxa to understand the general biological evolutionary history of limestone hills. In this case, the land snail is known to be a suitable model to understand the role of history and selection in the origins of biodiversity (Davison, 2002).

1.2 Problem Statement

Inventory and ecological studies are crucial for the conservation of limestone-associated species such as land snails to maintain the biodiversity balance in the limestone forest. Species inventories were reported by Vermeulen and Junau (2007) in the Bau-Serian limestone range yielding 148 species. However, these reports lack a systematic checklist with proper illustrations for every species in addition to the provisional species identities in previous reports cannot be used to compare with recently collected specimens.

The land snails in the tropical forest were formerly claimed to be neither abundant nor diverse compared to the temperate forest (Solem, 1984). His statement about the abundance and diversity of the land snails in tropical forests is not completely wrong since the abundance and diversity of land snails in the tropical forests are concentrated only in limestone forests and high altitude forests. The possible reasons behind his claim due to lack

of species inventory for the microsnail (<5 mm) and the generalization of tropical forests regardless of the differences in forest types in the tropics region. In tropical forests, the snail species diversity and abundance on limestone are distinctly higher (average 60 to 100 species per site with 1,000 to 10,000 individuals per bucketful of soil sample) compared to the non-limestone environments (average 30 to 50 species per site with 10 to 100 individuals per bucketful of soil sample) (Vermeulen & Whitten, 1999). The highly concentrated species of flora and fauna (including land snails) in limestone forests are possibly due to several factors including microhabitats.

Numerous authors have proposed standardized sampling protocols for land snails. The protocol for land snail sampling in limestone environments in Malaysia also differed from one study to another. In Liew et al. (2008), two sampling plot scales were used for Peninsular Malaysia and East Malaysia which differs in plot sizes and spaces. The result from the study can improve the inventory efficiency of sampling by selecting the right sampling scale for the tropical limestone hill forests.

Empty shells accumulated at the base of limestone cliffs contain more species than the live-taken snail samples which are indigenous to the local community. Still, using the empty shell as the ecology predictor must be cautious since the empty shell density pattern may be due to some obscure natural factors.

1.3 Objectives

The research aims to study the species composition, sampling effectiveness, and ecology of land snails in Bau limestone hills. This can be achieved through the following set of objectives:

i. To document the land snail species in the Bau limestone hill cluster, and describe new species previously unknown to science.

ii. To measure the species richness estimates and sampling effectiveness between live-taken snails versus empty shells.

iii. To investigate the associations between land snail species and microhabitats.

1.4 Chapter Summary

This thesis is about the study of the species composition and ecology of land snails in the limestone habitat of Western Sarawak, precisely in the Bau area. To date, the land snails from Sarawak are less known in terms of species diversity and composition compare to Sabah and Peninsular Malaysia. As the complete species checklist is done, we can prove the species of land snails in Sarawak, particularly in the Bau area are not just unique but very diverse in terms of species richness and microhabitats.

The land snail species diversity and abundance in tropical forests are significantly higher in limestone forests. However, the ecology of land snails in Sarawak remains nearly unknown. Using the smallest sampling scale regime can be done for the land snail ecological study in limestone hill forests since this habitat is known for its very high land snail concentration. The soil samples taken are rich with a mixture of live-taken snails together with empty shells. Empty shells indicate the presence of the particular species at the temporal and spatial scales. However, empty shells cannot have substituted for the live-taken snail for ecological study since the species diversity and abundance for both samples are completely different.

This thesis can be useful to other students and researchers who are interested with land snail study in Sarawak.

CHAPTER 2

LITERATURE REVIEW

2.1 Biodiversity in limestone hill

2.1.1 Bornean land snail's diversity

Globally, there are approximately 24,000 described and valid species of land snails in addition estimated between 11,000 and 40,000 species of land snails that are yet to be discovered and described (Lydeard et al., 2004). Currently, there are about 660 taxa of land snails recorded in Borneo Island, and 355 species recorded from Sarawak. Approximately 68% of the total land snails taxa in Borneo recorded from limestone forests (Collinge, 1901; Fulton, 1905; Godwin-Austen, 1889; 1891; Gredler, 1902; Khalik et al., 2018; 2019; Kobelt, 1902; Loosjes, 1953; Martens & Thiele, 1908; Parsons, 2016a; 2016b; Marzuki, 2019; Marzuki et al., 2021; Smith, 1895; Thompson & Dance, 1983; Vermeulen, 1990; 1991a; 1991b; 1992; 1993; 1994; 1996b; 1996c; 1999; 2003; 2007; 2021; Vermeulen & Whitten, 1998; Vermeulen & Junau, 2007; Vermeulen & Khalik, 2021; 2022; Vermeulen & Liew, 2022). The species richness of land snails in Borneo is remarkably higher than on other tropical islands. In fact, the land snail species diversity in Borneo Island is almost 30 percent higher compared to the combination of Sumatra, Java, and Bali including adjacent small satellite Islands. There are only 280 species recorded in Sumatra, 202 species recorded in Java, and 94 species recorded in Bali (Van Benthem-Jutting, 1948; 1950; 1952; 1959; Cilia & Abbas, 2012; Dharma, 1993; 2007; Djajasasmita, 1988; Loosjes, 1953; Maassen, 1999; 2000; 2002; 2006; 2009; Nurinsiyah, 2015; Nurinsiyah & Hausdorf, 2017; Vermeulen & Whitten, 1998).

In Borneo, approximately 27% of the total land snail species belongs to the prosobranch snail family Diplommatinidae. This family shows the highest degrees of endemism among the Bornean land snails with over 96 percent of the total taxa (Vermeulen, 1993; 1994; 1996; Vermeulen et al., 2015). Most of the Bornean Diplommatinid snails are strictly calcicole obligate and confined only on calcareous substrates which occur as small and isolated outcrops (Vermeulen, 1996). Surprisingly, 65% of the Bornean Diplommanid species were only described after 1990, and undoubtedly more undescribed species will be found in unexplored areas (Vermeulen, 1996; Vermeulen et al., 2015). Most of the Bornean endemic land snails' species are narrowly endemic and found in a single or a small group of limestone outcrops. Borneo is known for its Green Rhino snail (*Rhinocochlis nasuta*) and giant Bornean mushroom snail (*Exrhysota brookei*) which are sought after by the shell collector. On the other hand, Borneo is also home to one of the world's smallest land snail, *Acmella nana* with a size below 0.8 mm (Vermeulen et al., 2015).

The first checklist on Bornean non-marine molluscs was made by an Italian malacologist, Arturo Issel in 1874. The checklist consists of land, freshwater, and mangrove gastropods and bivalves inhibiting Borneo and adjacent islands. By the way, there are some recent works on revision and checklist of selected Bornean land snail's genera and families in Borneo (Vermeulen, 1990; 1991a; 1991b; 1992; 1993; 1994; 1996a; 1996b; 1999; 2007) and some others revision on selected genera focused on the particular region, e.g. Sabah (Liew et al., 2009; Vermeulen & Liew, 2022). Malacological studies in Borneo were started in the middle of the 19th century. *Amphidromus adamsii* (Original name: *Bulimus adamsii*), a remarkable Camaenid tree snail was the first land snail recorded in Borneo, which was described by Lovell Augustus Reeve in 1848 in his 5th Conchologia Iconica volume (Reeve, 1848-1849). However, the first land snail recorded in Sarawak was *Dyakia regalis* (Original

name: *Helix regalis*) which was described by William Henry Benson from the collection of W. Taylor in 1850. The interesting part where the type specimen was found in the forest just near the Sir James Brooke's house (Benson, 1850). There are some land snail genera such as *Damayantia* Issel, 1874, *Isselentia* Collinge, 1901, *Wiegmannia* Collinge, 1901, *Everettia* Godwin-Austen, 1891, *Kalamantania* Laidlaw, 1931, *Rhinocochlis* Thiele, 1931, *Sabalimax* Tillier & Bouchet, 1988, *Bruggennea* Dance, 1972, *Platycochlium* Laidlaw, 1950, and monotypic genus *Niahia* Vermeulen, 1996 are restricted in Borneo Island in addition of two problematic genera *Gunongia* Tillier & Bouchet, 1988, and *Kionghutania* Tillier & Bouchet, 1988 yet to be proven distinct by phylogenetic analysis (Vermeulen et al., 2015).

There are approximately 50 species of land snails were described and recorded in the Bau area prior to this study (H. Adams, 1872; Godwin-Austen, 1889; 1891; Smith, 1893; 1895; Thompson & Dance, 1983; Vermeulen, 1991a; 1991b; 1993; 1999). Two land snail species namely *Pincerna globosa* (Original name: *Alycaeus globosus*) and *Everettia cutteri* (Original name: *Macrochlamys cutteri*) were the first known land snail species described from the Bau area named "Busan Hill", hereafter known as Jambusan (H. Adams, 1870). Later, Henry Haversham Godwin-Austen recorded 17 species of land snail from the region between 1889 and 1891 with some of them regarded as new species (Godwin-Austen, 1889; 1891). Afterward, Edgar Albert Smith described three more species from the region (Smith, 1893; 1895). After the 20th century, Hugh Coomber Fulton described one more species from the Bau area (Fulton, 1901). There are some recent works on revision and checklist of selected Bornean land snail's genera and families in Borneo which included land snail species from the Bau limestone hill cluster area (Thompson & Dance, 1983; Vermeulen, 1991a; 1991b; 1993; 1994; 1996; 1999).

2.1.2 Flora and fauna endemism on limestone hill forest

Limestone areas are known to have a very high levels of endemism (Vermeulen & Whitten, 1999). Although the forest around limestone hill areas in Malaysia occupies only a very small portion of the total land area, it's known to support an extremely diverse species of flora and fauna. For example, there are about 21.4% of total plant species in Peninsular Malaysia found only in limestone forest areas (Chin, 1977). Most of them are strictly endemic to the limestone habitat and karst-dependent species which known only from narrow distributions and some of them restricted to a single hill response to the richness of plant species in Malaysian limestone hill forest (Kiew & Lim, 1996; Ipor et al., 2004; Kiew, 2001; Kiew et al., 2011).

Some plants species under the genera *Paraboea*, *Begonia*, *Impatiens*, *Monophyllaea*, and *Amorphophallus* are predominantly calcicole obligate species and most of them are narrowly endemic species and susceptible to a variety of threats (Ipor et al., 2004; Kiew et al., 2011). Borneo is known to support more *Begonia* species compare to Peninsular Malaysia (Ridley, 1906). There are more undescribed species than described species of *Begonia* found in Borneo (Kiew, 1998). The documentation of plants species in limestone forest especially in Borneo is not completely done and require additional effort and time to solve this matter. But, the destruction speed is more than what we had estimated.

Apart from the land snails, there are some species of animals that also specialize in limestone forest with restricted distribution. Although the animals living in limestone forest (especially the arthropods) are mostly small and unremarkable species, the role of each species in the limestone forest ecology are equally important (Vermeulen & Whitten, 1999; Grismer & Chan, 2009; Wood et al., 2013).

Some recommendations were proposed to manage the limestone resources in Southeast Asia and to protect the habitat from the threads (Kiew, 1998; Vermeulen & Whitten, 1999). For example, the existence of a broad buffer zone of forested vegetation surrounding limestone hills and site selections for industrial purposes.

2.2 Biogeography of Sarawak

Borneo is the second largest tropical island in the world after Papua with a total land area of 737,188 km^2 and surrounded by the Indo-Pacific region between Palawan and Mindanao from the northeast side, Sulawesi and Lesser Sunda Islands from the southeast side, Java from the South and Peninsular Malaysia from the northwest side. Politically, Borneo Island is divided into three countries; Malaysia, Brunei Darussalam, and Indonesia. The Malaysian part of Borneo consisted of Sarawak and Sabah (including the Federal Territories of Labuan) situated in northern Borneo. Sarawak with a total land area of 124,005 km^2, about 17% of Borneo's total land area, situated in north-west Borneo and crossed by Brunei Darussalam on the north-east side with a few satellite islands mostly on the north-western of the state. 76% of the total Sarawak land area is located below 500-meter altitude and 24% above 500-meter altitude (Gaveau et al., 2014).

The geological history of Borneo is very complicated. Historically, Borneo was a part of the ancient vast land called Sundaland stretching from Sumatra to the Indochina region. However, northern Borneo including Sarawak did not emerge above the sea until about 10 million years ago. The formation of northern Borneo done by long series of geological collisions between islands and continents together with volcanism activities started from the northwest part of Borneo in the middle Oligocene (30 ma) to the northern part of Borneo in the late Miocene (10 ma) (Hall, 2009).

2.3 Limestone hills of Borneo

Limestone hills in tropical regions is known as “arks” of biodiversity since very high species endemism in these areas (Clements et al., 2006). The tropical limestone forest areas (including Borneo) are among the least studied in the world (Vermeulen & Whitten, 1999). Apart from biodiversity studies, limestone hill is also known as the natural library for geological and archaeological studies. Unfortunately, the limestone forest in tropical areas are threatened by direct (e.g. limestone quarries) and indirect (e.g. agriculture) modern destruction practices (Clements et al., 2006). That is why the study of tropical limestone areas in term of biodiversity and biogeography in Borneo is very crucial, especially for conservation and forest management purposes. In Malaysia, limestone landscapes are mostly tower-like karst formations from long term geological processes. The limestone blocks are from the accumulation of Calcium Carbonate from ancient coral reefs rising from the surrounding area. The limestone hill formation in Malaysia usually occurs as isolated blocks or in some cases grouped into hill clusters. The calcareous rock erosion processes produce unique landscapes such as caves, sinkholes, pinnacle summits, steep to vertical cliffs, exposed sharp limestone bedrock, narrow gorges, broad valley, and polls which provide a variety of unique, isolated, and specific microhabitat for flora and fauna (Chin, 1977; Pearce, 2004).

The forest surrounding limestone hills is not simply just a patch of lowland forest. For example, there are about six types of vegetation found in Niah National Park which surrounds the Subis limestone massif (Pearce, 2004). The ecosystem of the forest in limestone is very complex. For instance, the vegetation recorded in Subis limestone massif differs from summit to summit although situated in the same limestone complex (Pearce,

2004). On the other hand, Kiew (1998) observed the Begonia species grow on different microhabitats although found in the same locality.

Sarawak is unique by several isolated and scattered limestone hills with different geological ages and varying in size (Pearce, 2003). Compare to Malayan limestone hills which range from Ordovician to Triassic, the age of limestone hill formations in Sarawak range from lower Cretaceous to late middle Miocene (Wolfenden, 1965; Chin, 1977; Simon et al., 2014).

Malaysia comprises 1393 limestone outcrops with an area covering 77,581 hectares. Sarawak, on the other hand, has the largest limestone outcrops base in Malaysia with 264 limestone outcrops and covered 27,836 hectares of land area in Sarawak (36 % of Malaysian limestone outcrop area occurs in Sarawak) (Liew et al., 2021a; 2021b). Despite the vast total land area in Sarawak, the limestone outcrops make up 0.22 % of the total land area in Sarawak. Limestone areas in Sarawak are remarkably widespread but not equally distributed. Massive limestone hill areas are stretched between Bau and Serian in the southwest part of Sarawak. In the northeast part of Sarawak, the limestone hill areas located in Batu Niah and Mulu with some smaller limestone hills are located in between both limestone hill clusters. Besides, there are some smaller isolated small limestone hills scattered between Kakus and Upper Baram in the central part of Sarawak (Vermeulen & Junau, 2007). Bau limestone Hill cluster comprises several limestone hill complexes that stretch 32 km diagonally. The cluster separated from the Padawan-Serian Limestone hill cluster by 7 km horizontally.

2.4 Land snail ecological study in Borneo

In Borneo, high levels of land snails in terms of species diversity are seemed to be related to limestone hill forest areas (Schilthuizen et al., 2002). As it's slow-moving and

short-range distributional pattern together with its low dispersal ability, land snails used as environmental and biodiversity indicators (Schilthuizen et al., 2002; Schilthuizen et al., 2005; Vermeulen & Whitten, 1998; Nurinsiyah et al., 2016). Land snail abundance in limestone forests is related to the soil pH and $CaCO_3$ content in the soil (Schilthuizen et al., 2003). The ecological study on land snails including speciation, endemism, and conservation in Bornean limestone habitat was previously done in Sabah but unfortunately, there is no study done in Sarawak to date with exception of recently published biogeographical and ecological studies on *Everettia* and *Georissa* snails (Schilthuizen et al., 2002; Schilthuizen et al., 2005; Schilthuizen, 2006; Liew et al., 2020; Khalik et al., 2020).

Solem (1984) claimed the land snails in tropical forests including Borneo are neither abundant nor diverse. Current studies showed the species richness in tropical forests are comparable with the temperate forest despite very low abundance (Emberton, 1995; Emberton et al., 1996; de Winter & Gittenberger, 1998; Schilthuizen & Rutjes, 2001; Foon et al., 2017). In addition, the land snail species diversity and abundance in the tropical forest are significantly higher in limestone forests especially areas near the outcrops but lower in the forest with relatively more acidic soil between or away from the outcrops.

The micro snail (< 5 mm) cover an essential ratio of land snail diversity in tropical forest particularly in limestone habitat. For example, the micro snail contributed 60% of the total land snail species found in Kinta Valley, Perak, and Tabin Limestone Hill, Sabah (Schilthuizen & Vermeulen, 2003; Foon et al., 2017). The sampling method for land snails in limestone habitats not just simply picking the snail by visual search or from randomly selected soil samples since the limestone forests are known for their unique landscapes which provide a variety of unique, isolated, and specific microhabitats for flora and fauna (Chin,

1977; Emberton, 1995; Pearce, 2004; Liew et al., 2008; Schilthuizen et al., 2013). Emberton et al. (1996) suggest using the timed searching method in addition to soil-plus-litter sampling for sampling microsnail based on their study in the Madagascar rainforest. In their study, the timed searching method yielded seven times as many microsnail species compare to litter sampling or soil-plus-litter sampling. However, this method has its weaknesses. Some species may present in soil-plus-litter and litter sampling methods but are absent in the timed searching method, especially for the well-camouflaged species and very small species. The species composition, geographical, and ecological niche heterogeneity between limestone and non-limestone habitat are very different despite the similarity in shell size variability between both regions. The study taken in the Sabah limestone habitat shows the great differences between the numbers of specimens collected alive and the specimens from the empty shell with only 18% of the specimens collected alive (Schilthuizen et al., 2003). Due to the differences in species composition and ecological niche heterogeneity in the Bornean land snails, a specialized sampling protocol was designed that integrated timed searching and soil-plus-litter methods required wherein agree with certain criteria such as high species completeness with sampling efficiency.

Land snails are known to be more successful in limestone habitats due to their calcareous composition which is important to their shell development (Alciatore et al., 2017). Some species are strictly calcicole and found in very limited distribution (Liew et al., 2014; Foon & Liew, 2017). Land snails that inhabit the limestone habitat, especially rock-dwelling species are particularly hiding inside the rock crevices and only appear on the limestone surface in the wet seasons. Some species prefer different habitats subject to seasonal changes whereas some other spend their whole life high up in bushes and trees (Vermeulen & Whitten, 1998). This is challenging to quantify because of temporal and

seasonal restrictions at which the living population assessments may be made (Thurman et al., 2008).

Empty shells indicate the presence of the particular species at the temporal and spatial scales (Říhová et al., 2018). Naturally accumulated empty shells offer a reliable means of acquiring the crucial abundance data of the living snails (Kidwell, 2001). The empty shells are used to estimate the density of living snails positively although the relationship is weak (Thurman et al., 2008; Stankowski, 2014). Accumulated empty shells consistently proved to contain more species than the live-taken snail samples which are indigenous to the local community (Kidwell, 2002; Staff et al., 1986; Carthew & Bosence, 1986). Moreover, the empty shell is also important for the biogeographical study of species-area relationships (Clements et al., 2008). However, using the empty shell as the ecology predictor must be done with cautiousness since the empty shell density pattern may be due to some obscure natural factors such as shell accumulation, shell transportation, snail population displacement, and shell decaying rates upon the soil acidity (Stankowski, 2014; Říhová et al., 2018).

CHAPTER 3

MATERIALS AND METHODS

3.1 Location of study

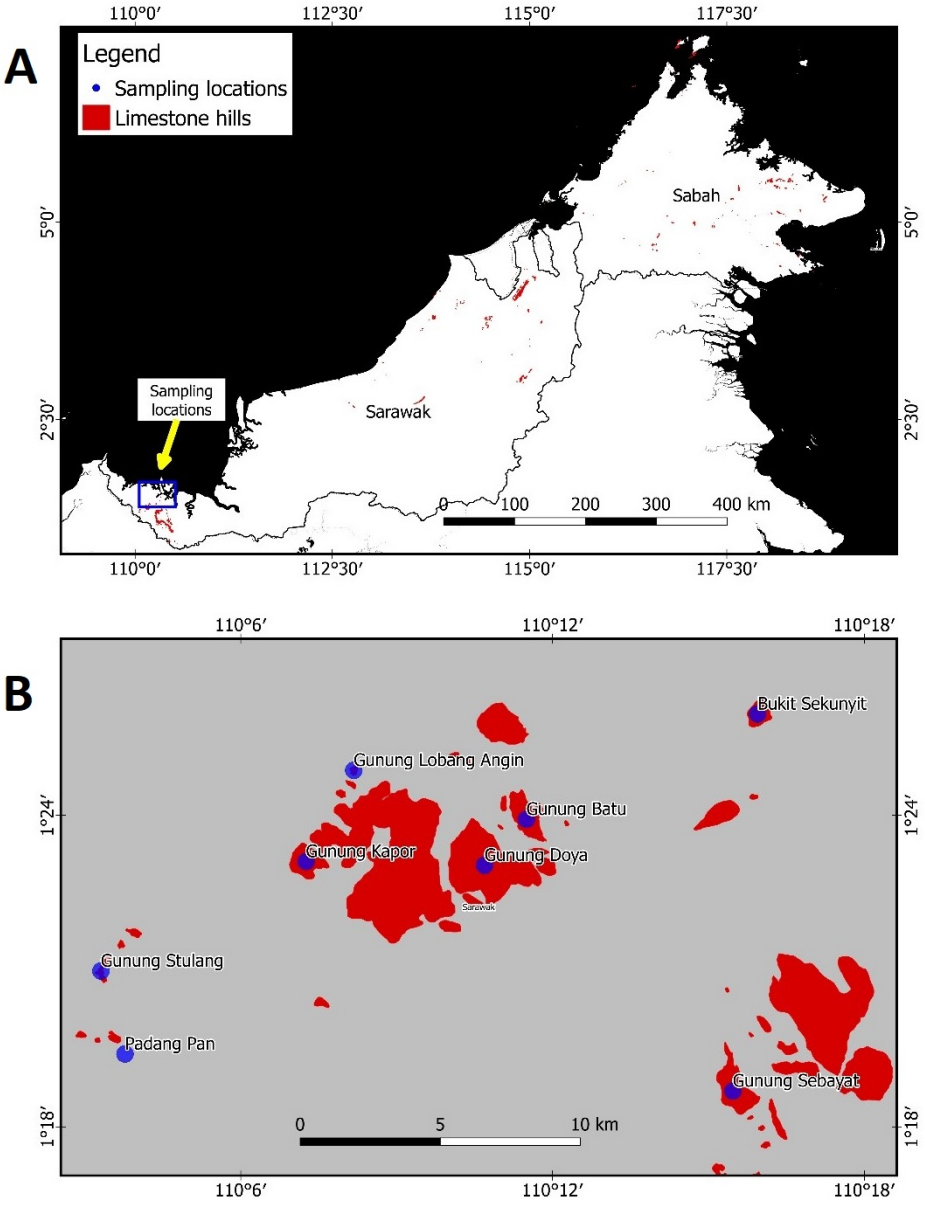


Figure 3.1: The sampling locations in this study; **A.** Map of Malaysian Borneo showing the Bau limestone hill cluster in Western Sarawak, and **B.** The eight (8) limestone hills sampled in and around Bau limestone hill cluster.

Figure 3.1A shows the eight limestone hills sampled in and around the Bau limestone hill cluster, Sarawak. The limestone hill name for Bau limestone Hills in this study is based on Liew et al. (2021b) except for Padang Pan. The selection of the limestone hills for this study are based on several factor which include accessibility, study duration and safety. There are about eight (8) limestone hills sampled in this study including three (3) limestone hills for ecological study (Figure 3.1B). The first location (hereafter called 'Bukit Sokwang') (= C1H1) is located north side of mykarst-336 Gunung Doya near Kampung (= Village) Skiat Baru, Jambusan, approximately 3 kilometres southeast of Bau town, with a surface area of roughly 322 Ha. The samplings were done at three different sites [Site 1 (= 1.3978083, 110.174425), Site 2 (= 1.3954694, 110.1764), and Site 3 (= 1.3971861, 110.175594)]. The limestone hill area is in the vicinity of Sarawak's newly gazetted Dered-Krian National Park. mykarst-342 Gunung Batu, also known as Gunung Jambusan (see Vermeulen, 1991a), and Gunung Beramu [eastern side of mykarst-336 Gunung Doya, also known as Gunung Sibuyoh (see Khalik et al., 2018)], are the limestone hills nearest to the site. The area consists of a small but remarkable cave in site 3 and a streamlet along the hill base from site 1 to site 3. Malacological surveys were done for this area previously by some authors (Dance, 1970; Vermeulen, 1993; 1994).

The second location (hereafter called 'Gunung Kapor') (= C1H2) is located in mykarst-329 Gunung Kapor vicinity near Kampung Krokong, approximately 5 kilometres southwest of Bau town, with a surface area of roughly 109 Ha. Fairy Caves Nature Reserve [Site 1 (= 1.3816, 110.117872) and Site 2 (= 1.3822472, 110.116339) in this study] is the main attraction in Gunong Kapor which located in Northeast of the hill whereby Buddha Caves in Site 3 (= 1.3906972, 110.11945) located in the south of the hill, just near the Bau-

Serikin junction. Malacological surveys were done for this area previously by some authors (Thompson & Dance, 1983; Vermeulen, 1991a; 1994).

The third location (hereafter called 'Lobang Angin') (= C1H3) is a small limestone hill located in mykarst-333 Gunung Lobang Angin vicinity along Sarawak Kanan River situated between Bau town and Gunong Kapor, approximately 2 kilometers west of Bau town, with a surface area of roughly 6 Ha. Wind Caves Nature Reserve is the main attraction in Lobang Angin. Malacological surveys were done for this area previously by some authors (Vermeulen, 1991a; 1994; Khalik et al., 2018). The samplings were done at three different sites [Site 1 (= 1.413372, 110.136725), Site 2 (= 1.4141694, 110.13708), and Site 3 (= 1.41527, 110.137117)].

Land snail specimens were also collected from five (5) other limestone outcrops in this study; Padang Pan (= 1.3233528, 110.062872), Gunung Stulang (= 1.346639, 110.0563139), Gunung Sebayat (= 1.306817, 110.25606), Bukit Sekunyit (= 1.4296694, 110.2631) and Gunung Batu (= 1.3974028, 110.1888861) together with the specimens from the previous surveys are adding up for the diversity and distribution study of land snail in Bau.

3.2 Microhabitats

In this study, five (5) microhabitats were recognized and selected. The selection of the microhabitats is based on my experience in collecting land snail in Sarawak prior to this study. First, soil near the limestone wall consists mainly of limestone particles and loam, without much organic matter. The limestone wall itself is the microhabitat strictly for calcicole obligate species such as *Plectostoma*, *Boysidia*, *Stomacosmethis*. Then, the soil around the small collapsed rock consists mainly of limestone particles and loam, but with

more organic matter. This microhabitat is ideal for *Opisthostoma*, *Acmella*, *Diplommatina*, and *Chamalycaeus*. Next, the soil around the tree consists mainly of thick organic matter without many limestone particles and loam. The humus deposited is more aerated with entangled tertiary roots differs from the soil around the rotten log with more compacted soil. The tree itself is the microhabitat for arboreal species such as *Leptopoma*, *Amphidromus*, *Dyakia*, *Vitrinula*, *Hemiplecta*, and *Kaliella*. After that, the soil around the rotten log consists mainly of thick organic matter without many limestone particles and loam. The rotten log is usually very wet and covered by mosses and fungi. This microhabitat is fit for fungi-eater snails like *Eurhyssota*, *Videna*, and *Geotrochus*. Finally, soil among small scrubs consists of a combination of limestone particles, loam, and organic matter. This microhabitat is favorable to detritus eater's snails like *Japonia*, *Opisthophorus*, *Diplommatina*, Ariophantid, and Charopid.

3.3 Data Sampling



Figure 3.2: Subplots (2 m x 2 m, 4m^2) that represent all the major microhabitats of land snail, **A.** near the limestone wall, **B.** around the small collapsed rock, **C.** around the tree, **D.** around the rotten log, and **E.** among small scrubs.

Nested standard sampling approaches were used in this project. Fieldwork was conducted from April 2017 to July 2018 from mid-morning to late evening. In the field, land snails were sampled in a series of nested plots with different sizes. The Bau limestone cluster was chosen for the study. Three (3) limestone hills were selected within an area of 20 km X 20 km (400 km^2) (Figure 2). In each of the three (3) hills, three (3) standard plots of 20 m X 20 m (400 m^2), which are located around a limestone hill within an area of 200 m X 200 m (40,000m^2), were searched for land snails, either living snails or empty shells following Schilthuizen (2003). In each of the 400m^2 sampling plots, a set of five (5) subplots (2 m x 2 m, 4m^2) that represent all the major microhabitats of land snails [(A) near the limestone wall,

(B) around the small collapsed rock, (C) around the tree, (D) rotten log, and (E) among small scrubs)] (figure 1), were selected accordingly and were searched for land snails, either living snails or empty shells. In each of the $4m^2$ subplots, a set of three (3) small plots (0.2 m x 0.2 m, $0.04m^2$) were selected randomly and collected for leaf litter and loose topsoil in each small plot for 10 minutes. Simultaneously, random samplings were done outside of the standard plots. The sampling time in each of the 20 m X 20 m plots is two-person hours.

In the laboratory, the empty shells were cleaned with water and the live-taken snails including slug and semi slug were preserved in 100% ethanol for future DNA work and wet collection. At the same time, the loose soils and leaf litters were dried in the oven set to 50ºC following Schilthuizen (2003). After that, the micro-snails were extracted from the dried soil using soft forceps under a stereomicroscope. All the specimens were sorted, identified to species level, and catalogued. All specimens were kept in the respective institutions, in Zoological Museum, Universiti Malaysia Sarawak (MZU.MOL), and Mohammad Effendi Personal Collection (ME) for further taxonomical studies.

3.4 Data analysis

3.4.1 The land snail species composition in Bau, Sarawak

Land snail specimens for all 135 plots (= 3 hills X 3 standard plots X 5 subplots X 3 small plots) were sorted, identified to the species level, and catalogued. For the species identification, the specimen's data were systematically categorized into family, genus, and species in the Microsoft Excel sheet. A complete literature on Bornean land snails was consulted, with emphasis on the most recent Bornean land snail species compilation website (https://borneanlandsnails.myspecies.info/). All specimens were identified to species level based on the original descriptions and ME Collection. After the accession of all samples, a

checklist of all species from the Bau limestone cluster from 135 plots including the previous expeditions was generated from the ME collection database and the findings were discussed including the species remarks and distributions. The taxonomic study is based on shell characters only. Species reported to be present in study sites in the literature, but not found during the sampling, were not included in the analysis. The representative specimens were photographed and measured with a Leica DFC495 Digital Microscope Camera mounted on a Leica M205C microscope. The type specimens were sputter coated with gold and viewed under high vacuum with a Scanning Electron Microscope (JEOL JSM-5610LV, JEOL Ltd., Tokyo) to further observe minute shell sculpture. The type specimens (Holotype and Paratypes) for the recently described were deposited in Zoological Museum, Universiti Malaysia Sarawak.

3.4.2 The species richness estimates and sampling effectiveness between live-taken snail versus empty shell

Sampling effectiveness for all 45 plots (= 3 standard plots X 5 subplots X 3 small plots) in each hill and 135 plots (= 3 hills X 3 standard plots X 5 subplots X 3 small plots) in cluster scale were quantified using completeness ratios (i.e., number of observed species/estimated species) according to the smallest scale of sampling regime, namely, 0.04 m^2 (small plot). Species completeness analysis was performed to extrapolate the species richness and inventory for different spatial scales using the iNEXT package in R-software (Hsieh et al., 2016). iNEXT package provides simple functions to compute and plot two types (sample-size and coverage-based) rarefaction and extrapolation of species diversity for abundance data or incidence data.

3.4.3 The associations between land snail species and microhabitats

The modularity algorithms are the measure of the structure of networks to identify modules in weighted bipartite networks. Bipartite networks are networks that have two different sets of nodes, where edges represent relations between the two different types of units. Networks that are defined by a single node type are known as unipartite networks. The degree of each node is the number of edges that each node is linked by. As the result, a certain species may be a generalist if a node is linked to multiple other nodes while the nodes that have few edge networks with more isolated from the rest of the network are known to be specialist species. According to diversity estimates, only 95 live-taken snails in Bau belong to 17 species available for ecological study. Bipartite interaction matrices were calculated, and bipartite network interactions were visualized, using the QuanBiMo bipartite package in R-software (Dormann & Strauss, 2014). In this package, cluster analysis was done to see the relationship between species community and assemblages based on presence-absence and abundance data of 17 live-taken land snail species from Bau. Furthermore, the associations between land snail species and microhabitats sampled at the Bau limestone hill cluster were simplified using an adjacency matrix and interaction matrix featuring nested modules. The adjacency matrix of a network is a matrix representing whether a node in a network relates with all the other nodes. Value in the biadjacency matrix in a weighted bipartite network represents the strength of the relationship between two nodes. A visualization of the adjacency matrix of land snail species and microhabitats sampled in this study visualized with the colour tone from pale to darker colour depending on the association degree between the species and the microhabitats. On the other hand, modularity is the tendency for a network to form closely interacting communities, which are known as modules, such that within-community connectivity is high and between-community

connectivity is low while nestedness describes the tendency for one type of specialist nodes to interact with the other type generalist nodes.

CHAPTER 4

RESULTS

4.1 Land snail inventory in Bau limestone hills

The study on land snail diversity in limestone hill forests was done in Bau between April and December 2017. A total of 1085 collection lots obtained from the eight limestone hills in Bau were examined. This checklist comprises a total of 122 land snail species belonging to 57 genera and 24 families. The family Diplommatinidae was the most species-rich family recorded in this limestone hill cluster, with 21 species recorded (17 %). This was followed by the family Cyclophoridae (n = 16 species, 13 %) and the family Ariophantidae (n = 14 species, 11 %). In terms of genera, the most diverse is *Kaliella* with nine species. This was followed by the genera *Microcystina* and *Diplommatina*, with eight species from each genus. Microsnails (size less than 5 mm) accounted for about 63 % of the total number of species.

An inventory of land snail and slug species from systematic and random sampling surveys at eight limestone hills in Bau, namely, mykarst-325 Gunung Stulang, Padang Pan, mykarst-329 Gunung Kapor (= C1H2), mykarst-333 Gunung Lobang Angin (= C1H3), Bukit Sokwang (= part of mykarst-336 Gunung Doya = C1H1), mykarst-342 Gunung Batu, mykarst-349 Bukit Sekunyit and mykarst-366 Gunung Sebayat are reported. The ME collection checklist did not account for eight morphospecies reported in previous studies of land snails in Bau (Appendix B).

4.1.1 Land snail taxa checklist from Bau limestone hill cluster

Class Gastropoda Cuvier, 1795

Subclass Caenogastropoda Cox, 1960

Family Alycaeidae Blanford, 1864

Genus *Chamalycaeus* Möllendorff, 1897

***Chamalycaeus specus* (Godwin-Austen, 1889)**

Figure 4.1A, 4.47A

Alycaeus specus Godwin-Austen 1889: 347, plate 37, figure 4, 4A.

Type locality. "In limestone caves at Jambusan, Borneo" [= Jambusan Hills, Bau, Sarawak]. Materials examined. Gunung Sebayat: *ME 8005. Gunung Doya: ME 9699, ME 9148, ME 9179. Gunung Kapor: *ME 3357, *ME 3359, *ME 3362, *ME 8085, *ME 8488, ME 9046, ME 9078, ME 9471. Lobang Angin: ME 9038, ME 9432. Gunung Batu: *ME 3351, *ME 3352, *ME 3353, *ME 8802. Distribution in Borneo. SARAWAK: Kuching, Serian, and Kapit Divisions. SABAH: Sandakan, Tawau, and West Coast Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. No live specimen was found during the surveys.

Genus *Pincerna* Preston, 1907

***Pincerna globosa* (H. Adams, 1870)**

Figure 4.1B, 4.46D

Alycaeus globosus Adams 1870: 794.

Type locality. “Busan, near Sarawak, Borneo” [= Jambusan Hills, Bau, Sarawak]. Materials examined. Bukit Sekunyit: *ME 1016, *ME 6980. Gunung Doya: *ME 1059, ME 9698, ME 8958, ME 9090. Gunung Kapor: *ME 1004, *ME 1015, *ME 1053, *ME 8489, ME 8974. Gunung Stulang: *ME 5904. Lobang Angin: *ME 1029, *ME 6979, ME 8726, ME 8746, ME 8749, ME 9022. Gunung Batu: *ME 1014, *ME 1023, *ME 1054, *ME 8829. Distribution in Borneo. SARAWAK: Kuching, Serian, and Miri Divisions. SABAH: West Coast Division. Distribution elsewhere. None. Endemic to Borneo. Remarks. Smith (1895) classified *Pincerna globosa* into five different forms: - *globosa*, *rabongensis*, *muluana*, *kinabaluana* and *pygmaea*, of which two forms were collected from Bau - *globosa* with a smaller yellowish-orange shell while *rabongensis* with a larger yellow shell. The differences between the two forms may due to the sexual dimorphism. The living snails were observed dwelling on the leaf surfaces of small trees and palms at the base of the limestone cliff.

Genus *Stomacosmethis* Bollinger, 1918

***Stomacosmethis hosei* (Godwin-Austen, 1889)**

Figure 4.1C

Alycaeus hosei Godwin-Austen 1889: 347, plate 37, figure 2.

Type locality. “Busan Hills, Borneo” [= Jambusan Hills, Bau, Sarawak]. Materials examined. Gunung Doya: *ME 1088, ME 9133. Gunung Kapor: *ME 1024, *ME 8084. Gunung Stulang: *ME 5903. Gunung Batu: *ME 1002, *ME 1010, *ME 7180, *ME 8803. Distribution in Borneo. SARAWAK: Kuching and Serian Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. The living snails were observed dwelling on the moderately wet vertical limestone rock surfaces that covered with lichens. The shell of this snail is always covered with calcareous dirt.

Stomacosmethis sadongensis **(E. A. Smith, 1895)**

Figure 4.1D, 4.46C

Alycæus (*Orthalycæus*) *sadongensis* Smith 1895: 117, plate 3, figure 27.

Type locality. “Sadong, Sarawak”. Materials examined. Gunung Kapor: *ME 1003, ME 8761. Gunung Batu: *ME 2896, *ME 2900, *ME 8804. Distribution in Borneo. SARAWAK: Kuching, Serian & Miri Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. It is different from other Bornean *Stomacosmethis* species by having a moderately tall, conical shell with fine spiral striae, pale yellow whorl, and simple peristome. The living snails were observed dwelling on the wet vertical limestone rock surfaces that covered with mosses and lichens.

Family Cyclophoridae Gray, 1847

Family Cyclophoridae Gray, 1847

Genus *Leprocochlias* Vermeulen, Marzuki & Khalik, ms.

***Leprocochlias cingulatus textrinum* Vermeulen, Marzuki & Khalik, ms.**

Figure 4.2A

Materials examined. Paratypes: 1 ex. (ME0008909), Bukit Sokwang (Site 3), northern site of Gunung Doya, limestone hill along Skio road, 2.05 miles E Bau, 1.3971861, 110.175594, coll. M. E. Marzuki, 22.IV.2017; 1 ex. (ME0009182), Bukit Sokwang (Site 1), northern site of Gunung Doya, limestone hill along Skio road, 2.05 miles E Bau, 1.3978083, 110.174425, coll. M. E. Marzuki, 22.IV.2017; 2 ex. (ME0002839), Gunung Batu, limestone outcrop along Skio road, Jambusan, 2.4 miles E Bau, 1.3974028, 110.1888861, coll. M. E. Marzuki, 23.VI.2010.

Description. Shell: small-sized, high-conical, dextral, rather solid. Colour white, translucent, shiny. Suture depressed. Whorls 5, convex, regularly increasing in diameter. Periphery rounded, angular at ultimate whorl. Protoconch: elevated, white, more or less rounded with malleated sculpture. Teleoconch: Radial sculpture ornamented with distinct transverse and densely placed growth lines all over the shell. Spiral sculpture with 19 spiral ridges on the last whorl - 7 above the periphery, 1 along the periphery, 7 below the periphery and 4 near the basal. Spiral striae in between spiral ridges absent. Aperture: more or less circular, somewhat oblique, parietal area between spiral ridges below the periphery. Peristomes simple, thickened lip on the palatal side, without a notch. In some specimens, periostracum thin and corneous, without hair and appendages in fresh condition especially on the basal side. Umbilicus: open, moderately wide, 0.40-0.70 mm in diameter. Dimensions: Shell height 3.91-4.78 mm; shell width 3.73-4.48 mm; Aperture height and width 1.53-1.85 mm.

Remarks. The characters of simple peristome and thickened lip on the columellar side are shared between *Leprocochlias cingulatus textrinum* and congeners. However, *Leprocochlias cingulatus textrinum* differs from most congeners in the presence of 19 spiral ridges and slightly angulated last whorl. *Leprocochlias cingulatus textrinum* resembles *Craspedotropis juvenilis* Vermeulen, 1999 in having high spire but differs in the absence of conspicuous ridges on the last whorls and the rounded periphery. It is similar to *Craspedotropis borneensis* (Godwin-Austen, 1889) and *Craspedotropis gretathunbergae* Schilthuizen et al., 2020 in presence of spiral ridges, but differs by having 19 spiral ridges on the last whorl instead of 9 spiral ridges in *C. borneensis* and 4 spiral ridges in *C. gretathunbergae*. In addition, it has angulated last whorl at the periphery as compare to *C. borneensis* but not keeled as compare to *Craspedotropis andrei* Vermeulen, 1999. The new genus and species will be described in later publication.

Geographic distribution and habitat. It is known from the Bau limestone hill clusters. No living snail was found during the surveys.

Etymology. From Latin '*textrinum*', = a weaving, referring to the sculpture; the word used as noun in apposition.

Genus *Cyclophorus* Montfort, 1810

***Cyclophorus perdix borneensis* (Metcalfe, 1851)**

Figure 4.2B, 4.46A

Cyclostoma borneensis Metcalfe 1851: 71.

Type locality. “Borneo”. Materials examined. Gunung Sebayat: *ME 8007. Bukit Sekunyit: *ME 2631. Gunung Doya: *ME 2675, ME 8921, ME 8947, ME 9169. Gunung Kapor: *ME 2636, *ME 2647, ME 8068, ME 8706, ME 8753, ME 8769, ME 9468. Gunung Stulang: *ME 5905. Kampung Bunga Rampai: *ME 2610, *ME 5947. Kampung Padang Pan: *ME 6667. Lobang Angin: *ME 2648, ME 9183, ME 9483. Gunung Batu: *ME 2633, *ME 2642, *ME 8805. Distribution in Borneo. SARAWAK: Kuching, Samarahan, Serian, Mukah, Kapit, and Miri Divisions. SABAH: West Coast Division. KALIMANTAN: West Kalimantan, South Kalimantan and East Kalimantan Provinces. Distribution elsewhere. West Malaysia (?) (Stoliczka 1872; Morgan 1885). Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest.

Genus *Ditropopsis* E. A. Smith, 1897

***Ditropopsis everetti* (E. A. Smith, 1895)**

Figure 4.2C

Cyathopoma everetti Smith 1895: 115, plate 3, figure 21-22.

Type locality. “Rumbang, Sarawak” [= Rumbang Hills, Padawan, Sarawak]. Materials examined. Gunung Sebayat: *ME 8009. Gunung Kapor: *ME 0835, *ME 0842, ME 8494, ME 9079, ME 9239. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. None. Endemic to Borneo. Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in limestone forest. It is different from other

Bornean *Ditropopsis* species by having seven distinct lirae on the last whorl comprising one supraperipheral, two peripherals, one basal and three umbilical lirae.

Genus *Japonia* A. A. Gould, 1859

***Japonia barbata* (L. Pfeiffer, 1855)**

Figure 4.3A-B, 4.45A

Cyclostoma (*Leptopoma*) *barbatum* Pfeiffer 1855: 104-105.

Type locality. "Borneo, Sarawak". Materials examined. Gunung Doya: *ME 0817, ME 8903, ME 9092, ME 9668. Gunung Kapor: *ME 0737, *ME 0780, *ME 0784, *ME 2949, *ME 8069, *ME 8490, ME 8768, ME 8783, ME 9047, ME 9609, ME 9841. Lobang Angin: *ME 0791, ME 9083, ME 9134, ME 9275. Gunung Batu: *ME 0783, *ME 0796, *ME 0800, *ME 8808. Gunung Sebayat: *ME 8008. Kampung Bunga Rampai: *ME 0833, *ME 0834. Kampung Padang Pan: *ME 6668. Distribution in Borneo. SARAWAK: Kuching, Samarahan, Serian, Sibu, and Mukah Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. It is different from other Bornean *Japonia* species by the following combination of characters: more depressed medium-sized shell with wide umbilicus, last whorl with distinctly keeled at the periphery, with long, deciduous, slender, feather-like hairs along the first peripheral ridge and below the periphery. Shell variability are found in different populations: shells from Jambusan areas have smooth surface with very faint lirae; shells from Lobang Angin areas have a distinctly keeled periphery (figure 5B); shells from the non-limestone areas usually have a somewhat round periphery with equally strong lirae (figure 5A). *Japonia similis* (Smith, 1893) is different from this species by having a larger

high spire shell with moderately wide umbilicus. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest.

Japonia bauensis Marzuki, Liew & Mohd-Azlan, 2021

Figure 4.3C-D, 4.4

Japonia bauensis Marzuki et al. 2021: 14-16, Figure 4C-D, 5.

Type locality. "Malaysia, Sarawak, Kuching Division, Gunung Doya, limestone hill near Sungai Sebuyoh, 3.4 miles SE Bau, 1.38257, 110.194283". Materials examined. Gunung Doya: *MZU.MOL.20.02, *ME 817, ME 9667, ME 8907, ME 9167. Gunung Kapor: *ME 743, *ME 779, *ME 5974, *ME 7231, *MZU.MOL.20.03, ME 8491, ME 9216. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. None. Endemic to Borneo. Remarks. It is similar to *Japonia barbata* (L. Pfeiffer, 1855), but differs by having a smaller shell with short spire, wide umbilicus, and rounded spire along the periphery. In addition, it has very short, deciduous, slender, feather-like hairs along the first peripheral ridge and below the periphery as compare to *J. barbata*. The shells of some populations (i.e., Gunung Kapor areas) without or with inconspicuous spiral lirae (figure 5C).

Japonia metcalfei (Issel, 1874)

Figure 4.5A

Cyclophorus (*Craspedotropis*) *metcalfei* Issel 1874: 432-433, plate 6, figure 4-6.

Type locality. “Territorio di Sarawak”. Materials examined. Gunung Doya: ME 9161. Lobang Angin: ME 9279. Gunung Batu: *ME 2916. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. None. Endemic to Borneo. Remarks. No live specimen was found during the surveys.

Japonia mundyana **(Godwin-Austen, 1889)**

Figure 4.5B

Lagocheilus mundyanus Godwin-Austen 1889: 338-339, plate 39, figure 6, 6A-B.

Type locality. “Busan Hills, Borneo” [= Jambusan Hills, Bau, Sarawak]. Materials examined. Gunung Kapor: *ME 0821, *ME 8493, ME 9249. Gunung Batu: *ME 0808, *ME 0838. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. None. Remarks. It is different from other the Bornean *Japonia* species by having a considerably smaller shell with higher spire. No live specimen was found during the surveys.

Japonia rabongensis **(E. A. Smith, 1895)**

Figure 4.5C

Lagochilus rabongensis Smith 1895: 120-121, plate 4, figure 6.

Type locality. “Mount Rabong, West Sarawak” [= Merabong Hill, Padawan, Sarawak]. Materials examined. Gunung Kapor: *ME 8492, ME 9080. Gunung Batu: *ME 0824. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. None.

Endemic to Borneo. Remarks. It is similar to *Japonia metcalfei* (Issel, 1874), but differs in having higher spire and narrow umbilicus. No live specimen was found during the surveys.

Genus *Leptopoma* L. Pfeiffer, 1847

***Leptopoma sericatum* (L. Pfeiffer, 1851)**

Figure 4.5D

Cyclostoma (*Leptopoma*) *sericatum* Pfeiffer 1851: 244.

Type locality. "Borneo". Materials examined. Bukit Sekunyit: *ME 1350. Gunung Doya: *ME 1355, ME 8906, ME 9155. Gunung Kapor: *ME 1290, *ME 1347, *ME 1352, *ME 8070, ME 9232, ME 9403. Gunung Stulang: *ME 5900. Gunung Batu: *ME 1351, *ME 1354, *ME 1359, *ME 8831. Distribution in Borneo. SARAWAK: Kuching, Serian, Kapit and Miri Division. SABAH. BRUNEI DARUSSALAM. KALIMANTAN: West Kalimantan, South Kalimantan and East Kalimantan Provinces. Distribution elsewhere. None. Endemic to Borneo. Remarks. The living snails were observed dwelling on the leaf of tree near the cliff in lowland limestone forest.

***Leptopoma undatum* (Metcalfe, 1851)**

Figure 4.5E

Cyclostoma undatum Metcalfe 1851: 71.

Type locality. “Borneo”. Materials examined. Gunung Stulang: *ME 5899. Kampung Padang Pan: *ME 6723. Gunung Batu: *ME 2684, *ME 2686. Distribution in Borneo. SARAWAK: Kuching and Miri Divisions. SABAH: Interior, Sandakan, Tawau, and West Coast Divisions. BRUNEI DARUSSALAM: Temburong District. KALIMANTAN: West Kalimantan and East Kalimantan Provinces. Distribution elsewhere. Palawan (Vermeulen 1999). Remarks. The living snails were observed dwelling on the leaf of tree near the cliff in lowland limestone forest.

Genus *Opisthoporus* Benson, 1851

***Opisthoporus biciliatus* (Mousson, 1849)**

Figure 4.6A, 4.45C

Pterocyclos biciliatum Mousson 1849: 49-50, plate 20, figure 9.

Type locality. “Java” [= Borneo (Metcalfe, 1851)]. Materials examined. Gunung Doya: *ME 4744, ME 9144, ME 9192. Gunung Kapor: *ME 3723, *ME 4742, *ME 4746, *ME 5973, *ME 8073, *ME 8460, ME 8754, ME 8757, ME 8777. Lobang Angin: *ME 4743, ME 8725, ME 8729, ME 8739, ME 9484. Gunung Batu: *ME 4745, *ME 4748, *ME 8806. Distribution in Borneo. SARAWAK: Kuching, Samarahan, Serian, and Sibu Divisions. KALIMANTAN: West Kalimantan Province. Distribution elsewhere. None. Endemic to Borneo. Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest. It is different from other Bornean *Opisthoporus* species by having a moderately large shell, short sutural tube projecting

upward, long, double, deciduous appendages along the first peripheral ridge and below the periphery that seen on a fresh shell.

Opisthoporus birostris (L. Pfeiffer, 1854)

Figure 4.6B, 4.45D

Cyclostoma birostre Pfeiffer 1854b: 300.

Type locality. “Sarawak, Borneo”. Materials examined. Bukit Sekunyit: *ME 4735. Gunung Doya: *ME 1312. Gunung Kapor: *ME 4731, *ME 4736, *ME 4737, *ME 8072, *ME 8495, ME 8755, ME 8758, ME 9605. Lobang Angin: *ME 4738. Gunung Batu: *ME 4732, *ME 4734, *ME 4739, *ME 8830. Distribution in Borneo. SARAWAK: Kuching Division. SABAH: Interior Divison (?). Distribution elsewhere. None. Endemic to Borneo. Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest. It is different from other Bornean *Opisthoporus* species by having a large shell, short sutural tube projecting downward, and thick brown periostracum seen on a fresh shell.

Opisthoporus cavernae (Godwin-Austen, 1889)

Figure 4.6C

Rhiostoma cavernae Godwin-Austen 1889: 342, plate 36, figure 1, 1A.

Type locality. “Sarawak proper, Borneo” [= Kuching, Sarawak]. Materials examined. Gunung Doya: ME 8904, ME 9093. Distribution in Borneo. SARAWAK: Kuching and Serian Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest. It is different from other Bornean Opisthoporus species by having a moderate shell, short sutural tube projecting upward, long Rhiostoma-like detached tuba.

***Opisthoporus euryomphalus* (L. Pfeiffer, 1856)**

Figure 4.6D, 4.45B

Cyclostoma (*Opisthoporus*) *euryomphalum* Pfeiffer 1856: 337.

Type locality. “Borneo”. Materials examined. Gunung Doya: *ME 1295, ME 8905, ME 9113, ME 9157. Gunung Kapor: *ME 1294, *ME 1298, *ME 1299, *ME 8071, *ME 8496, ME 8779. Gunung Batu: *ME 1300, *ME 1301, *ME 2613, *ME 8807. Distribution in Borneo. SARAWAK: Kuching Division. KALIMANTAN: West Kalimantan Province. Distribution elsewhere. None. Endemic to Borneo. Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest. It is different from *O. biciliatus* by having a smaller shell without hairy periostracum.

Genus *Platyrhaphe* Möllendorff, 1890

***Platyrhaphe linita* (Godwin-Austen, 1889)**

Figure 4.6E, 4.46B

Cyclotus linitus Godwin-Austen 1889: 345, plate 36, figure 3.

Type locality. “Busan Hills, Borneo” [= Jambusan Hills, Bau, Sarawak]. Materials examined. Gunung Doya: *ME 9700, ME 8908, ME 9094, ME 9175. Gunung Batu: *ME 0881, *ME 0882. Distribution in Borneo. SARAWAK: Kuching and Serian Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. This species is one of the only four species of *Platyrhaphe* described in Borneo and the only species recorded in Sarawak. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest. The shell always covered with thick dirt.

Genus *Pterocyclos* Benson, 1832

***Pterocyclos tenuilabiatus* (Metcalfe, 1851)**

Figure 4.6F

Cyclostoma tenuilabiatum Metcalfe 1851: 71-72.

Type locality. “Borneo”. Materials examined. Gunung Kapor: *ME 8074, ME 9467. Gunung Stulang: *ME 5901. Distribution in Borneo. SABAH: West Coast, Interior, Sandakan, and Tawau Divisions. SARAWAK: Kuching Division. KALIMANTAN: West Kalimantan Province. Distribution elsewhere. None. Endemic to Borneo. Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest.

Family Diplommatinidae L. Pfeiffer, 1856

Genus *Diplommatina* Benson, 1849

***Diplommatina adversa* (H. Adams & A. Adams, 1851)**

Figure 4.7A, 4.48A

Paxillus adversus Adams & Adams 1851: 63.

Type locality. “Singapore”. Materials examined. Bukit Sekunyit: *ME 0462. Gunung Doya: *ME 0543, ME 9695, ME 8898, ME 9089. Gunung Kapor: *ME 0455, *ME 0456, *ME 0523, *ME 0525, *ME 8067, *ME 8513, ME 8760, ME 8766, ME 8776. Kampung Padang Pan: *ME 6672. Lobang Angin: *ME 0463, *ME 0524, ME 8735, ME 8742, ME 8748. Gunung Batu: *ME 0459, *ME 0526, *ME 0535, *ME 8799. Distribution in Borneo. SARAWAK: Kuching and Serian Divisions. SABAH: Tawau Division. Distribution elsewhere. West Malaysia, Singapore, Bunguran (Indonesia) and Sirhassen (Laidlaw 1949). Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest.

***Diplommatina busanensis* Godwin-Austen, 1889**

Figure 4.7B

Diplommatina busanensis Godwin-Austen 1889: 348-349, plate 37, figure 4.

Type locality. “Busan Hills, Borneo” [= Jambusan Hills, Bau, Sarawak]. Materials examined. Gunung Doya: ME 8902, ME 8991, ME 9088. Gunung Kapor: *ME 0307, *ME 0483, *ME 0600, *ME 8485, ME 9233, ME 9260, ME 9278. Gunung Batu: *ME 0467, *ME 8800. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. None. Endemic to Borneo. Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest.

Diplommatina concinna H. Adams, 1872

Figure 4.7C, 4.48B

Diplommatina concinna Adams 1872: 13, plate 3, figure 22.

Type locality. “Borneo”. Materials examined. Gunung Sebayat: *ME 8003. Bukit Sekunyit: *ME 0464. Gunung Doya: *ME 0544, *ME 9696, ME 8992, ME 9087, ME 9101. Gunung Kapor: *ME 0466, *ME 0491, *ME 0517, *ME 0599, *ME 8147, *ME 8484, ME 9005, ME 9137, ME 9230. Gunung Stulang: *ME 5902. Kampung Bunga Rampai: *ME 0736. Kampung Padang Pan: *ME 6671. Lobang Angin: *ME 0515, ME 8745, ME 8981, ME 9024. Gunung Batu: *ME 0512, *ME 0538, *ME 0540, *ME 0597, *ME 8797. Distribution in Borneo. SARAWAK: Kuching, Serian and Miri Divisions. Distribution elsewhere. Bunguran (Indonesia) (Smith 1874). Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest.

Diplommatina maduana maduana Laidlaw, 1949

Figure 4.8A

Diplommatina maduana Laidlaw 1949: 209, figure 3B.

Type locality. “Gua Madu, Kelantan”. Materials examined. Gunung Sebayat: *ME 8004. Gunung Doya: *ME 0542, ME 9030, ME 9086, ME 9162. Gunung Kapor: *ME 0475, *ME 0532, *ME 0598, *ME 8486, ME 9004, ME 9028, ME 9076. Gunung Batu: *ME 0534, *ME 8798. Distribution in Borneo. SARAWAK: Kuching, Serian and Miri Divisions. Distribution elsewhere. West Malaysia (Laidlaw 1949). Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest.

Diplommatina onyx **Fulton, 1901**

Figure 4.8B

Diplommatina onyx Fulton 1901: 244.

Type locality. “Busan, N. Borneo” [= Jambusan Hills, Sarawak]. Materials examined. Gunung Doya: *ME 0541, ME 9014, ME 9102, ME 9150. Gunung Kapor: ME 8487. Gunung Batu: *ME 0484, *ME 0537, *ME 8888. Distribution in Borneo. SARAWAK: Kuching, Serian and Miri Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest.

Diplommatina spinosa Godwin-Austen, 1889

Figure 4.8C, 4.48C

Diplommatina spinosa Godwin-Austen 1889: 349, plate 38, figure 1.

Type locality. “Cave exploration A, Borneo” [= Tupak Cave, Jambusan Hills (Cranbrook, 2013)]. Materials examined. Gunung Batu: *ME 0522, *ME 0539, *ME 0596, *ME 8801. Distribution in Borneo. SARAWAK: Kuching and Serian Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest.

Diplommatina toretos Vermeulen, 1993

Figure 4.8D

Diplommatina toretos Vermeulen 1993: 19-20, figure 13A-D.

Type locality. “SARAWAK. 1st Div.: G. Pangga 3 km ENE. Of Bau”. Materials examined. Gunung Doya: *ME 0545. Gunung Batu: *ME 0536. Distribution in Borneo. SARAWAK: Kuching, Serian and Miri Divisions. SABAH: West Coast Division. Distribution elsewhere. None. Endemic to Borneo. Remarks. No live specimen was found during the surveys.

Genus *Moussonia* O. Semper, 1865

Moussonia isseli (Godwin-Austen, 1889)

Figure 4.7D

Diplommatina isseli Godwin-Austen 1889: 348, plate 38, figure 5, 5A.

Type locality. “Sarawak proper and Busan Hills, Borneo” [= Kuching and Jambusan Hills, Bau, Sarawak]. Materials examined. Gunung Batu: *ME 2869. Distribution in Borneo. SARAWAK: Kuching Division. SABAH: Interior and West Coast Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. No live specimen was found during the surveys.

Genus *Opisthostoma* W. T. Blanford & H. F. Blanford, 1860

***Opisthostoma ballorum* Vermeulen, 1991**

Figure 4.9A

Opisthostoma ballorum Vermeulen 1991a: 162-163, figure 10b.

Type locality. “SARAWAK. 1st Div.: G. Kapur 6 km SE. of Bau”. Materials examined. Gunung Doya: ME 8989, ME 9109, ME 9149. Gunung Kapor: *ME 0274, *ME 0277, ME 9002, ME 9206. Lobang Angin: ME 9171. Gunung Batu: *ME 0273, *ME 0276, *ME 0331, *ME 8796. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. None. Endemic to Borneo. Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest.

***Opisthostoma brachyacrum brachyacrum* Thompson, 1978**

Figure 4.9B

Opisthostoma (*Opisthostoma*) *brachyacrum* Thompson 1978: 388-389, Figs 2A-E.

Type locality. “BORNEO: Sarawak. Fourth Division. Limestone hill on the trail from the Niah River to Niah Cave, Batu Niah”. Materials examined. Gunung Kapor: *ME 0285. Gunung Batu: *ME 0279, *ME 0284, *ME 0353. Distribution in Borneo. SARAWAK: Kuching and Miri Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest.

Opisthostoma brachyacrum lambi **(Vermeulen, 1991)**

Figure 4.9C

Opisthostoma lambii Vermeulen 1991a: 155.

Type locality. “SARAWAK. 1st Div.: W. Of Kpg. Lobang Batu 12.5 km S. Of Tebakang”. Materials examined. Gunung Sebayat: *ME 8002. Bukit Sekunyit: *ME 0311. Gunung Doya: *ME 0287, ME 9082, ME 9246. Gunung Kapor: *ME 0281, *ME 0310, *ME 2875, ME 8978, ME 9003, ME 9077. Kampung Padang Pan: *ME 6670. Lobang Angin: ME 9106, ME 9147, ME 9224. Distribution in Borneo. SARAWAK: Kuching, Serian and Kapit Divisions. SABAH: Interior and West Coast Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest.

Opisthostoma cryptodon Vermeulen, 1991

Figure 4.9D

Opisthostoma cryptodon Vermeulen 1991: 148-150, figure 4B.

Type locality. “SARAWAK. 1st Div.: W. of Kpg. Lobang Batu 12.5 km S. of Tebakang”. Materials examined. Gunung Doya: ME 8901, ME 8988, ME 9084. Gunung Kapor: *ME 0278, ME 9099, ME 9253. Lobang Angin: ME 8980, ME 9141. Gunung Batu: *ME 0329. Distribution in Borneo. SARAWAK: Kuching and Serian Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest.

Opisthostoma planiapex Vermeulen, 1991

Figure 4.10A

Opisthostoma planiapex Vermeulen 1991: 145-147, figure 3C.

Type locality. “SARAWAK. 1st Div.: G. Kapur 6 km SE. of Bau”. Materials examined. Gunung Kapor: *ME 0263, *ME 0352, *ME 8483, ME 9205, ME 9250, ME 9267. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. None. Endemic to Borneo. Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest.

Opisthostoma simile Vermeulen, 1994

Figure 4.10B

Opisthostoma (*Opisthostoma*) *simile* Vermeulen 1994: 96, figure 15A-B, 67.

Type locality. “SARAWAK. 1st Div.: G. Lelat 1-mile SW. of Nyabet, 24 miles SSE. of Kuching”. Materials examined. Gunung Kapor: ME 9598, ME 11471, ME 11478. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. None. Endemic to Borneo. Remarks. No live specimen was found during the surveys

***Opisthostoma tridens* Vermeulen, 1991**

Figure 4.10C

Opisthostoma tridens Vermeulen 1991: 152, figure 5C-D.

Type locality. “SARAWAK. 1st Div.: Kpg. Beratok along road Kuching-Serian”. Materials examined. Gunung Kapor: *ME 0333. Distribution in Borneo. SARAWAK: Kuching and Serian Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. No live specimen was found during the surveys.

Genus *Plectostoma* H. Adams, 1865

***Plectostoma austeni* (E. A. Smith, 1894)**

Figure 4.11A, 4.47C

Opisthostoma austeni Smith 1894a: 272-273.

Type locality. “Rumbang, Sarawak” [= Rumbang Hills, Padawan, Sarawak]. Materials examined. Gunung Doya: *ME 0248, ME 9013, ME 9244. Gunung Kapor: *ME 0255. Lobang Angin: *ME 0250, ME 8734, ME 8744, ME 9180. Gunung Batu: *ME 0249, *ME 0253, *ME 0259, *ME 8794. Distribution in Borneo. SARAWAK: Kuching and Serian Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. The living snails were observed dwelling inside the rock crevices and cave walls, away from direct exposure to light. Single sinistral shell was found within the normal sinistroid populations.

Plectostoma everetti (Smith, 1893)

Figure 4.11B, 4.47D

Opisthostoma everetti Smith 1893: 346-347, plate 25, figure 12-12A.

Type locality. “Jambusan, N.W. Borneo” [= Jambusan Hills, Bau, Sarawak]. Materials examined. Gunung Doya: ME 8900, ME 9012, ME 9158. Gunung Batu: *ME 0219, *ME 0222, *ME 2834, *ME 8793. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. None. Endemic to Borneo. Remarks. The living snails were observed dwelling on the moderately wet vertical limestone rock surfaces covered with mosses and lichens.

Plectostoma margaretchanae Marzuki, Liew & Mohd-Azlan, 2021

Figure 4.11C, 4.12

Plectostoma margaretchanae Marzuki et al. 2021: 30-32.

Type locality. “Malaysia, Sarawak, Kuching Division, Gunung Batu, limestone hill along Skio road, Jambusan, 2.4 miles E Bau, 1.3974028, 110.1888861”. Materials examined. Gunung Batu: *MZU.MOL.20.04, *ME0000227, *ME0000217. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. None. Endemic to Borneo. Remarks. It is different from other Bornean *Plectostoma* species by having a tiny shell, long projecting tuba, free from the spire, and constriction with a transverse palatalis and transverse basalis. It is most similar to *P. pyrgiscus* (Vermeulen, 1994) and *P. tuba* (Vermeulen, 1994) but *P. pyrgiscus* has higher spire of six whorls with widely spaced radial ribs, while *P. tuba* also has higher spire without spiral striation, and with double peristome.

Plectostoma wallacei busauense **(Smith, 1893)**

Figure 4.11D

Opisthostoma busauense Smith 1893: 348, plate 25, figure 16-16A.

Type locality. “Busau, N.W. Borneo” [= Jambusan Hills, Bau, Sarawak]. Materials examined. Bukit Sekunyit: *ME 2145. Gunung Doya: ME 9495. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. None. Endemic to Borneo. Remarks. The living snails were observed dwelling on the wet vertical limestone rock surfaces covered with mosses and lichens.

Plectostoma wallacei teinostoma **(Vermeulen, 1994)**

Figure 4.11E

Opisthostoma (*Plectostoma*) *wallacei teinostoma* Vermeulen 1994: 129, figure 59A-B, 71.

Type locality. “SARAWAK. 1st Div.: G. Pangga 3 km ENE. of Bau”. Materials examined. Gunung Doya: *ME 0716, ME 8899, ME 9031, ME 9085. Gunung Kapor: *ME 0234, *ME 5972, ME 9204, ME 9213, ME 9251, *ME 9842. Gunung Batu: *ME 0226, *ME 0229, *ME 0703, *ME 8795. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. None. Endemic to Borneo. Remarks. The living snails were observed dwelling on the wet vertical limestone rock surfaces covered with mosses and lichens. Shells from Jambusan areas are very similar to *Plectostoma dancei dispersum* (Vermeulen, 1994) but differ by having a deep red colour shell and fine spiral striation on the shell surface.

***Plectostoma wallacei wallacei* Ancey, 1887**

Figure 4.11F, 4.47B

Plectostoma wallacei Ancey 1887: 276-277.

Type locality. “Borneo”. Materials examined. Gunung Doya: *ME 0239, *ME 9697. Gunung Kapor: *ME 0218, *ME 0240, *ME 0242, *ME 0243, *ME 0244, *ME 2915, *ME 8066, *ME 8482, ME 8759, ME 8767, ME 8780. Lobang Angin: *ME 0246, ME 8730, ME 8733, ME 8743. Gunung Batu: *ME 0245, *ME 0247. Gunung Stulang: *ME 5898. Kampung Padang Pan: *ME 6669. Distribution in Borneo. SARAWAK: Kuching and Serian Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. The living snails

were observed dwelling on the wet vertical limestone rock surfaces covered with mosses and lichens.

Family Pupinidae L Pfeiffer, 1853

Genus *Pupina* Vignard, 1829

***Pupina doriae* Godwin-Austen, 1889**

Figure 4.13A

Pupina doriae Godwin-Austen 1889: 351, plate 39, figure 2, 2A-B.

Type locality. "Busan Hills, Borneo" [= Jambusan Hills, Bau, Sarawak]. Materials examined. Gunung Doya: *ME 1114, ME 8946, ME 9112. Gunung Kapor: *ME 1116, ME 9234. Gunung Batu: *ME 1115, *ME 1121, *ME 8809. Distribution in Borneo. SARAWAK: Kuching and Serian Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest. It is different from other Bornean *Pupina* species by having a smaller pearly white shell with a wide notch near the sutural margin.

***Pupina evansi* Godwin-Austen, 1889**

Figure 4.13B, 4.48D

Pupina evansi Godwin-Austen 1889: 351-352, plate 39, figure 3, 3A.

Type locality. “From deposit in Cave A, Borneo” [= Tupak Cave, Jambusan Hills (Cranbrook, 2013)]. Materials examined. Gunung Sebayat: *ME 8006. Gunung Doya: *ME 1129. Gunung Kapor: *ME 1127, *ME 1130, ME 8786, ME 9254. Lobang Angin: ME 9053, ME 9203. Distribution in Borneo. SARAWAK: Kuching Division. SABAH: West Coast Division (?). Distribution elsewhere. Sirhassen, Natuna Islands (Smith 1894b). Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest. It is different from other Bornean *Pupina* species by having an intermediate size, globose, pale brown shell with a narrow notch near the sutural margin.

Pupina hosei **Godwin-Austen, 1889**

Figure 4.13C

Pupina hosei Godwin-Austen 1889: 351, plate 39, figure 1, 1A.

Type locality. “Busan Hills, Borneo” [= Jambusan Hills, Bau, Sarawak]. Materials examined. Gunung Batu: *ME 1132, *ME 1134. Distribution in Borneo. SARAWAK: Kuching and Miri Divisions. SABAH: Sandakan Division. Distribution elsewhere. Balabac and Palawan in Phillipines (Kobelt and Möllendorff 1897). Remarks. No live specimen was found during the surveys. It is different from other Bornean *Pupina* species by having a larger high spire dark brown shell with a wide notch near the sutural margin.

Genus *Rhaphaulus* L. Pfeiffer, 1856

Rhaphaulus bombycinus **(L. Pfeiffer, 1855)**

Figure 4.13D

Anaulus bombycinus Pfeiffer 1855: 105-106, plate 32, figure 10.

Type locality. “Borneo, Sarawak”. Materials examined. Gunung Kapor: *ME 1098, *ME 1099, *ME 3358, ME 9017, ME 9215. Lobang Angin: ME 9556. Gunung Batu: *ME 1100, *ME 1103. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. None. Endemic to Borneo. Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest. See remarks under *Rhaphaulus pfeifferi* (Issel, 1874).

***Rhaphaulus pfeifferi* Issel, 1874**

Figure 4.13E

Raphaulus pfeifferi Issel 1874: 443-444, plate 7, figure 4-6.

Type locality. “Territorio di Sarawak”. Materials examined. Lobang Angin: ME 9556. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. None. Endemic to Borneo. Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest. It is different from *R. bombycinus* by having a smaller shell with less oblique spire and with a more spreading sutural tube.

Family Assimineidae H. Adams & A. Adams, 1856

Genus *Acmella* W. T. Blanford, 1869

Acmella bauensis Marzuki, Liew & Mohd-Azlan, 2021

Figure 4.14A, 4.15A-E, 4.16A-C

Acmella bauensis Marzuki et al. 2021: 37.

Type locality. "Malaysia, Sarawak, Kuching Division, Fairy Caves, south part of Gunung Kapor, 4 miles Southwest Bau, 1.3816583, 110.1173028". Materials examined. Gunung Kapor: *MZU.MOL.20.01, *ME0002340. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. None. Endemic to Borneo. Remarks. This species differs from other Bornean *Acmella* species by having dull shell surface with inconspicuous, closely spaced spiral striae crossed by inconspicuous growth lines. *Acmella conica* Vermeulen & Junau, 2007 and *Acmella obtusa* Vermeulen & Junau, 2007, both from Central Sarawak, have a smaller shell with an elliptic aperture with a flattened parietal side. *Acmella minuttisima* (Maassen, 2000), from Sumatra, and *Acmella subcancellata* Vermeulen, Liew & Schilthuizen, 2015, from Sabah have more prominent spiral striae on the shell surface.

Acmella cyrtoglyphe Vermeulen, Liew & Schilthuizen, 2015

Figure 4.14B

Acmella cyrtoglyphe Vermeulen et al. 2015: 7-9, figure 1A-D.

Type locality. "Malaysia, Sabah, Interior Province, Sepulut valley, Gua Sanaron". Materials examined. Gunung Doya: ME 8960. Distribution in Borneo. SABAH: Interior, Sandakan

and Tawau Divisions. SARAWAK: Kuching Division. KALIMANTAN: Exact location was not mentioned in Vermeulen et al. (2015). Distribution elsewhere. No record. Endemic to Borneo. Remarks. No live specimen was found during the surveys.

Acmella nana Vermeulen, Liew & Schilthuizen, 2015

Figure 4.14C, 4.16D-E

Acmella nana Vermeulen et al. 2015: 14, figure 5A-D.

Type locality. "Malaysia, Sarawak, 4th Division, Niah Caves, Southside of limestone area, West side of the quarry, soil-filled crevice opened in quarry". Materials examined. Gunung Kapor: *ME 8497. Gunung Doya: ME 9091. Distribution in Borneo. SARAWAK: Kuching and Miri Divisions. SABAH: Interior and Sandakan Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. No live specimen was found during the surveys. The shells from Bau population are larger than the description of the type specimen (Height 0.88 mm. Width 0.76 mm).

Acmella ovoidea Vermeulen, Liew & Schilthuizen, 2015

Figure 4.14D

Acmella ovoidea Vermeulen et al. 2015: 12-13, figure 4A-D.

Type locality. "Malaysia, Sabah, Interior Province, Pinangah valley, Batu Urun (= Bukit Sinobang)". Materials examined. Gunung Doya: ME 9103, ME 9104. Gunung Kapor: *ME

1889, *ME 8148, ME 9000, ME 9178, ME 9408. Kampung Padang Pan: *ME 6673. Lobang Angin: *ME 1081. Gunung Batu: *ME 2215. Distribution in Borneo. SABAH: Interior, Sandakan and Tawau Divisions. SARAWAK: Kuching and Serian Divisions. KALIMANTAN: East Kalimantan Province. Distribution elsewhere. None. Endemic to Borneo. Remarks. No live specimen was found during the surveys.

Genus *Anaglyphula* B. Rensch, 1932

***Anaglyphula sauroderma* Vermeulen, Liew & Schilthuizen, 2015**

Figure 4.14E

Anaglyphula sauroderma Vermeulen et al. 2015: 18, figure 8A-D.

Type locality. "Malaysia, Sabah, Tawau Province, Batu Baturong c. 50 km W.S.W. of Lahad Datu". Materials examined. Gunung Doya: ME 9143. Gunung Batu: *ME 2141. Distribution in Borneo. SARAWAK: Kuching Division. SABAH: Tawau Division. KALIMANTAN: East Kalimantan Province. Distribution elsewhere. None. Endemic to Borneo. Remarks. This is the first record of this species in Sarawak. The living snails were observed dwelling on wet rotten wood surfaces at the base of the limestone cliff.

Genus *Solenomphala* Heude, 1882

***Solenomphala scalaris* (Heude, 1882)**

Figure 4.14F

Assiminea (*Solenomphala*) *scalaris* Heude 1882: 83-84, plate 21, figure 5, 5a-c.

Type locality. “Ad parietes humidos in civitate Chang-hai sat copiosa” [=Shanghai, China]. Materials examined. Gunung Kapor: *ME 8091, ME 9231. Gunung Batu: *ME 2216, *ME 2339, ME 8810. Distribution in Borneo. SARAWAK: Kuching, Samarahan, and Mukah Divisions. Distribution elsewhere. East to Southeast Asia (Fukuda and Ponder 2003). Remarks. This amphibious snail is an introduced species because all the known records were found in the damp area among human settlements (Chan, 1997; this study). The shell form is similar to *Cyclotropis bollingi* Brandt, 1974, but differs by having fine spiral sculptures.

Family Hydrocenidae Troschel, 1857

Genus *Georissa* W. T. Blanford, 1864

***Georissa bauensis* Khalik, Hendriks, Vermeulen & Schilthuizen, 2018**

Figure 4.17A, 4.49A

Georissa bauensis Khalik et al. 2018: 42.

Type locality. “Wind Cave Passage 3, Wind Cave Nature Reserve, Bau, Sarawak, Malaysia”. Materials examined. Lobang Angin: *ME 0908, ME 8731, ME 8736. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. None. Endemic to Borneo. Remarks. The living snails were observed dwelling on the wet vertical limestone rock surfaces covered with mosses and lichens.

Georissa everetti Smith, 1895

Figure 4.17B

Georissa everetti Smith 1895: 125, plate 4, figure 15.

Type locality. “Rumbang, W. Sarawak” [Rumbang Hills, Padawan, Sarawak]. Materials examined. Gunung Batu: *ME 0906. Distribution in Borneo. SARAWAK: Kuching and Miri Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. No live specimen was found during the surveys.

Georissa hosei Godwin-Austen, 1889

Figure 4.17C

Georissa hosei Godwin-Austen 1889: 353, plate 39, figure 11.

Type locality. “Borneo”. Materials examined. Gunung Doya: *ME 1478. Gunung Kapor: *ME 8498. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. None. Endemic to Borneo. Remarks. No live specimen was found during the surveys.

Georissa hungerfordi Godwin-Austen, 1889

Figure 4.17D

Georissa hungerfordi Godwin-Austen 1889: 354, plate 39, figure 9.

Type locality. “Borneo”. Materials examined. Gunung Kapor: *ME 11472. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. None. Endemic to Borneo. Remarks. No live specimen was found during the surveys.

Georissa leucococca **Vermeulen, Liew & Schilthuizen, 2015**

Figure 4.17E

Georissa leucococca Vermeulen et al. 2015: 33, figure 19A-B.

Type locality. “Malaysia, Sabah, Interior Province, Sepulut valley, Gua Pungiton”. Materials examined. Gunung Doya: ME 9701, ME 9496. Distribution in Borneo. SARAWAK: Kuching and Serian Divisions. SABAH: Interior and Tawau Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. No live specimen was found during the surveys.

Family Achatinellidae Gulick, 1873

Genus *Elasmias* Pilsbry, 1910

Elasmias sundanum **(Möllendorff, 1897)**

Figure 4.18A

Tornatellina sundana Möllendorff 1897a: 90.

Type locality. “Java” [= Java island, Indonesia]. Materials examined. Kampung Padang Pan: *ME 6828. Lobang Angin: ME 8982. Distribution in Borneo: SARAWAK: Kuching and Serian Divisions. Distribution elsewhere: Sumatra to Java (van Benthem-Jutting 1952) Remarks. This is the first record of this species in Borneo. No live specimen was found during the surveys.

Family Achatinidae Swainson, 1840

Genus *Lissachatina* Bequaert, 1950

***Lissachatina fulica* (Bowdich, 1822)**

Figure 4.18B

Achatina fulica Bowdich 1822: plate 13, figure 3.

Type locality. “L’ile de France”. Materials examined. Gunung Doya: ME 8920, ME 9228. Gunung Kapor: *ME 8507, ME 9016, ME 9241. Distribution in Borneo. SARAWAK: Kuching, Samarahan, Serian, Sibu, Mukah and Miri Divisions. SABAH: Kudat, West Coast, Interior, Sandakan and Tawau Divisions. KALIMANTAN. Distribution elsewhere. Circumtropical (Vermeulen and Whitten 1998). Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest. Introduced species. The species was firstly introduced into Sarawak in 1928 as poultry food, and became pest a following year later (Jarrett 1931). Apparently widespread throughout Borneo.

Genus *Allopeas* Baker, 1935

Allopeas clavulinum (Potiez & Michaud, 1838)

Figure 4.19A

Bulimus clavulinus Potiez & Michaud 1838: 136.

Type locality. “L’ile Bourbon” [= Reunion island]. Materials examined. Gunung Sebayat: *ME 8013. Gunung Doya: *ME 2905, ME 9704, ME 8928, ME 8948, ME 9036. Gunung Kapor: *ME 0753, *ME 2877, *ME 2948, *ME 8506, ME 9043, ME 9229, ME 9248. Lobang Angin: ME 9105, ME 9276. Gunung Batu: *ME 2835, *ME 2841, *ME 2870, *ME 8821. Distribution in Borneo. SARAWAK: Kuching, Serian, Sibu and Miri Divisions. SABAH: Interior, Sandakan, Tawau and West Coast Divisions. Distribution elsewhere. Circumtropical (Vermeulen and Whitten 1998). Remarks. The animal observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest. Introduced species. Widespread throughout Borneo.

Allopeas gracile (T. Hutton, 1834)

Figure 4.19B, 5.53B

Bulimus gracilis Hutton 1834: 84-85, 93.

Type locality. “Mirzapoor, India” [= Mirzapur, Uttar Pradesh, India]. Materials examined. Gunung Doya: ME 8929, ME 8949, ME 9035. Gunung Kapor: *ME 0312, *ME 1229, *ME 2942, *ME 2943, *ME 8149, *ME 8504, ME 8970, ME 9011, ME 9069. Kampung Padang

Pan: *ME 6681. Lobang Angin: ME 9135, ME 9263. Gunung Batu: *ME 2842, *ME 2866, *ME 8822. Distribution in Borneo. SARAWAK: Kuching, Serian, Mukah and Miri Divisions. SABAH: Interior, Kudat, Sandakan, Tawau and West Coast Divisions. KALIMANTAN: West Kalimantan Province. Distribution elsewhere. Circumtropical (Vermeulen and Whitten 1998). Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest. Introduced species. Widespread throughout Borneo.

Genus *Opeas* Albers, 1850

***Opeas hannense* (Rang, 1831)**

Figure 4.19C

Helix (*Cochlicella*) *hannensis* Rang 1831: 41-42, plate 3, figure 8.

Type locality. “Cap-Verd” [= Cape Verde]. Materials examined. Gunung Kapor: ME 9096, ME 9237. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. Circumtropical (Vermeulen and Liew 2022) Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest.

Genus *Paropeas* Pilsbry, 1906

***Paropeas achatinaceum* (Pfeiffer, 1846)**

Figure 4.19D, 4.53A

Bulimus achatinaceus Pfeiffer 1846a: 82.

Type locality. “Java” [= Java island, Indonesia]. Materials examined. Gunung Kapor: *ME 2876, *ME 2878, *ME 2946, *ME 2951, *ME 5977, *ME 8086, *ME 8505, ME 8785, ME 8964. Lobang Angin: ME 8983, ME 9172, ME 9269. Gunung Batu: *ME 8823. Distribution in Borneo. SARAWAK: Kuching, Serian, Kapit and Miri Divisions. LABUAN. SABAH: Sandakan and West Coast Divisions. KALIMANTAN: West Kalimantan Province. Distribution elsewhere. South to East Asia, South-east Asia, Pacific Islands (Naggs 1994; Vermeulen and Whitten 1998). Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest. Widespread throughout Borneo.

Family Diapheridae Panha & Naggs, 2010

Genus *Platycochlium* Laidlaw, 1950

***Platycochlium sarawakense* Laidlaw, 1950**

Figure 4.20A

Platycochlium sarawakense Laidlaw 1950: 370-372, figure 1A-B.

Type locality. “Gunong Kapor, Bau District, Sarawak”. Materials examined. Gunung Doya: *ME 2906, ME 8930, ME 8950, ME 8993. Gunung Kapor: *ME 8150, *ME 8503, ME 9050. Gunung Batu: *ME 2838, *ME 2843, *ME 2871, *ME 8819. Distribution in Borneo. SARAWAK: Kuching and Serian Divisions. Distribution elsewhere. None. Endemic to

Borneo. Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest.

Family Streptaxidae Gray, 1860

Genus *Gulella* L. Pfeiffer, 1856

***Gulella bicolor* (Hutton, 1834)**

Figure 4.20B

Pupa bicolor Hutton 1834: 86, 93.

Type locality. “Mirzapoor, India” [= Mirzapur, Uttar Pradesh, India]. Materials examined. Gunung Kapor: ME 9095. Distribution in Borneo. SABAH: Interior, Kudat, Tawau and West Coast Divisions. SARAWAK: Kuching, Samarahan, Serian, Sibu and Miri Divisions. Distribution elsewhere. South to East Asia, Malay Archipelago (Vermeulen and Whitten 1998). Remarks. No live specimen was found during the surveys. Introduced species.

Family Succineidae Beck, 1837

Genus *Succinea* Draparnaud, 1801

***Succinea obesa* Martens, 1867**

Figure 4.20C

Succinea obesa Martens 1867: 387, plate 22, figure 21.

Type locality. “Oestliches Java, am See von Grati bei Passuruan gesammelt” [= Ranu Grati Lake, near Pasuruan, eastern Java, Indonesia]. Materials examined. Gunung Batu: *ME 2903, *ME 8820. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. Sumatra, Java and Madura (van Benthem-Jutting 1952). Remarks. No live specimen was found during the surveys. The shells from Bau are tally to the descriptions of *Succinea obesa* Martens, 1867 sensu van Benthem-Jutting (1952). Two other species, namely, *Succinea borneensis* Pfeiffer, 1853 and *Succinea subrugata* Pfeiffer, 1853, were described from Borneo. However, the original descriptions of the two species were not detailed enough for species identification.

Family Ariophantidae Godwin-Austen, 1883

Genus *Damayantia* Issel, 1874

***Damayantia carinata* Collinge, 1901**

Figure 4.21A, 4.50A

Damayantia carinata Collinge 1901: 298-299, plate 1, figure 4-5 and plate 2, figure 22-23.

Type locality. “Kuching, Mt. Penrissen, and Mt. Santubong, N.W. Borneo”. Materials examined. Gunung Doya: ME 8922. Lobang Angin: ME 9054. Distribution in Borneo. SARAWAK: Kuching and Sibu Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. It is an arboreal semi-slug which also found in lowland peat swamp forest.

Genus *Hemiplecta* Albers, 1850

***Hemiplecta densa* (A. Adams & Reeve, 1850)**

Figure 4.21B, 4.50C

Helix densa Adams & Reeve 1850: 62, plate 16, figure 8.

Type locality. “Philippine Islands”. Materials examined. Gunung Doya: ME 8892, ME 9160. Gunung Kapor: *ME 2581, *ME 4723, *ME 4724, *ME 5971, *ME 8079, ME 8791, ME 9243. Gunung Stulang: *ME 5907. Kampung Padang Pan: *ME 6674. Lobang Angin: ME 9485. Gunung Batu: *ME 4725, *ME 4726, *ME 8833. Distribution in Borneo. SARAWAK: Kuching Division. LABUAN. SABAH: Sandakan Division. KALIMANTAN: West Kalimantan and East Kalimantan Provinces. Distribution elsewhere. Philippines, Java and Sumatra (Mousson 1857; Smith 1895). Remarks. Further study is needed to clarify the taxonomic status of this species together with *Hemiplecta humpreysiana* (I. Lea, 1840).

Genus *Macrochlamys* Gray, 1847

***Macrochlamys infans* (L. Pfeiffer, 1854)**

Figure 4.21C

Helix infans Pfeiffer 1854a: 290.

Type locality. “Sarawak, Borneo”. Materials examined. Gunung Batu: *ME 1858, *ME 2854. Distribution in Borneo. SARAWAK: Kuching Division. LABUAN. Distribution

elsewhere. None. Endemic to Borneo. Remarks. No live specimen was found during the surveys. It is different from *Macrochlamys tersa* (Issel, 1874) by having a white shell without spiral sculpture or only with very fine spiral grooves. The taxonomic status and occurrence of *M. infans* in Java and Bali were discussed in Vermeulen (1996).

Macrochlamys sanctijohni **(Godwin-Austen, 1891)**

Figure 4.21D

Microcystina st.johni Godwin-Austen 1891: 38, plate 4, figure 3-3A.

Type locality. "Busan Hills, Borneo" [=Jambusan Hills, Bau, Sarawak]. Materials examined. Gunung Sebayat: *ME 8011. Gunung Doya: *ME 3053, ME 9111, ME 9184. Gunung Kapor: *ME 3850, *ME 8509, ME 9208, ME 9240, ME 9900. Gunung Batu: *ME 2837. Distribution in Borneo. SARAWAK: Kuching Division. SABAH: West Coast Division (?). Distribution elsewhere. Palawan (Smith 1895). Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest. It is different from other Bornean *Macrochlamys* species by having a small reddish-brown shell with well-spaced fine spiral grooves.

Macrochlamys tersa **(Issel, 1874)**

Figure 4.21E, 4.50B

Nanina (*Macrochlamys*) *tersa* Issel 1874: 399-400, plate 5, figure 1-4.

Type locality. “Borneo”. Materials examined. Gunung Doya: ME 8936, ME 8957, ME 9037. Gunung Kapor: *ME 2880, *ME 2882, *ME 2945, *ME 3040, *ME 8089, *ME 8771, ME 8966, ME 9048, ME 9620. Kampung Padang Pan: *ME 6680. Lobang Angin: ME 9142, ME 9152, ME 9272. Gunung Batu: *ME 1858, *ME 2855, *ME 2868, ME 8827. Distribution in Borneo. SARAWAK: Kuching, Serian and Miri Divisions. SABAH: Kudat, West Coast, Interior and Tawau Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest. It is different from other Bornean *Macrochlamys* species by having a moderate size pale brown shell with closely spaced very fine spiral grooves.

Genus *Microcystina* Mörch, 1872

***Microcystina arabii* Marzuki, Liew & Mohd-Azlan, 2021**

Figure 4.22A, 4.23A-F

Microcystina arabii Marzuki et al. 2021: 53-56.

Type locality. “Malaysia, Sarawak, Kuching Division, Bukit Sokwang (Site 2), northern site of Gunung Doya, limestone hill along Skio road, 2.05 miles E Bau, 1.3954694, 110.1764”. Materials examined. Gunung Doya: MZU.MOL.20.06, ME 9154, ME 9165, ME 9168. Gunung Batu: *ME 2899, *ME 1757, *ME 8889. Gunung Kapor: *ME 2899, *ME 1762. Gunung Lobang Angin: ME 11489. Distribution in Borneo. SARAWAK: Kuching and

Serian Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. It is different from *Microcystina sinica* Möllendorff, 1885, *Microcystina oswaldbrakeni* Marzuki, Liew & Mohd-Azlan, 2021, and *Microcystis bunguranensis* Smith, 1894 by having cancellated sculpture on the shell surface. The shells of this species display high variability in terms of colour and height/width ratio.

***Microcystina atoni* Marzuki, Liew & Mohd-Azlan, 2021**

Figure 4.22B, 4.24A-F

Microcystina atoni Marzuki et al. 2021: 56-58.

Type locality. "Malaysia, Sarawak, Kuching Division, Gunung Batu, limestone outcrop along Skio road, Jambusan, 2.4 miles E Bau, 1.3974028, 110.1888861". Materials examined. Gunung Batu: *MZU.MOL.20.10, *MZU.MOL.20.11, *ME 9903. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. None. Endemic to Borneo. Remarks. It is similar to *Microcystina chionodiscus* Vermeulen, 1996 and *Microcystina striatula* Vermeulen, Liew & Schilthuizen, 2015, in terms of the shell shape, but it does not have the spiral striation on the protoconch and teleoconch. It is also different from *Microcystina microrhynchus* Vermeulen, Liew & Schilthuizen, 2015, and *Microcystina kilat* Marzuki, Liew, & Mohd-Azlan, 2021, by lacking shell grooves radial sculptures with an open but narrow umbilicus.

***Microcystina kilat* Marzuki, Liew & Mohd-Azlan, 2021**

Figure 4.22C, 4.25A-F

Microcystina kilat Marzuki et al. 2021: 58-60.

Type locality. "Malaysia, Sarawak, Kuching Division, Lobang Angin (Site 2), limestone outcrop near Sungai Sarawak Kanan, 1.75 miles W of Bau, 1.4141694, 110.13708". Materials examined. Gunung Lobang Angin: MZU.MOL.20.18, ME 9430, ME 1764, ME 9273. Gunung Doya: ME 9898, ME 9897, ME 8943. Gunung Kapor: *ME 1829, ME 9895, ME 8088, ME 9902, ME 9899, ME 9646, ME 9001. Gunung Batu: *MZU.MOL.20.19, *ME 9904, *ME 1767. Distribution in Borneo. SARAWAK: Kuching and Serian Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. It is different from *Microcystina callifera* Vermeulen, Liew & Schilthuizen, 2015, by having a shell without spiral sculpture. A shell with an umbilicus that entirely covered by callus separates this species with *Microcystina microrhynchus* Vermeulen, Liew & Schilthuizen, 2015, from Sabah.

***Microcystina lirata* Marzuki, Liew & Mohd-Azlan, 2021**

Figure 4.22D, 4.26A-F

Microcystina lirata Marzuki et al. 2021: 60-62.

Type locality. "Malaysia, Sarawak, Kuching Division, Buddha Caves (Site 3), north part of Gunung Kapor, 3 miles SW Bau, 1.3906972, 110.11945". Materials examined. Gunung Kapor: MZU.MOL.20.14, MZU.MOL.20.15, ME 9214, ME 8979, ME 9235. Padang Pan:

*ME 6721. Gunung Doya: ME 8774. Lobang Angin: ME 9166. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. None. Endemic to Borneo. Remarks. It is different from *Microcystina circumlineata* (Möllendorff, 1897) by having a smaller white shell with somewhat punctured-like secondary spiral grooves in between moderately spaced spiral threads.

***Microcystina oswaldbrakeni* Marzuki, Liew & Mohd-Azlan, 2021**

Figure 4.27A, 4.28A-F

Microcystina oswaldbrakeni Marzuki et al. 2021: 62-64.

Type locality. "Malaysia, Sarawak, Kuching Division, Bukit Sokwang (Site 2), northern site of Gunung Doya, limestone hill along Skio road, 2.05 miles E Bau, 1.3954694, 110.1764". Materials examined. Gunung Doya: *MZU.MOL.20.16, *MZU.MOL.20.17, *ME 2268, *ME 1751. Gunung Batu: *ME 1758, *ME 3275, *ME 8818, *ME 10295. Gunung Kapor: *ME 7194, ME 10478, ME 11473. Gunung Sebayat: *ME 8012. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. None. Endemic to Borneo. Remarks. It is different from *Microcystina seclusa* Godwin-Austen, 1891 by having a smaller shell with silky surfaces that covered by well-spaced faint spiral grooves and a closed umbilicus and. This species also similar to *Microcystina arabii* Marzuki, Liew, & Mohd-Azlan, 2021, see the remark under that species.

***Microcystina paripari* Marzuki, Liew & Mohd-Azlan, 2021**

Figure 4.27B, 4.29A-F

Microcystina paripari Marzuki et al. 2021: 65-66.

Type locality. “Malaysia, Sarawak, Kuching Division, Bukit Sokwang (Site 2), northern site of Gunung Doya, limestone hill along Skio road, 2.05 miles E Bau, 1.3954694, 110.1764”. Materials examined. Gunung Kapor: MZU.MOL.20.12, MZU.MOL.20.13, ME 9647, ME 9329, *ME 3845, ME 9469, *ME 8510, *ME 1761, ME 9044. Gunung Doya: *ME 1749, ME 9677. Gunung Batu: *ME 783, *ME 1746. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. None. Endemic to Borneo. Remarks. It is different from *Microcystina muscorum* van Benthem-Jutting, 1959 and *Microcystina gratilla* van Benthem-Jutting, 1950 by having a shell without spiral striation on both protoconch and teleoconch.

***Microcystina physotrochus* Vermeulen, Liew & Schilthuizen, 2015**

Figure 4.27C

Microcystina physotrochus Vermeulen et al. 2015: 57-59, figure 37A-C.

Type locality. “Malaysia, Sabah, Sandakan Province, Kinabatangan Valley, Batu Keruak 2, near Sukau”. Materials examined. Gunung Doya: ME 8953. Gunung Kapor: *ME 2262, *ME 2264, *ME 2265, *ME 2266, ME 9072, ME 9098, ME 9256. Lobang Angin: ME 9174. Gunung Batu: *ME 2263. Distribution in Borneo. SARAWAK: Kuching, Bintulu and Miri Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. The living snails

were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest.

Microcystina seclusa Godwin-Austen, 1891

Figure 4.27D

Microcystina seclusa Godwin-Austen 1891: 38.

Type locality. “Borneo, cave-earth”. Materials examined. Gunung Doya: ME 8933, ME 8954. Gunung Kapor: ME 8153, ME 9209. Gunung Batu: *ME 0439, *ME 2261. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. None. Endemic to Borneo. Remarks. No live specimen was found during the surveys. It is different from *Microcystis bunguranensis* Smith, 1894 from Natuna Island by having a larger and higher spire shell (Smith 1894b).

Genus *Vitrinula* Gray, 1857

Vitrinula glutinosa (Metcalfe, 1851)

Figure 4.21F, 4.50D

Helix glutinosa Metcalfe 1851: 70-71.

Type locality. “Borneo”. Materials examined. Gunung Doya: *ME 1620, ME 8915, ME 9114. Gunung Kapor: *ME 1617, *ME 1618, *ME 1619, *ME 8080, *ME 8508, ME 8782, ME 8967, ME 9407. Kampung Padang Pan: *ME 6675. Lobang Angin: ME 8728, ME 8750,

ME 9023. Gunung Batu: *ME 1621, *ME 4785, *ME 4983, *ME 8832. Distribution in Borneo. SARAWAK: Kuching, Sibu, Mukah, Kapit and Miri Divisions. KALIMANTAN: West Kalimantan Province. Distribution elsewhere. None. Endemic to Borneo. Remarks. This species exhibits high variability in shell form, ranging from high to low spire, and in colour from pale to dark brown.

Family Camaenidae Pilsbry, 1895

Genus *Bradybaena* Beck, 1837

***Bradybaena similaris* (Férussac, 1822)**

Figure 4.30A

Helix (*Helicigona*) *similaris* Férussac 1822: 43.

Type locality. "Timor". Materials examined. Bukit Sekunyit: *ME 4905. Gunung Batu: *ME 4906, *ME 8828. Distribution in Borneo. SABAH: Interior, West Coast, Kudat and Sandakan Divisions. SARAWAK: Kuching, Samarahan, Sibu, Mukah, Kapit and Miri Division. Distribution elsewhere. Southeast mainland Asia to Indo-Australian archipelago, South America (Reeve 1851; Vermeulen and Whitten 1998). Remarks. Probably introduced species. The species is only known from disturbed habitat.

Genus *Chloritis* Beck, 1837

***Chloritis tomentosa* (L. Pfeiffer, 1854)**

Figure 4.30B

Helix tomentosa Pfeiffer 1854a: 289-290.

Type locality. “Sarawak, Borneo”. Materials examined. Gunung Doya: ME 8917, ME 9164. Gunung Kapor: *ME 1532, *ME 1549, *ME 8077, ME 9266. Kampung Padang Pan: *ME 6683. Gunung Batu: *ME 1540, *ME 1547, *ME 1548. Distribution in Borneo. SARAWAK: Kuching Division. LABUAN: Kuraman Island. SABAH: Kudat and West Coast (?) Division. Distribution elsewhere. Sumatra (?) (Bock 1881; van Benthem-Jutting 1959). Remarks. No live specimen was found during the surveys. This species is different from *Bradybaena similaris* (Férussac, 1822) by having very fine hair pits that cover the shell surfaces and a slightly angular peristome between columellar and basal sides.

Genus *Landouria* Godwin-Austen, 1918

***Landouria winteriana* (L. Pfeiffer, 1842)**

Figure 4.30C

Helix winteriana Pfeiffer in Philippi 1842: pp. 23 (7), plate 2, figure 7.

Type locality. “Java” [= Java island, Indonesia]. Materials examined. Bukit Sekunyit: *ME 1580. Gunung Kapor: *ME 1579, *ME 1583, *ME 1584, *ME 5979, *ME 8078, ME 8778, ME 9226. Lobang Angin: ME 9274. Distribution in Borneo. SARAWAK: Kuching and Miri Divisions. Distribution elsewhere. Indo-Australian archipelago (Vermeulen and Whitten

1998). Remarks. The shells from Bau are similar with syntype of *Plectotropis kraepelini* Leschke, 1914, ZMH 98416 [= *Landouria winteriana* (Pfeiffer, 1842)]. For further details, see Nurinsiyah et al. (2019:10-17)

Genus *Ganesella* W. T. Blanford, 1863

***Ganesella acris* (Benson, 1859)**

Figure 4.30D, 4.52B

Helix acris Benson 1859: 387-388.

Type locality. “Teria Ghát montium Khasiæ” [= Khasi Hills, Teria Ghat, India]. Materials examined. Gunung Doya: ME 8916. Gunung Kapor: *ME 1561, *ME 1562, *ME 1564, *ME 1567, *ME 1570, *ME 8512, ME 8773, ME 8963, ME 9041. Kampung Padang Pan: *ME 6682. Lobang Angin: ME 8939, ME 8977. Gunung Batu: *ME 1565. Distribution in Borneo. SARAWAK: Kuching and Miri Divisions. SABAH: Tawau, Sandakan and West Coast Divisions. Distribution elsewhere. South to Southeast Asia mainland, Sumatra to Java (Benson 1859; Crosse 1879; Smith 1887; van Benthem-Jutting 1959). Remarks. The species was originally described from Khasi Hills, India.

Genus *Amphidromus* Albers, 1850

***Amphidromus angulatus* Fulton, 1896**

Figure 4.30E

Amphidromus angulatus Fulton 1896: 84-85, plate 6, figure 3.

Type locality. “Sarawak”. Materials examined. Gunung Doya: ME 8919, ME 9176, ME 9191. Gunung Kapor: *ME 4611, *ME 4632, *ME 8075, ME 8789, ME 9045, ME 9223. Lobang Angin: *ME 4631. Gunung Batu: *ME 4612, *ME 4630. Distribution in Borneo. SARAWAK: Kuching and Miri Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. No live specimen was found during the surveys. This species similar to *Amphidromus thalassochromus* Vermeulen & Junau, 2007, and *Amphidromus coeruleus* Clench & Archer, 1932, in terms of shell shape and colour patterns on shell surface. However, it is different from *A. thalassochromus* by having a rounded last whorl at the periphery and it is different from *A. coeruleus* by having a somewhat obese shell with a short spire.

***Amphidromus epidemiae* Wang, 2021**

Figure 4.30F, 4.52A

Amphidromus epidemiae Wang, 2021: 47, figure 1.

Type locality. “Malaysia, Sarawak State, Kuching Division, Bau, 1° 25’ N, 110° 09’ E”. Materials examined. Gunung Doya: ME 8918, ME 8923. Gunung Kapor: *ME 3724, *ME 4160, *ME 4595, *ME 4596, *ME 4597, *ME 5970, *ME 8076, ME 8752, ME 8756, ME 9242. Gunung Batu: *ME 4599. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. None. Endemic to Borneo. Remarks. This species different from *Amphidromus similis* Pilsbry, 1900, by having a shell with white translucent callus and parietal wall.

Family Chronidae Thiele, 1931

Genus *Kaliella* W. T. Blanford, 1863

***Kaliella barrakporensis* (L. Pfeiffer, 1852)**

Figure 4.31A, 4.51C

Helix barrakporensis Pfeiffer 1852: 156.

Type locality. “Barrakpore, Indiæ” [= Barrackpore, West Bengal, India]. Materials examined. Gunung Doya: ME 8931, ME 8951, ME 9034. Gunung Kapor: *ME 1910, *ME 1926, *ME 8156, ME 8787, ME 9009, ME 9026. Gunung Stulang: *ME 5896. Kampung Padang Pan: *ME 6678. Lobang Angin: ME 8986, ME 9021, ME 9268. Gunung Batu: *ME 1912, *ME 8813. Distribution in Borneo. SARAWAK: Kuching, Serian and Miri Divisions. SABAH: Interior, Sandakan, Tawau and West Coast Divisions. KALIMANTAN. Distribution elsewhere. Africa and South Asia mainland to Indo-Australian archipelago, Europe (Godwin-Austen 1882; Vermeulen and Whitten 1998; Preece and Naggs 2014).

***Kaliella busauensis* (E. A. Smith, 1895)**

Figure 4.31B

Sitala busauensis Smith 1895: 111, plate 3, figure 9.

Type locality. “Busau, Sarawak” [= Jambusan Hills, Bau, Sarawak]. Materials examined. Gunung Sebayat: *ME 8304. Gunung Doya: ME 9702, ME 8990. Gunung Kapor: *ME

1880. Lobang Angin: ME 9259, ME 9264. Gunung Batu: *ME 1868, *ME 1873, *ME 1892. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. None. Endemic to Borneo. Remarks. No live specimen was found during the surveys. It is different from other Bornean *Kaliella* species by having a dark brown higher spire shell with cancellated shell surface due to the prominent spiral grooves and oblique radial riblets.

***Kaliella calculosa* (Gould, 1852)**

Figure 4.31C

Helix calculosa Gould 1852: 48.

Type locality. "Tahiti" [= Tahiti Island, French Polynesia]. Materials examined. Bukit Sekunyit: *ME 1885. Gunung Doya: *ME 1865, ME 8932, ME 8952, ME 8995. Gunung Kapor: *ME 1863, *ME 1898, *ME 1911, ME 8973, ME 9049, ME 9238. Kampung Padang Pan: *ME 6722. Lobang Angin: ME 8747, ME 9177, ME 9259. Gunung Batu: *ME 1866, ME 8816. Distribution in Borneo. SARAWAK: Kuching, Serian and Miri Divisions. SABAH: Interior, Sandakan, Tawau and West Coast Divisions. Distribution elsewhere. South Asia mainland to Indo-Australian archipelago and Pacific Islands (Vermeulen et al. 2015). Remarks. The juvenile shell of this species is similar to *Kaliella barrakporensis* (Pfeiffer, 1852), and *K. busauensis* (Smith, 1895), but it is different from the two species by having a lower conical, brittle, whitish shell with moderately spaced spiral striae above the periphery.

Kaliella doliolum (L. Pfeiffer, 1846)

Figure 4.31D

Helix doliolum Pfeiffer 1846b: 41-42.

Type locality. “Sibonga, island of Zebu” [= Sibonga, Cebu Island, Philippines]. Materials examined. Gunung Kapor: *ME 1851, *ME 1874, *ME 1895, ME 9010, ME 9074, ME 9252. Distribution in Borneo. SARAWAK: Kuching, Serian and Miri Divisions. SABAH: Interior, Kudat, Sandakan, Tawau and West Coast Divisions. Distribution elsewhere. Southeast Asia mainland to Indo-Australian archipelago and Pacific Islands (Vermeulen et al. 2015). Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliffs in lowland limestone forest.

Kaliella microconus (Mousson, 1865)

Figure 4.32A

Nanina microconus Mousson 1865: 192.

Type locality. “Lomma-Lomma (Viti)” [= Loma Loma, Fiji]. Materials examined. Bukit Sekunyit: *ME 1884. Gunung Doya: *ME 1877, *ME 9703, ME 8934, ME 8959, ME 8996. Gunung Kapor: *ME 1860, *ME 1896, *ME 1909, *ME 8154, *ME 8499, ME 8975, ME 9007, ME 9073. Kampung Padang Pan: *ME 6677. Lobang Angin: ME 8738, ME 8987, ME 9146. Gunung Batu: *ME 1855, *ME 1893, *ME 1913, ME 8817. Distribution in Borneo. SARAWAK: Kuching, Serian and Miri Divisions. SABAH: Interior, Kudat, Sandakan, Tawau and West Coast Divisions. KALIMANTAN: South Kalimantan Province.

Distribution elsewhere. South-east Asia to Australia and the Pacific Islands (Vermeulen and Whitten 1998). Remarks. No live specimen was observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest.

Kaliella micula **(Mousson, 1857)**

Figure 4.32B

Zonites micula Mousson 1857: 158.

Type locality. "Insula Balie" [= Bali Island, Indonesia]. Materials examined. Gunung Kapor: ME 9650. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. Peninsular Malaysia to Lesser Sunda (Vermeulen and Whitten 1998). Remarks. No live specimen was found during the surveys. It is different from *Kaliella scandens* by having a larger shell with wider whorls that are rapidly increasing in size. For further details on the differences between this species and *K. dendrobates* (Tillier & Bouchet, 1989), see Vermeulen et al. (2015: 105).

Kaliella platyconus **Möllendorff, 1897**

Figure 4.32C

Kaliella platyconus Möllendorff 1897b: 59.

Type locality. "Java" [= Java island, Indonesia]. Materials examined. Gunung Batu: *ME 8814. Distribution in Borneo. SARAWAK: Kuching and Samarahan Divisions. Distribution

elsewhere. Sumatra to Sumbawa (Vermeulen and Whitten 1998). Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest. The shells from Bau were the first record of this species in Borneo. This species is different from *Kaliella barrakporensis* (Pfeiffer, 1852) and *K. accepta* (Smith, 1895) by having a low conical shell with wider whorls.

Kaliella scandens **(Cox, 1871)**

Figure 4.32D

Helix scandens Cox 1871: 645, plate 52, figure 5.

Type locality. "Port Macquarie, east coast of Australia". Materials examined. Bukit Sekunyit: *ME 1883. Gunung Doya: *ME 1882, ME 8935, ME 9033, ME 9110. Gunung Kapor: *ME 1897, *ME 1928, *ME 8155, *ME 8500, ME 9008, ME 9025, ME 9075, *ME 9486. Lobang Angin: ME 8985, ME 9202, ME 9277. Gunung Batu: *ME 1875, *ME 8835. Distribution in Borneo: SARAWAK: Kuching, Serian and Miri Divisions. SABAH: Interior, Sandakan, Tawau and West Coast Divisions. KALIMANTAN: Exact location was not mentioned in Vermeulen et al. (2015). Distribution elsewhere: South-east Asia to Australia and the Pacific Islands (Vermeulen et al. 2015).

Kaliella angulata **(Issel, 1874)**

Figure 4.33A

Trochomorpha (?) *angulata* Issel, 1874: 405, plate 5, figure 5-8.

Type locality. “Sarawak”. Materials examined. Lobang Angin: ME 8747. Distribution in Borneo: SARAWAK: Kuching Division. Distribution elsewhere: None. Endemic to Borneo. Remarks. Shell sculpture similar to *Kaliella calculosa* (Gould, 1852) but different by having sharply keeled whorl at the periphery. This species is different from *Kaliella barrakporensis* (Pfeiffer, 1852) by having a brittle, spirally striated, low conical shell, with wider whorls.

Family Endodontidae Pilsbry, 1895

Genus *Beilania* Preston, 1913

***Beilania philippinensis* (C. Semper, 1874)**

Figure 4.35D

Endodonta philippinensis Semper 1874: 140.

Type locality. “Antipolo bei Manila, Luzon” [= Antipolo, Luzon Island, Philippines]. Materials examined. Gunung Batu: *ME10290. Distribution in Borneo. SARAWAK: Kuching and Miri Divisions. SABAH: Tawau and West Coast Divisions. Distribution elsewhere. Philippines, Java, Sulawesi to Timor (Solem, 1957). Remarks. No live specimen was found during the surveys.

Genus *Philalanka* Godwin-Austen, 1898

***Philalanka jambusanensis* Marzuki, Liew & Mohd-Azlan, 2021**

Figure 4.33B, 4.34A-E

Philalanka jambusanensis Marzuki et al. 2021: 76-78.

Type locality. “Malaysia, Sarawak, Kuching Division, Gunung Batu, limestone outcrop along Skio road, Jambusan, 2.4 miles E Bau, 1.3974028, 110.1888861”. Materials examined. Gunung Batu: *MZU.MOL.20.20, *ME 1879. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. None. Endemic to Borneo. Remarks. It is different from *Philalanka thienemanni* Rensch, 1932, by having a shell with spiral striation only on first 1½ whorls above the peripheral thread and a narrowly open umbilicus. This species is different from *Philalanka micromphala* van Benthem-Jutting, 1952 by having a high-conical white shell with spiral sculpture absent above the periphery.

Philalanka kusana **(Aldrich, 1889)**

Figure 4.33C

Trochomorpha kusana Aldrich 1889: 24, plate 3, figure 3, 3A-B.

Type locality. “Kusan and Penggiron districts in South-eastern Borneo” [= Kusan and Pangeran in South Kalimantan, Indonesian Borneo]. Materials examined. Gunung Doya: ME 8956, ME 9115. Gunung Kapor: *ME 2238, *ME 2244, *ME 2249, *ME 8157, ME 8501, ME 8788, ME 9029. Gunung Stulang: *ME 5897. Lobang Angin: ME 8737, ME 9181, ME 9270. Gunung Batu: *ME 2252, *ME 2254. Distribution in Borneo. SARAWAK: Kuching, Serian, Kapit and Miri Divisions. SABAH: Interior, Kudat, Sandakan, Tawau and West Coast Divisions. KALIMANTAN: Exact location was not mentioned in Vermeulen et

al. (2015). Distribution elsewhere. West Malaysia to Papua (Vermeulen et al. 2015). Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest.

***Philalanka moluensis* (E. A. Smith, 1893)**

Figure 4.33D

Sitala moluensis Smith 1893: 343, plate 25, figure 4.

Type locality. "Molu or Mulu Mountains, N. Borneo". Materials examined. Gunung Doya: *ME 0443. Distribution in Borneo. SARAWAK: Kuching and Miri Divisions. SABAH: Interior, Sandakan, Tawau and West Coast Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. No live specimen was found during the surveys.

Family Punctidae Morse, 1864

Genus *Paralaoma* Iredale, 1913

***Paralaoma angusta* Vermeulen, Liew & Schilthuizen, 2015**

Figure 4.35A, 4.36A-F

Paralaoma angusta Vermeulen et al. 2015: 109, figure 76A-B.

Type locality. "Malaysia, Sabah, West Coast Province, Crocker Range, Kiansom Waterfall". Materials examined. Gunung Doya: ME 8927, ME 8945, ME 8994. Gunung Kapor: *ME

1734, *ME 1760, *ME 1927, ME 8976, ME 9042, ME 9067, ME 9262, ME 9641. Kampung Bunga Rampai: *ME 0741. Lobang Angin: ME 9265. Gunung Batu: *ME 1756, *ME 1763, *ME 8836. Distribution in Borneo. SARAWAK: Kuching and Serian Divisions. SABAH: West Coast Division. KALIMANTAN: South Kalimantan Province. Distribution elsewhere. None. Remarks. This is the first record of this species in Sarawak. The living snails were observed dwelling among leaf litter and plant debris near the cliffs in lowland limestone forest. The shells from Bau are slightly larger and more obese than the shells from Sabah. Dimensions: Height up to 1.65 mm; width up to 2.37 mm; diameters of the first three whorls 0.41 mm, 0.93 mm, 1.65 mm respectively; number of whorls up to 4½; aperture height up to 0.93 mm; aperture width up to 1.24 mm.

Paralaoma sarawakensis **Marzuki, Liew & Mohd-Azlan, 2021**

Figure 4.35B, 4.37A-F

Paralaoma sarawakensis Marzuki et al. 2021: 80-84.

Type locality. "Malaysia, Sarawak, Kuching Division, Bukit Sokwang (Site 3), northern site of Gunung Doya, limestone hill along Skio road, 2.05 miles E Bau, 1.3971861, 110.175594". Materials examined. Gunung Doya: MZU.MOL.20.21, ME 8944, *ME 2269. Gunung Sebayat: *ME 8010. Gunung Sekunyit: *ME 2234. Gunung Batu: *ME 2230, *ME 2235, *ME 2257. Gunung Kapor: *ME 2229, ME 9211, ME 9261. Distribution in Borneo. SARAWAK: Kuching, Serian and Miri Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. It is different from '*Charopa*' *lafargei* Vermeulen & Marzuki, 2014 of West Malaysia, by having a depressed-conic shell and a protoconch with fine, moderately

spaced spiral striations consisting of rows of minute striaes which are arranged in dashed line pattern towards the teleoconch.

Family Charopidae Hutton, 1884

Genus *Sundacharopa* Vermeulen & Liew, 2022

***Sundacharopa argos* Vermeulen & Liew, 2022**

Figure 4.35C, 4.38A-F

Sundacharopa argos Vermeulen & Liew, 2022: 246-248, figure 120 e-f.

Type locality. "Malaysia, Sabah, upper Padas river valley, Long Pa Sia". Materials examined. Gunung Doya: *ME 8593, ME 8998. Kampung Padang Pan: ME 9491. Gunung Kapor: ME 9896, ME 9136. Gunung Batu: *ME 7177, *ME 1890. Lobang Angin: ME 9039, ME 9138. Distribution in Borneo. SARAWAK: Kuching and Miri Divisions. SABAH: West Coast, Interior, Sandakan and Tawau Division. BRUNEI DARUSSALAM. Distribution elsewhere. None. Endemic to Borneo. Remarks. The living snails were observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest. It is different from other Bornean Charopa species by its prominent, rather deep, well-spaced radial grooves crossing the spiral striae at more or less regular intervals on the shell surface.

Family Dyakiidae Gude & B. B. Woodward, 1921

Genus *Dyakia* Godwin-Austen, 1891

***Dyakia busanensis* Godwin-Austen, 1891**

Figure 4.39A

Dyakia busanensis Godwin-Austen 1891: 31.

Type locality. "Busan Hills, Borneo" [= Jambusan Hills, Bau, Sarawak]. Materials examined. Gunung Doya: *ME 1600, ME 8913, ME 9015, ME 9159. Gunung Kapor: *ME 1595, *ME 1596, *ME 1598, *ME 1599, *ME 8082, *ME 8457, ME 9056, ME 9217. Gunung Batu: *ME 1597, *ME 4861, *ME 8811. Distribution in Borneo. SARAWAK: Kuching and Sri Aman Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. Another form of this species was described by Smith (1895) as *concolor* from Sri Aman, Sarawak.

***Dyakia subdebilis* E. A. Smith, 1895**

Figure 4.39B

Dyakia subdebilis Smith 1895: 104, plate 2, figure 11.

Type locality. "Sarawak". Materials examined. Gunung Sebayat: *ME 8303. Gunung Kapor: *ME 1602. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. None. Endemic to Borneo. Remarks. This species was placed as junior synonym of *Dyakia regalis* (Benson, 1850) by Laidlaw (1963). However, the shells from Bau are different from

Dyakia regalis by having a straw yellow to light brown shell and with shiny surface below the periphery.

Genus *Everettia* Godwin-Austen, 1891

***Everettia cutteri* (H. Adams, 1870)**

Figure 4.40A

Macrochlamys cutteri Adams 1870: 794, plate 48, figure 21.

Type locality. "Busan, near Sarawak, Borneo" [= Jambusan Hills, Bau, Sarawak]. Materials examined. Gunung Doya: ME 8961. Gunung Kapor: *ME 1630, ME 8968. Gunung Batu: *ME 1628, *ME 1629. Distribution in Borneo. SARAWAK: Kuching and Miri Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. No live specimen was found during the surveys. This species is different from *Vitrinula baramensis* (Kobelt, 1897) and *Vitrinula moluensis* (E. A. Smith, 1893) by having a shell with wide pale brown band encircling the periphery. Anatomical studies by Godwin-Austen (1891) confirmed the placement of this species under genus Everettia.

***Everettia microrhytida* Marzuki, Liew & Mohd-Azlan, 2021**

Figure 4.40B, 4.41D-F

Everettia microrhytida Marzuki et al. 2021: 85-89.

Type locality. “Malaysia, Sarawak, Kuching Division, Gunung Batu, limestone outcrop along Skio road, Jambusan, 2.4 miles E Bau, 1.3974028, 110.1888861”. Materials examined. Gunung Batu: *MZU.MOL.20.25, *MZU.MOL.20.26. Padang Pan: *ME 6829. Gunung Lobang Angin: ME 9145, ME 9845. Distribution in Borneo. SARAWAK: Kuching Division. Distribution elsewhere. None. Endemic to Borneo. Remarks. This species is similar to *Everettia consul* (Pfeiffer, 1854) in terms of general shape and size. However, it is different from *E. consul* by lacking spiral sculpture and with only very fine (sometimes inconspicuous), somewhat wrinkled, punctured-like sculpture in both the apical and apertural side. Everettia consul, on the other hand, has a shell with more elevated spire and its shell surface with densely placed radial threads and somewhat cut by irregularly spaced spiral grooves.

Everettia minuta Marzuki, Liew & Mohd-Azlan, 2021

Figure 4.40C, 4.41A-C

Everettia minuta Marzuki et al. 2021: 89-90.

Type locality. “Malaysia, Sarawak, Kuching Division, Fairy Caves (Site 1), south part of Gunung Kapor, 4 miles SW Bau, 1.3816, 110.117872”. Materials examined. Gunung Kapor: MZU.MOL.20.23, ME 8965, MZU.MOL.20.24, *ME 1512. Gunung Batu: *ME 1513. Gunung Lobang Angin: ME 9139, ME 9222. Remarks. The species is similar to *Everettia jucunda* (Pfeiffer, 1863), *E. bangueyensis* (Smith, 1895) and *E. jucundior* Liew, Vermeulen & Schilthuizen, 2009 from Sabah. *Everettia jucunda* differs by having a larger shell (up to 17.3 mm wide), with one and half more whorls. *Everettia jucundior* differs by having a larger

shell (up to 19.5 mm wide) with slightly shouldered whorls. *Everettia bangueyensis* differs by having a smaller shell (up to 9.0 mm wide), and a flat spire with slightly shouldered whorls.

Genus *Rhinocochlis* Thiele, 1931

***Rhinocochlis nasuta* (Metcalfe, 1851)**

Figure 4.39C, 4.52C

Helix nasuta Metcalfe 1851: 70.

Type locality. "Borneo". Materials examined. Bukit Sekunyit: *ME 4878. Gunung Doya: *ME 1610, ME 8914, ME 8924, ME 9040. Gunung Kapor: *ME 4868, *ME 4872, *ME 4874, ME 8081, ME 8456, ME 8772, ME 8971, ME 9406. Gunung Stulang: *ME 5906. Lobang Angin: *ME 4882, *ME 4883, ME 8727, ME 8740, ME 8885. Gunung Batu: *ME 4869, *ME 4870, *ME 4871. Distribution in Borneo: SARAWAK: Kuching, Serian, Kapit and Miri Divisions. KALIMANTAN: West Kalimantan and East Kalimantan Provinces. Distribution elsewhere: None. Endemic to Borneo. Remarks. It is different from *Rhinocochlis moluensis* (Godwin-Austen, 1891), and Rhinocochlis chlorosoma (Vermeulen, Liew & Schilthuizen, 2015), by having a shell with the curved beak-like extension of the palatal side of the aperture.

Genus *Elaphroconcha* Gude, 1911

***Elaphroconcha striata* (Gray, 1834)**

Figure 4.39D

Nanina striata Gray 1834: 59.

Type locality. "_". Materials examined. Gunung Kapor: ME 8792. Kampung Padang Pan: *ME 6676. Distribution in Borneo. SARAWAK: Kuching, Samarahan, Mukah and Miri Divisions. LABUAN: Labuan and Papan Islands. Distribution elsewhere. West Malaysia, Singapore and China (Benson, 1842; Foon et al., 2017). Remarks. Probably an introduced species. The species is only known from disturbed habitats in Borneo.

Family Trochomorphidae Möllendorff, 1890

Genus *Geotrochus* van Hasselt, 1823

***Geotrochus conicoides* (Metcalfe, 1851)**

Figure 4.42A

Helix conicoides Metcalfe 1851: 71.

Type locality. "Borneo". Materials examined. Gunung Doya: *ME 1637, ME 8911. Distribution in Borneo. SARAWAK: Kuching, Serian and Miri Divisions. SABAH: West Coast and Tawau Divisions. KALIMANTAN: West Kalimantan Province. Distribution elsewhere. Sumatra (?) (Van Benthem-Jutting, 1959). Remarks. No live specimen was found

during the surveys. The shells from Bau have a more depressed shell than the shells from Niah.

Geotrochus subscalaris Vermeulen, Liew & Schilthuizen, 2015

Figure 4.42B

Geotrochus subscalaris Vermeulen et al. 2012: 129-131, figure 91.

Type locality. "Malaysia, Sabah, Sandakan Province, Kinabatangan valley, Batu Pangi". Materials examined. Gunung Kapor: *ME 1636. Distribution in Borneo. SARAWAK: Kuching Division. SABAH. West Coast Division. Distribution elsewhere. No record. Endemic to Borneo. Remarks. This is the first record of this species in Sarawak. No living specimen was found during the surveys. The shells from Bau are more depressed than the shells from Sabah.

Genus *Videna* H. Adams & A. Adams, 1855

Videna bicolor (Martens, 1864)

Figure 4.42C, 4.51B

Trochomorpha bicolor Martens 1864: 267.

Type locality. "Im mittleren Sumatra" [= Central Sumatra, Indonesia]. Materials examined. Bukit Sekunyit: *ME 1202. Gunung Doya: *ME 3356, ME 8910, ME 9032, ME 9116. Gunung Kapor: *ME 1199, *ME 1205, *ME 3361, ME 8775, ME 9225, ME 9844. Kampung

Bunga Rampai: *ME 1198. Lobang Angin: ME 8732, ME 9271. Gunung Batu: *ME 1106, *ME 1203, *ME 1209, *ME 8825. Distribution in Borneo. SARAWAK: Kuching, Serian, Sibu, Mukah, Kapit and Miri Divisions. SABAH: Interior and West Coast Divisions. KALIMANTAN: West Kalimantan and South Kalimantan Provinces. Distribution elsewhere. Sumatra to Lesser Sunda (Vermeulen and Whitten 1998). Remarks. The living snails were observed dwelling on wet rotten wood surfaces and crown of a plant of the limestone cliff. It is different from *Videna nepiadelphos* Vermeulen & Liew, 2022 by having a medium-sized dark brown shell with wide umbilicus and smooth shell surfaces. This is the most common *Videna* species in Sarawak.

***Videna nepiadelphos* Vermeulen & Liew, 2022**

Figure 4.42D, 4.51A

Videna nepiadelphos Vermeulen & Liew, 2022: 336-337, figure 163g-i.

Type locality. "Malaysia, Sabah, Tawau Prov., Danum valley Conservation Area". Materials examined. Gunung Doya: *ME 1228, ME 9163, ME 9193, ME 9405. Gunung Kapor: *ME 1179, *ME 1222, *ME 1226, *ME 3360, *ME 5976, *ME 8090, *ME 8458, ME 8762, ME 8972. Kampung Padang Pan: *ME 6724. Lobang Angin: ME 8984, ME 9404. Gunung Batu: *ME 1224, *ME 8824. Distribution in Borneo. SARAWAK: Kuching Division. SABAH: West Coast, Interior, Sandakan and Tawau Division. Distribution elsewhere. Peninsular Malaysia to Indo-Australian archipelago (Maassen 2001). Remarks. The living snails were observed dwelling on wet rotten wood surfaces at the base of the limestone cliff. It is

different from *Videna bicolor* (Martens, 1864) by having a pale brown smaller shell with narrower umbilicus and shell surfaces striated with conspicuous spiral grooves.

Family Ryssotidae Schileyko, 2003

Genus *Exrhysota* H. B. Baker, 1941

***Exrhysota brookei* (A. Adams & Reeve, 1848)**

Figure 4.42E

Helix brookei Adams & Reeve 1850: 60, plate 15, figure 4A-B.

Type locality. "Mountains of Borneo". Materials examined. Gunung Kapor: *ME 8083, ME 8790. Distribution in Borneo. SARAWAK: Kuching, Sibu, Kapit and Miri Divisions. SABAH: Sandakan, Tawau and East Coast Divisions. KALIMANTAN: West Kalimantan, South Kalimantan and East Kalimantan Provinces. Distribution elsewhere. None. Endemic to Borneo. Remarks. This is the largest native land snail species in Borneo. For further details on the generic and familial placement of this species, see Sutcharit et al. (2019: 2).

Family Helicarionidae Bourguignat, 1877

Genus *Helicarion* Férussac, 1821

***Helicarion dyakanum* (Godwin-Austen, 1891)**

Figure 4.43A, 4.51D

Microcystis dyakana Godwin-Austen 1891: 36-37, plate 4, figure 4-4C.

Type locality. “Busan Hills, Borneo” [= Jambusan Hills, Bau, Sarawak]. Materials examined. Bukit Sekunyit: *ME 2850. Gunung Doya: ME 8955, ME 8999, ME 9156. Gunung Kapor: *ME 2879, *ME 2881, *ME 2947, *ME 5978, *ME 8087, *ME 8459, ME 8770, ME 8969. Kampung Padang Pan: *ME 6679. Lobang Angin: ME 8751, ME 9398. Gunung Batu: *ME 2840, *ME 2867, *ME 8815. Distribution in Borneo. SARAWAK: Kuching, Serian and Miri Divisions. SABAH: Interior Division. Distribution elsewhere. Lombok (Vermeulen & Liew, 2022; Smith 1899). Remarks. Living snails were observed dwelling on the leaf surfaces of small trees and palms at the base of limestone cliffs.

Family Euconulidae H. B. Baker, 1928

Genus *Rahula* Godwin-Austen, 1907

***Rahula raricostulata* (E. A. Smith, 1893)**

Figure 4.43B

Sitala raricostulata Smith 1893: 342-343, plate 25, figure 2.

Type locality. “Busau or Busan, Sarawak” [= Jambusan Hills, Bau, Sarawak]. Materials examined. Gunung Doya: ME 8937, ME 8962. Gunung Kapor: *ME 0860, *ME 1508, ME 9097, ME 9207. Lobang Angin: ME 8938, ME 9221. Gunung Batu: *ME 1891. Distribution in Borneo. SARAWAK: Kuching and Serian Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. No live specimen was found during the surveys. It is different

from *Rahula delopleura* Vermeulen, Liew & Schilthuizen, 2015, by having a shell with distinct, prominent spiral lirae on the protoconch.

Family Clausiliidae J. E. Gray, 1855

Genus *Phaedusa* H. Adams & A. Adams, 1855

***Phaedusa borneensis* (L. Pfeiffer, 1854)**

Figure 4.43C, 4.49C

Clausilia borneensis Pfeiffer 1854a: 296.

Type locality. "Sarawak, Borneo". Materials examined. Gunung Doya: *ME 2904, ME 8912, ME 9153. Gunung Kapor: *ME 2890, *ME 2891, *ME 2892, *ME 2893, *ME 2944, *ME 5975, ME 8784, ME 9257. Gunung Batu: *ME 2897, *ME 2898. Distribution in Borneo. SARAWAK: Kuching, Serian and Miri Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. The living snails were observed dwelling on the moderately wet vertical limestone rock surfaces covered with lichens.

Family Valloniidae Morse, 1864

Genus *Ptychopatula* Pilsbry, 1889

***Ptychopatula dioscoricola* (C. B. Adams, 1845)**

Figure 4.44A

Helix dioscoricola Adams 1845: 16.

Type locality. “Jamaica”. Materials examined. Gunung Doya: ME 8942, ME 8997. Gunung Kapor: *ME 8151, *ME 8502, ME 9006, ME 9027, ME 9070. Kampung Padang Pan: *ME 6830. Lobang Angin: ME 9140, ME 9173. Distribution in Borneo. SARAWAK: Kuching, Bintulu, Miri and Limbang Divisions. SABAH: Sandakan Division. Distribution elsewhere. Circumtropical (Pilsbry 1920-21). Remarks. No live specimen was found during the surveys. It is different from *Ptychopatula circumlitum* (Hedley, 1897) and *P. orcella* (Stoliczka, 1873) by having higher spire shell with an umbilicus that partly or entirely covered by the reflected peristome. This species also differs from *Pupisoma pulvisculum* (Issel, 1874) by having a larger shell with spiral lirae on shell surfaces.

Ptychopatula orcella **(Stoliczka, 1873)**

Figure 4.44B

Pupa (*Pupisoma*) *orcella* Stoliczka 1873: 33, plate 2, figure 2.

Type locality. “Penang island”. Materials examined. Gunung Doya: ME 8925. Distribution in Borneo. SARAWAK: Kuching Division. SABAH: Tawau Division. Distribution elsewhere. Malay Peninsula, Indo-Australian archipelago (Vermeulen and Whitten 1998). Remarks. No live specimen was found during the surveys. It is different from *Ptychopatula circumlitum* (Hedley, 1897) and *P. dioscoricola* (C. B. Adams, 1845) by having irregularly spaced ribs on shell surfaces (visible at 40x magnification). This is probably the first record of sinistral form for species in the Genus *Ptychopatula*. For further details, see Pilsbry (1920-21: 29).

Genus *Pupisoma* Stoliczka, 1873

***Pupisoma moleculina* (van Benthem-Jutting, 1940)**

Figure 4.44C

Costigo moleculina van Benthem-Jutting 1940: 331-332.

Type locality. “Forest between the village of Tjisolok and the hot springs (Tjipanas) some miles inland, south coast of West Java”. Materials examined. Gunung Kapor: ME 9051, ME 9212. Distribution in Borneo. SARAWAK: Kuching Division. SABAH: Sandakan Division. Distribution elsewhere. Peninsular Malaysia, Sumatra and Java (van Benthem-Jutting 1940; Vermeulen and Raven 1998; Maassen 2000). Remarks. This is the first record of this species in Sarawak. No live specimen was found during the surveys.

***Pupisoma pulvisculum* (Issel, 1874)**

Figure 4.44D

Helix (*Fruticicola*) *pulvisculum* Issel 1874: 406-407, plate 5, figure 24-27.

Type locality. “Borneo”. Materials examined. Gunung Doya: ME 9108, ME 9151. Gunung Kapor: *ME 8152, ME 9055, ME 9210, ME 9470. Lobang Angin: ME 9258. Distribution in Borneo. SARAWAK: Kuching, Miri and Limbang Divisions. SABAH: Sandakan and West Coast Divisions. Distribution elsewhere. Lombok (Smith 1899). Remarks. No live specimen was found during the surveys. It is different from *Ptychopatula vermeuleni* Maassen, 2000

and *P. solemi* Maassen, 2000 by having minutely rugulose shell surfaces (visible at 40x magnification). For further details, see Pilsbry (1920-21: 30-31).

Family Vertiginidae Fitzinger, 1833

Genus *Boysidia* Ancey, 1881

***Boysidia salpinx* Thompson & Dance, 1983**

Figure 4.44F, 4.49B

Boysidia (*Dasypupa*) *salpinx* Thompson & Dance 1983: 106-107, Figure 2-6, 7-8.

Type locality. “Gunong Subis, a limestone massif about 40 mi SW of Mira, Niah area, Fourth Div., Sarawak, Borneo, 03°51’N, 113°45’E”. Materials examined. Gunung Kapor: *ME 2883, ME 8781, ME 9071, ME 9843. Distribution in Borneo. SARAWAK: Kuching, Serian and Miri Divisions. Distribution elsewhere. None. Endemic to Borneo. Remarks. The living snails were observed dwelling inside the shaded rock crevices and cave walls.

Clade Systellommatophora

Family Veronicellidae Gray, 1840

Genus *Valiguna* Grimpe & Hoffmann, 1925

***Valiguna flava* (Heynemann, 1885)**

Figure 4.49D

Vaginula flava Heynemann 1885: 10-11, plate 2, figure 3.

Type locality. “Borneo”. Materials examined. Gunung Kapor. Distribution in Borneo. SARAWAK: Kuching Division. SABAH: Interior, West Coast and Tawau Divisions. Distribution elsewhere. Sumatra, Peninsular Malaysia, Singapore (Heynemann 1885; Forcart 1973; Low 2014). Remarks. The living slug was observed dwelling among leaf litter and plant debris near the cliff in lowland limestone forest. However, no specimen was collected during the surveys. For further details, see Schilthuizen and Liew (2008: 292-293).

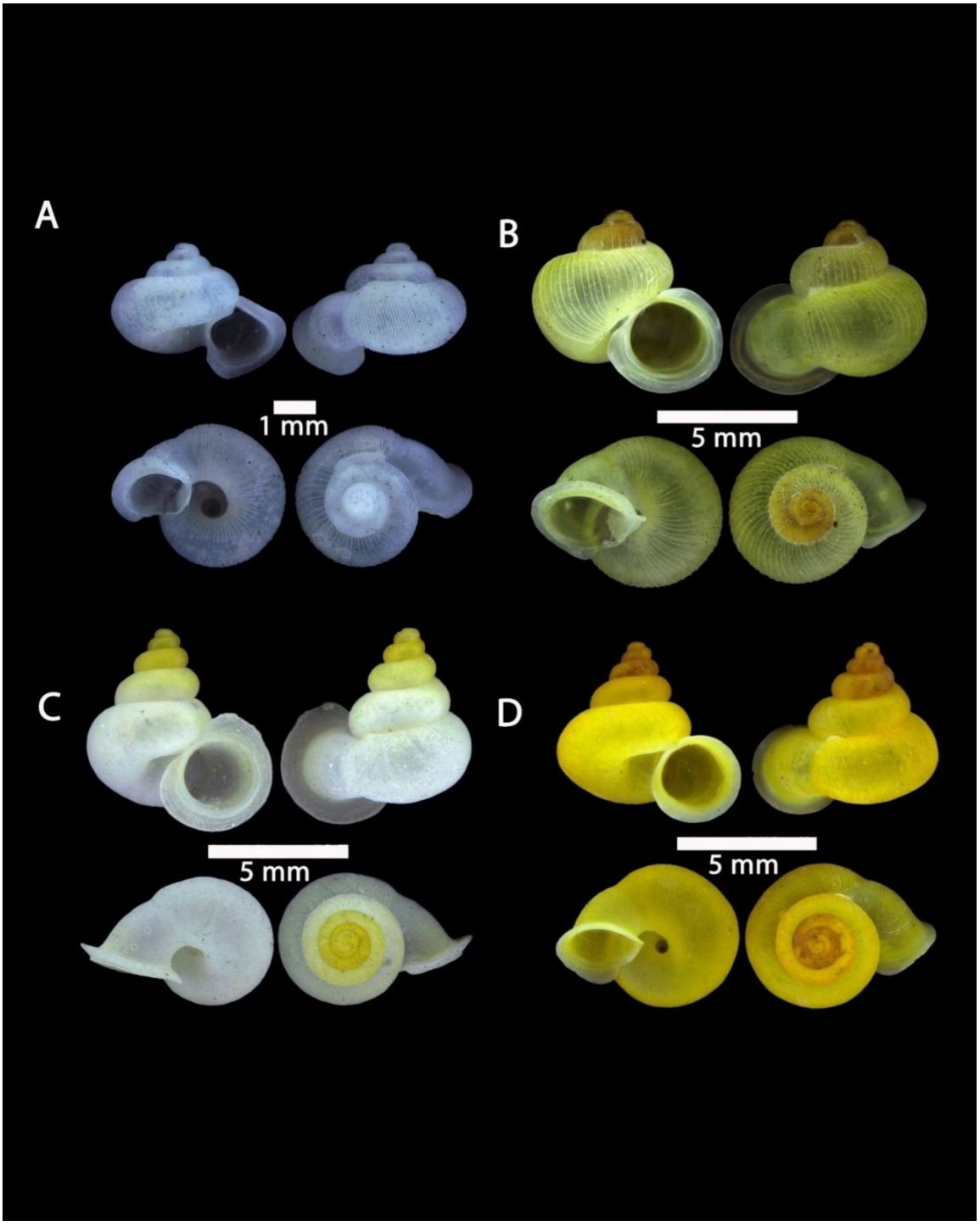


Figure 4.1: A. *Chamalycaeus specus* (Godwin-Austen, 1889) ME 9046 Gunung Kapor **B.** *Pincerna globosa* (H. Adams, 1870) ME 6979 Lobang Angin **C.** *Stomacosmethis hosei* (Godwin-Austen, 1889) ME 1010 Gunung Batu **D.** *Stomacosmethis sadongensis* (Smith, 1895) ME 8761 Gunung Kapor.

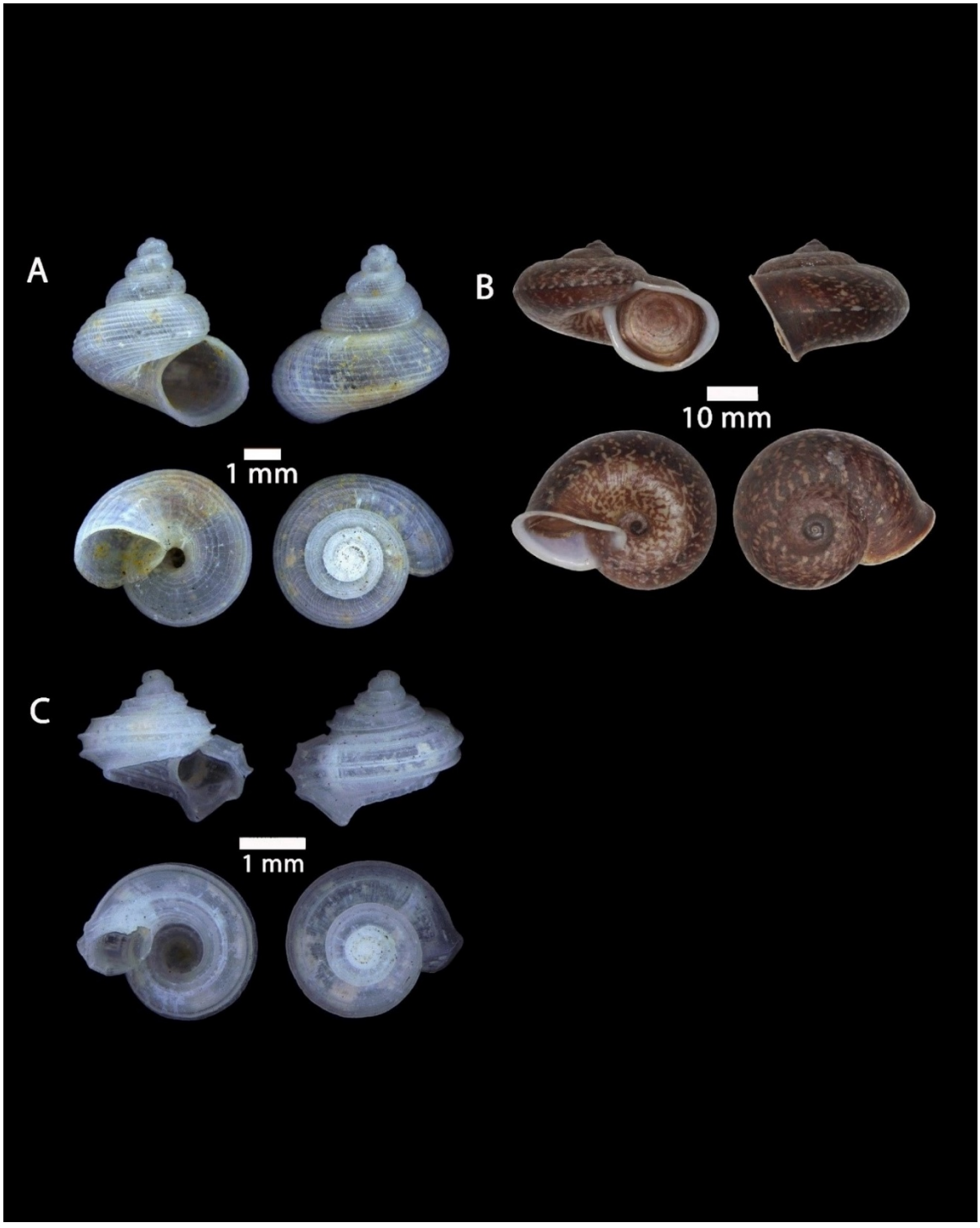


Figure 4.2: A. *Leprocochlias cingulatus textrinum* Vermeulen, Marzuki & Khalik, ms. ME 839 Gunung Batu **B.** *Cyclophorus perdix borneensis* (Metcalfe, 1851) ME 8921 Gunung Doya **C.** *Ditropopsis everetti* (E. A. Smith, 1895) ME 835 Gunung Kapor.

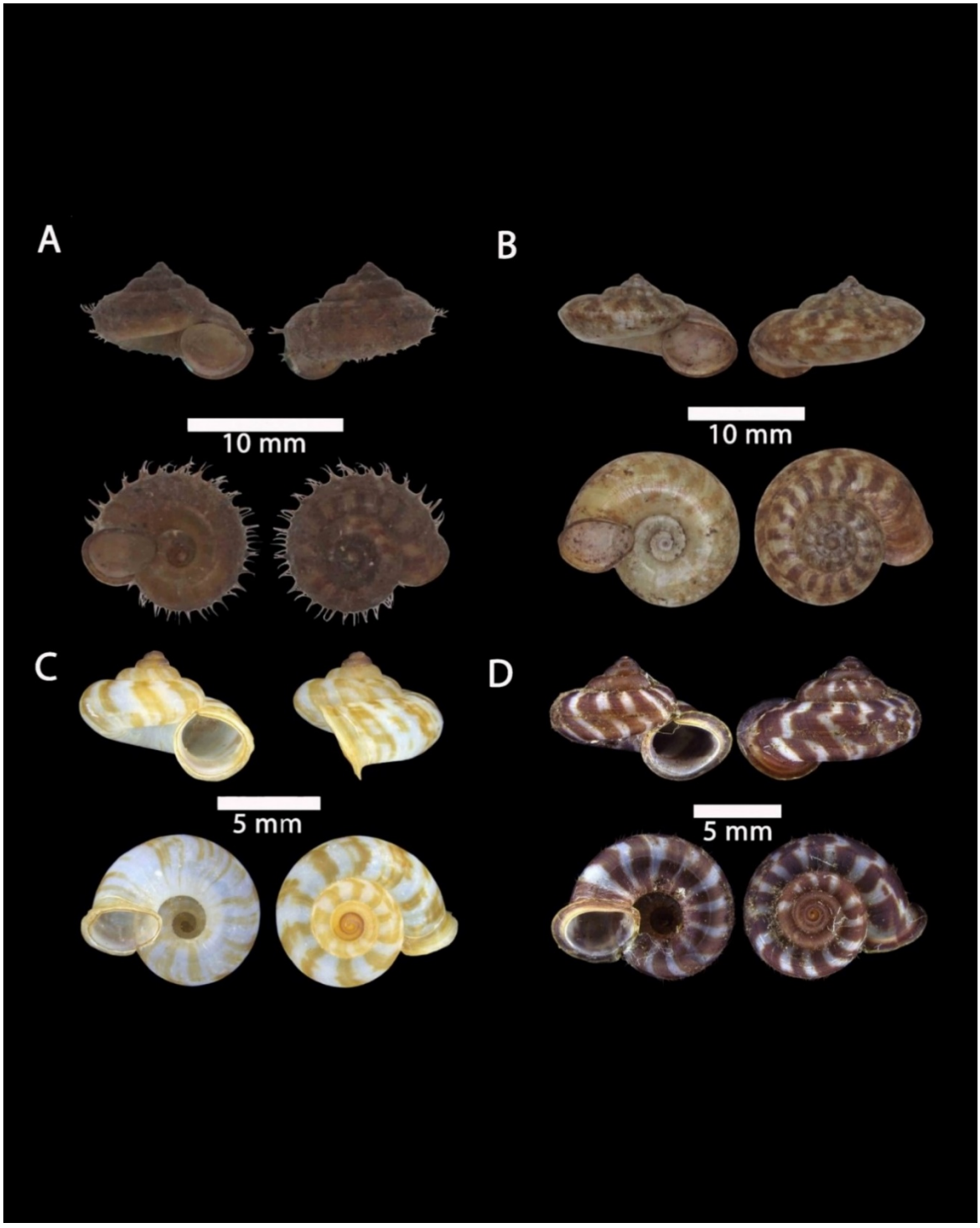


Figure 4.3: A. *Japonia barbata* (L. Pfeiffer, 1855) ME 833 Kampung Bunga Rampai **B.** *Japonia barbata* (L. Pfeiffer, 1855) ME 2141 Lobang Angin. **C.** *Japonia bauensis* Marzuki, Liew & Mohd-Azlan, 2021, ME 7231 PARATYPE Gunung Kapor **D.** *Japonia bauensis* Marzuki, Liew & Mohd-Azlan, 2021, MZU.MOL.20.03 HOLOTYPE Gunung Doya.

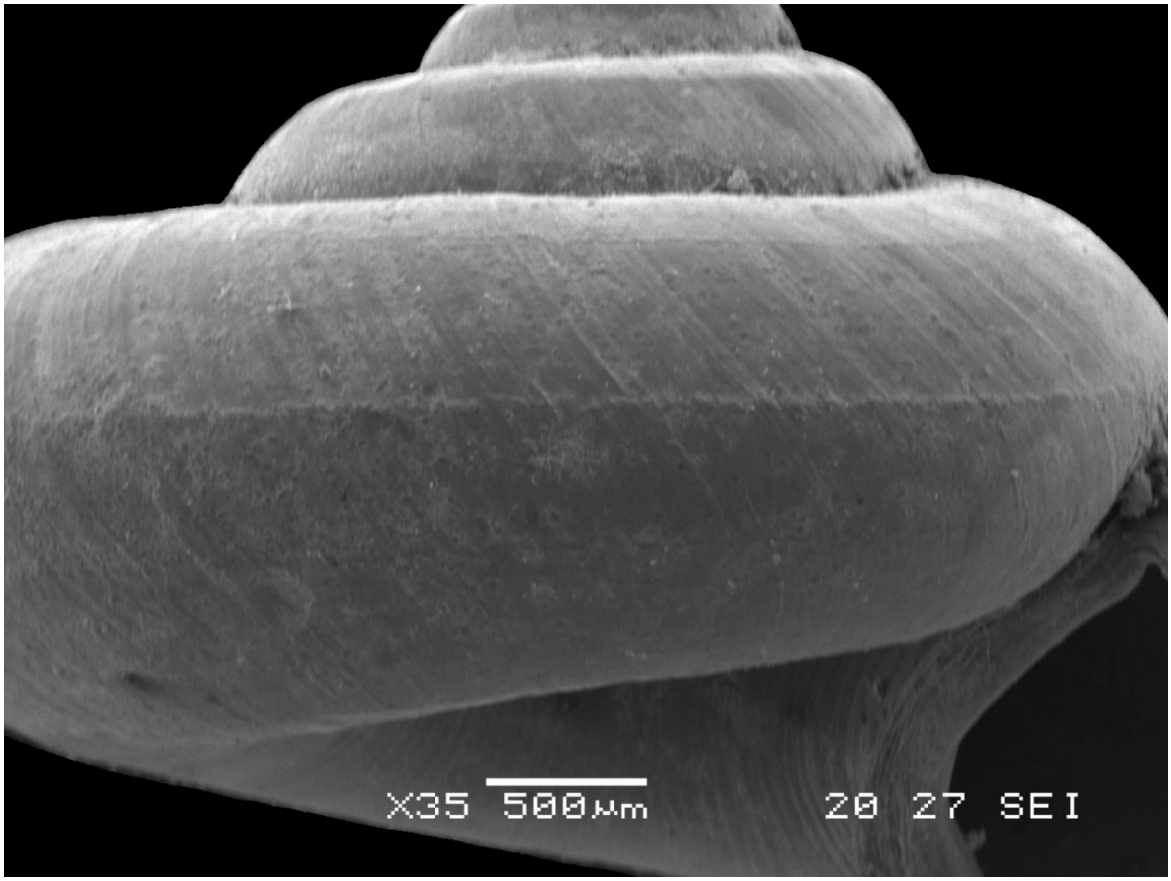


Figure 4.4: *Japonia bauensis* Marzuki, Liew & Mohd-Azlan, 2021, ME 7231 PARATYPE. Enlargement of the body whorl showing the shell sculpture.

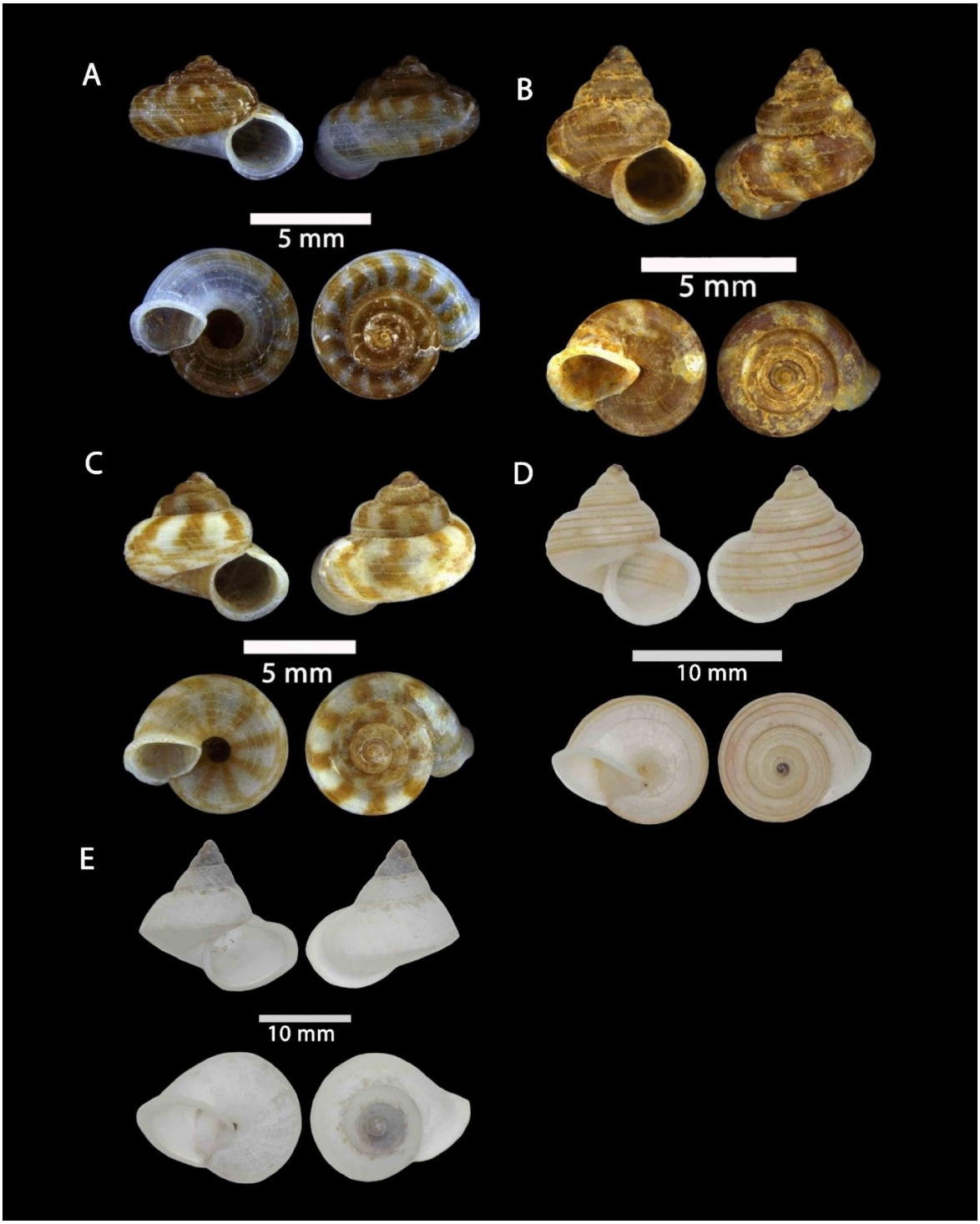


Figure 4.5: A. *Japonia metcalfei* (Issel, 1874) ME 2916 Gunung Batu **B.** *Japonia mundyana* (Godwin-Austen, 1889) ME 0838 Gunung Batu **C.** *Japonia rabongensis* (E. A. Smith, 1895) ME 9080 Gunung Kapor **D.** *Leptopoma sericatum* (Pfeiffer, 1851) ME 5900 Gunung Stulang **E.** *Leptopoma undatum* (Metcalfe, 1851) ME 2684 Gunung Batu.

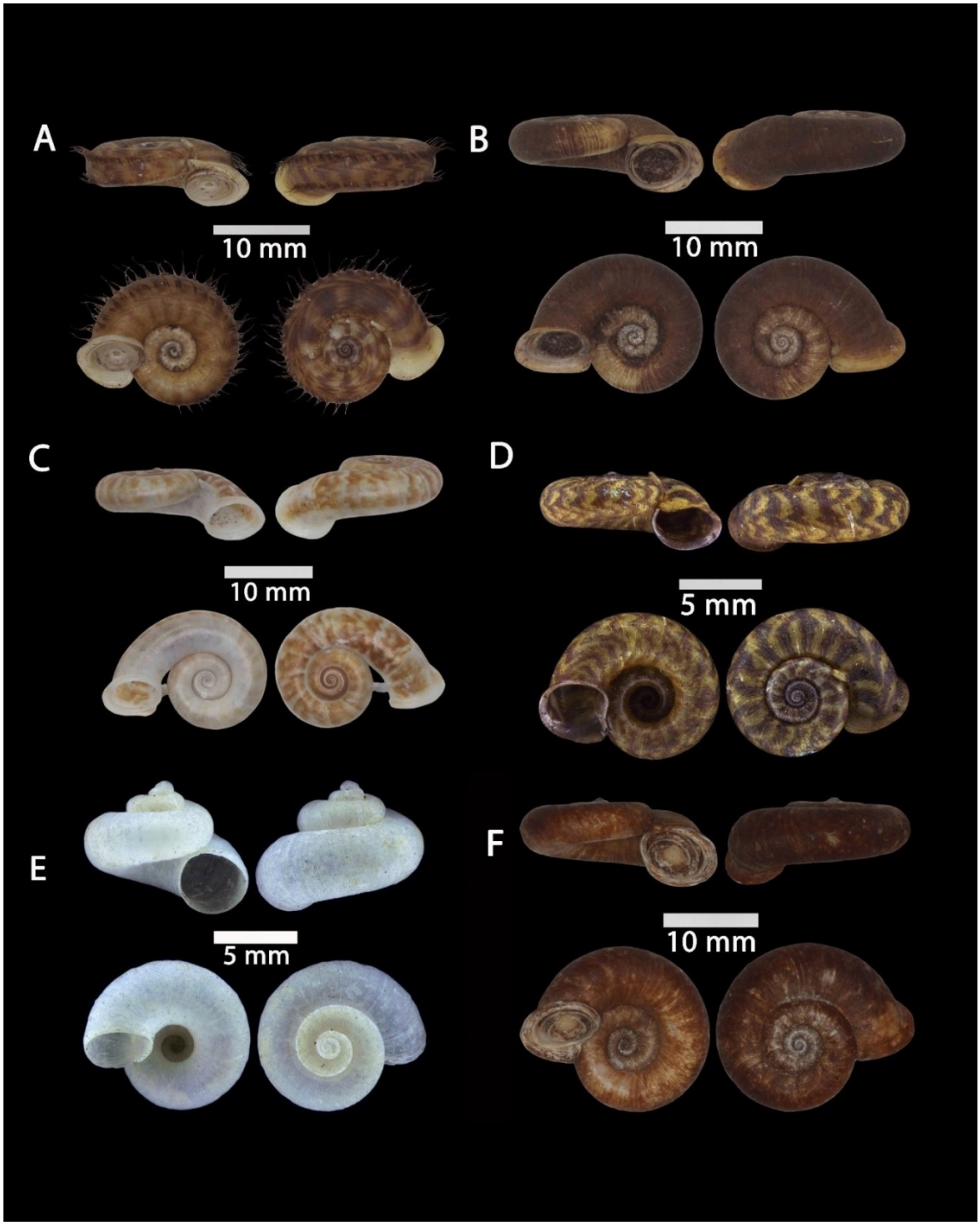


Figure 4.6: A. *Opisthophorus biciliatus* (Mousson, 1849) ME 8754 Gunung Kapor **B.** *Opisthophorus birostris* (L. Pfeiffer, 1854) ME 8758 Gunung Kapor **C.** *Opisthophorus cavernae* (Godwin-Austen, 1889) ME 8904 Gunung Doya **D.** *Opisthophorus euryomphalus* (L. Pfeiffer, 1856) ME 8779 Gunung Kapor **E.** *Platyrhaphe linita* (Godwin-Austen, 1889) ME 0881 Gunung Batu **F.** *Pterocyclos tenuilabiatus* (Metcalfe, 1851) ME 5910 Gunung Batu.

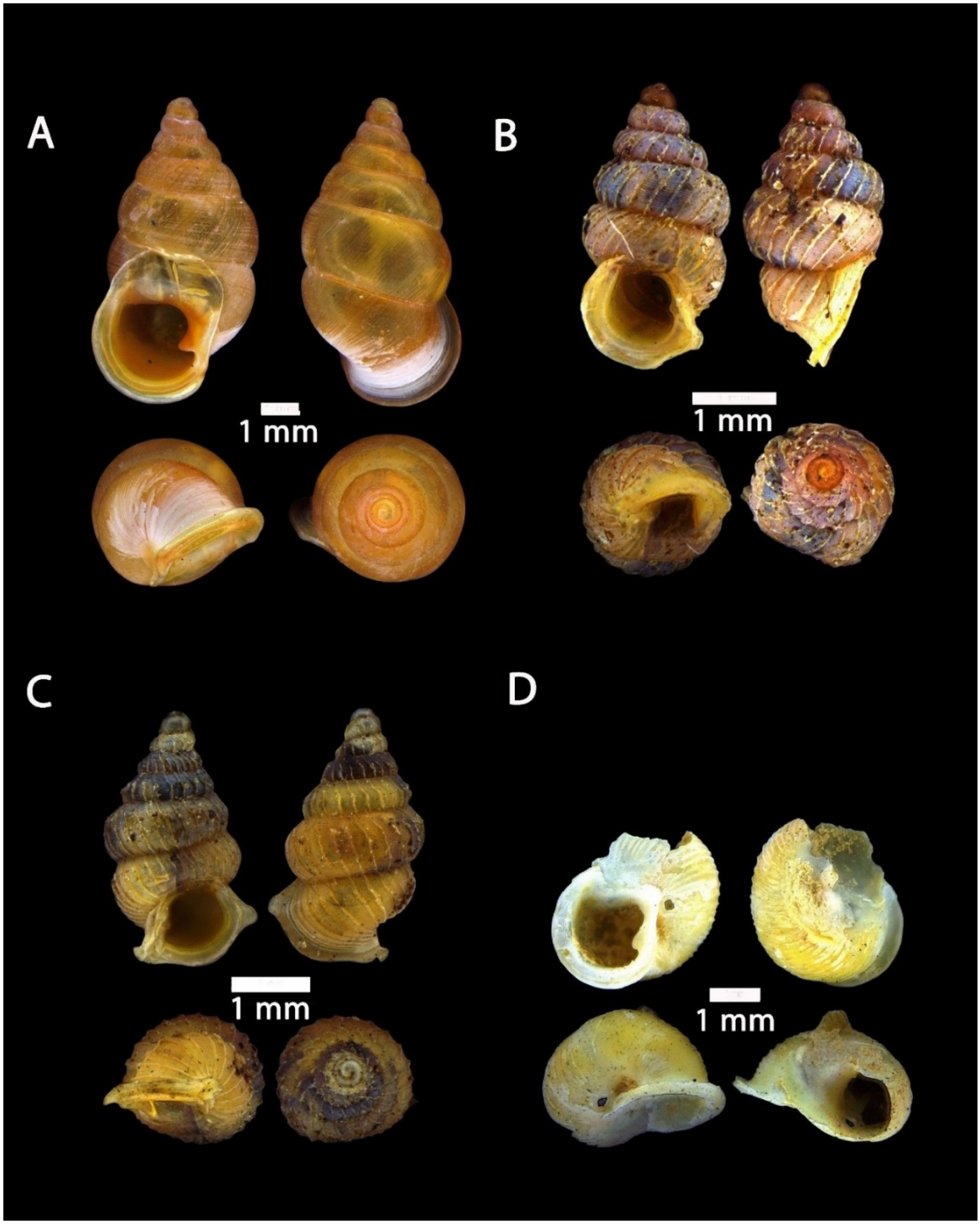


Figure 4.7: A. *Diplommatina adversa* (H. Adams & A. Adams, 1851) ME 8799 Gunung Batu **B.** *Diplommatina busanensis* Godwin-Austen, 1889 ME 8991 Gunung Doya **C.** *Diplommatina concinna* H. Adams, 1872 ME 8745 Lobang Angin **D.** *Moussonia isseli* (Godwin-Austen, 1889) ME 2869 Gunung Batu.

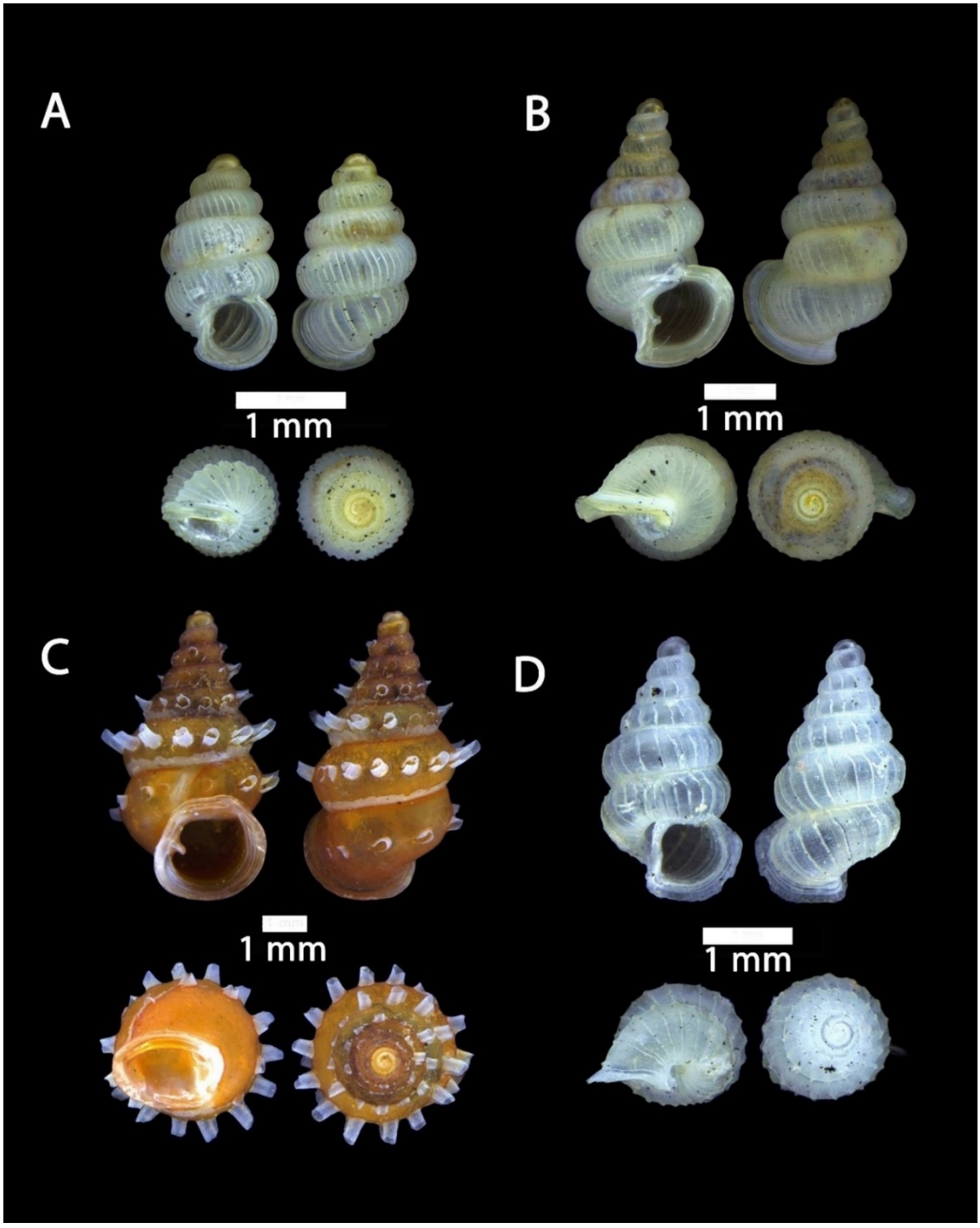


Figure 4.8: A. *Diplommatina maduana maduana* Laidlaw, 1949 ME 9030 Gunung Doya **B.** *Diplommatina onyx* Fulton, 1901 ME 9102 Gunung Doya **C.** *Diplommatina spinosa* Godwin-Austen, 1889 ME 8801 Gunung Batu **D.** *Diplommatina toretos* Vermeulen, 1993 ME 0536 Gunung Batu.

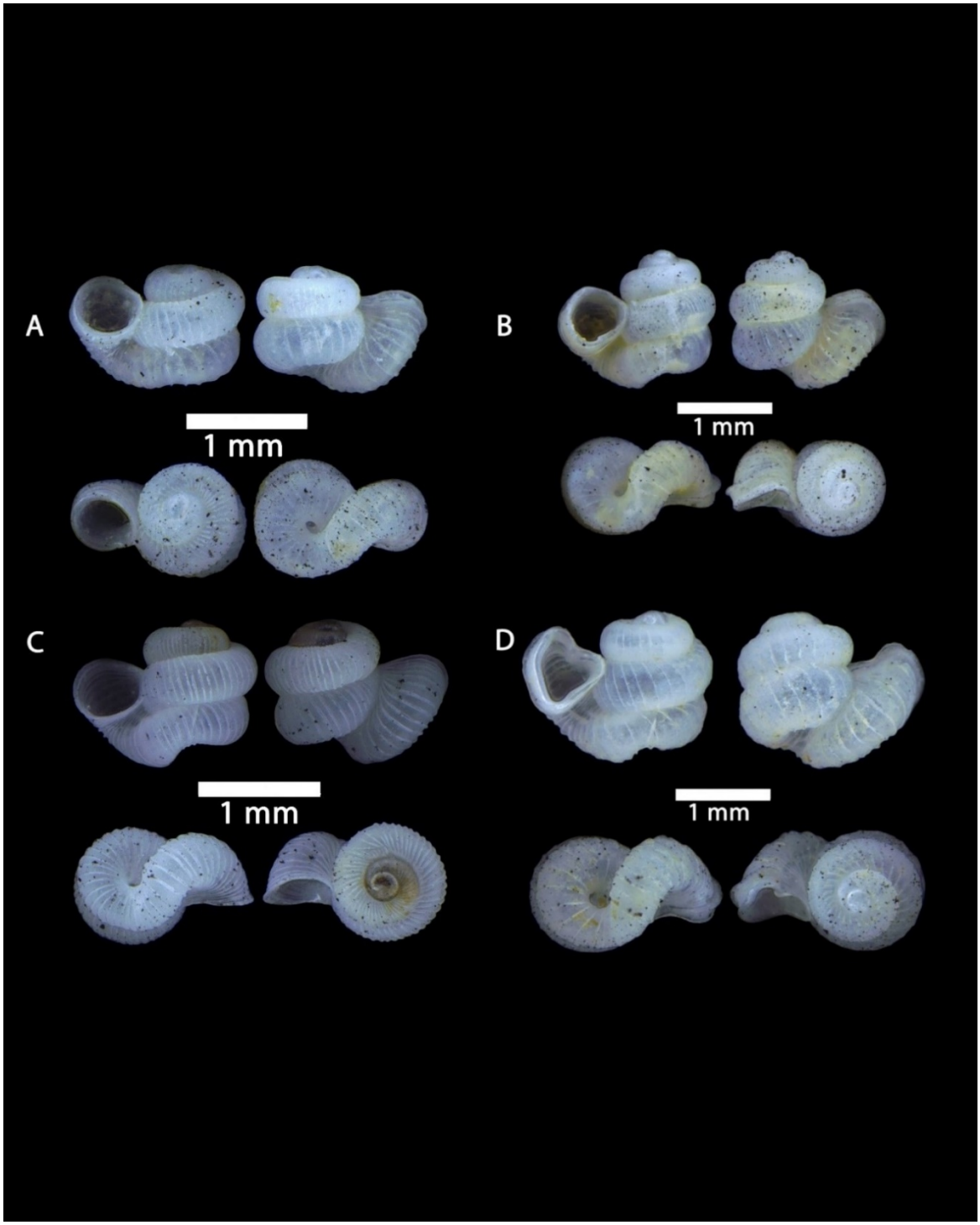


Figure 4.9: A. *Opisthostoma ballorum* Vermeulen, 1991 ME 9002 Gunung Kapor **B.** *Opisthostoma brachyacrum brachyacrum* Thompson, 1978 ME 0353 Gunung Batu **C.** *Opisthostoma brachyacrum lambi* (Vermeulen, 1991) ME 9003 Gunung Kapor **D.** *Opisthostoma cryptodon* Vermeulen, 1991 ME 9084 Gunung Doya.

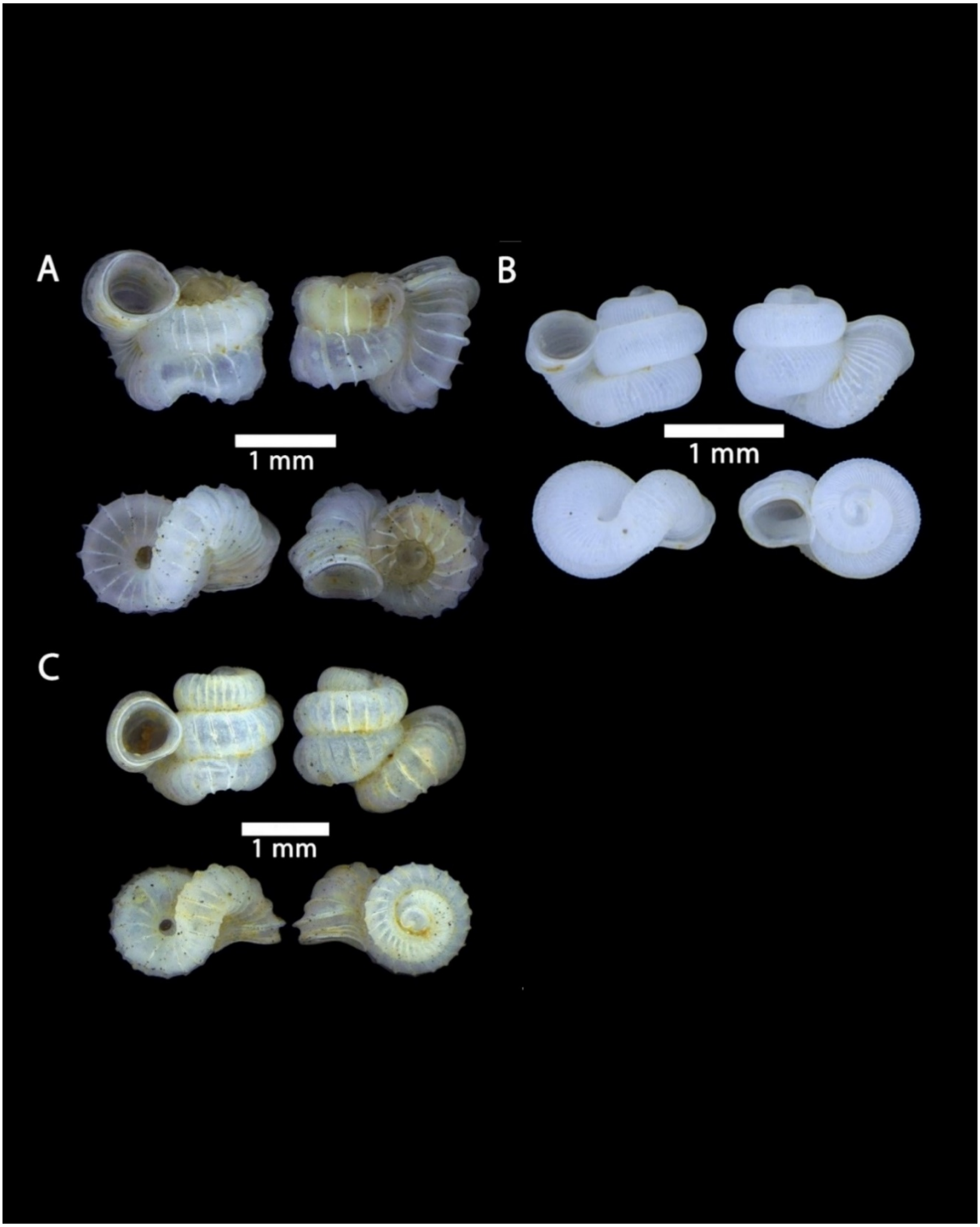


Figure 4.10: A. *Opisthostoma planiapex* Vermeulen, 1991 ME 9250 Gunung Kapor **B.** *Opisthostoma simile* Vermeulen, 1991 ME 11471 Gunung Kapor **C.** *Opisthostoma tridens* Vermeulen, 1991 ME 0333 Gunung Kapor.

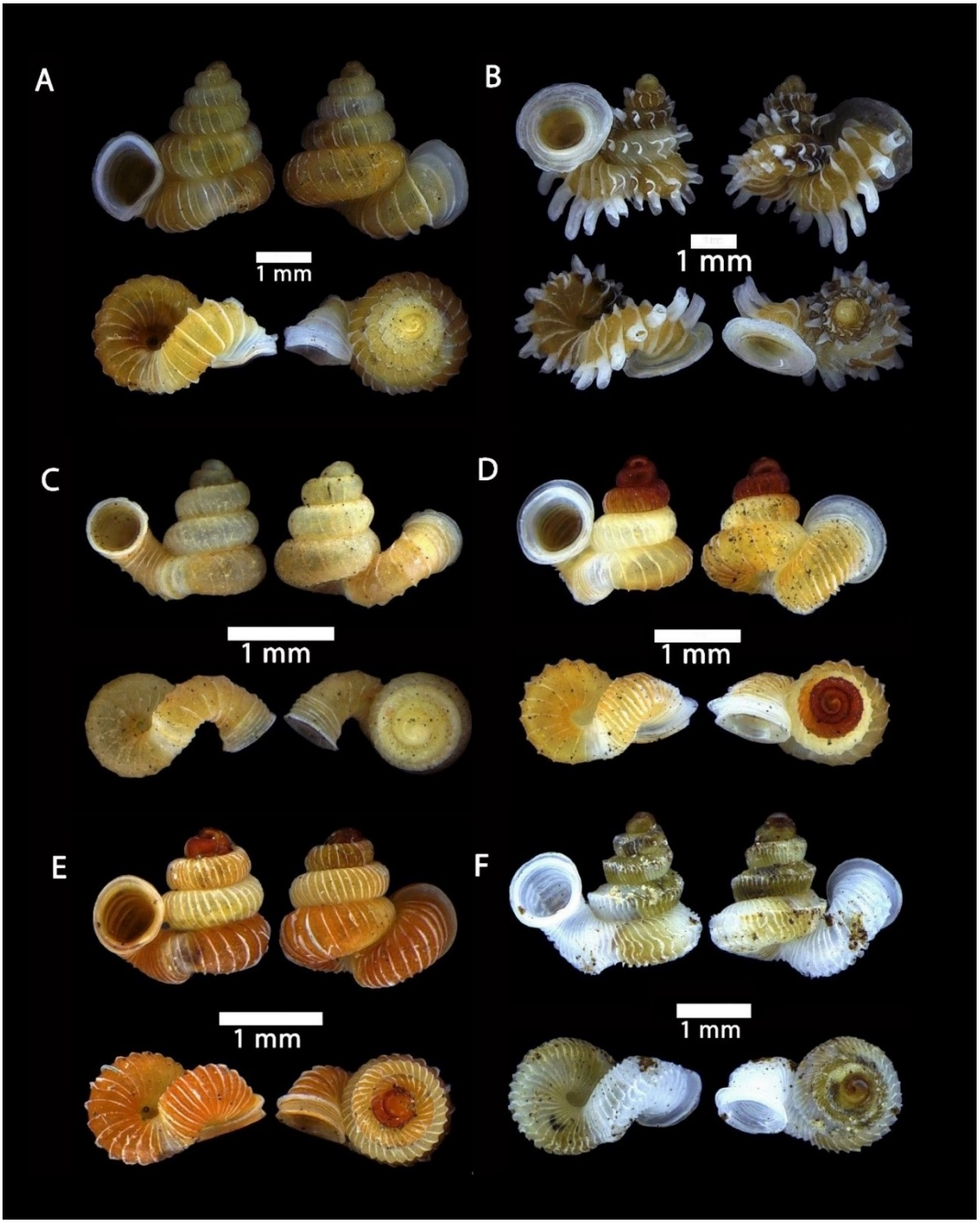


Figure 4.11: A. *Plectostoma austeni* (E. A. Smith, 1894) ME 8734 Lobang Angin **B.** *Plectostoma everetti* (E. A. Smith, 1893) ME 8793 Gunung Batu **C.** *Plectostoma margaretchanae* Marzuki, Liew & Mohd-Azlan, 2021, MZU.MOL.20.06 PARATYPE Gunung Batu **D.** *Plectostoma wallacei busauense* (E. A. Smith, 1893) ME 9495 Gunung Doya **E.** *Plectostoma wallacei teinostoma* (Vermeulen, 1994) ME 8899 Gunung Doya **F.** *Plectostoma wallacei wallacei* Ancey, 1887 ME 5898 Gunung Stulang.

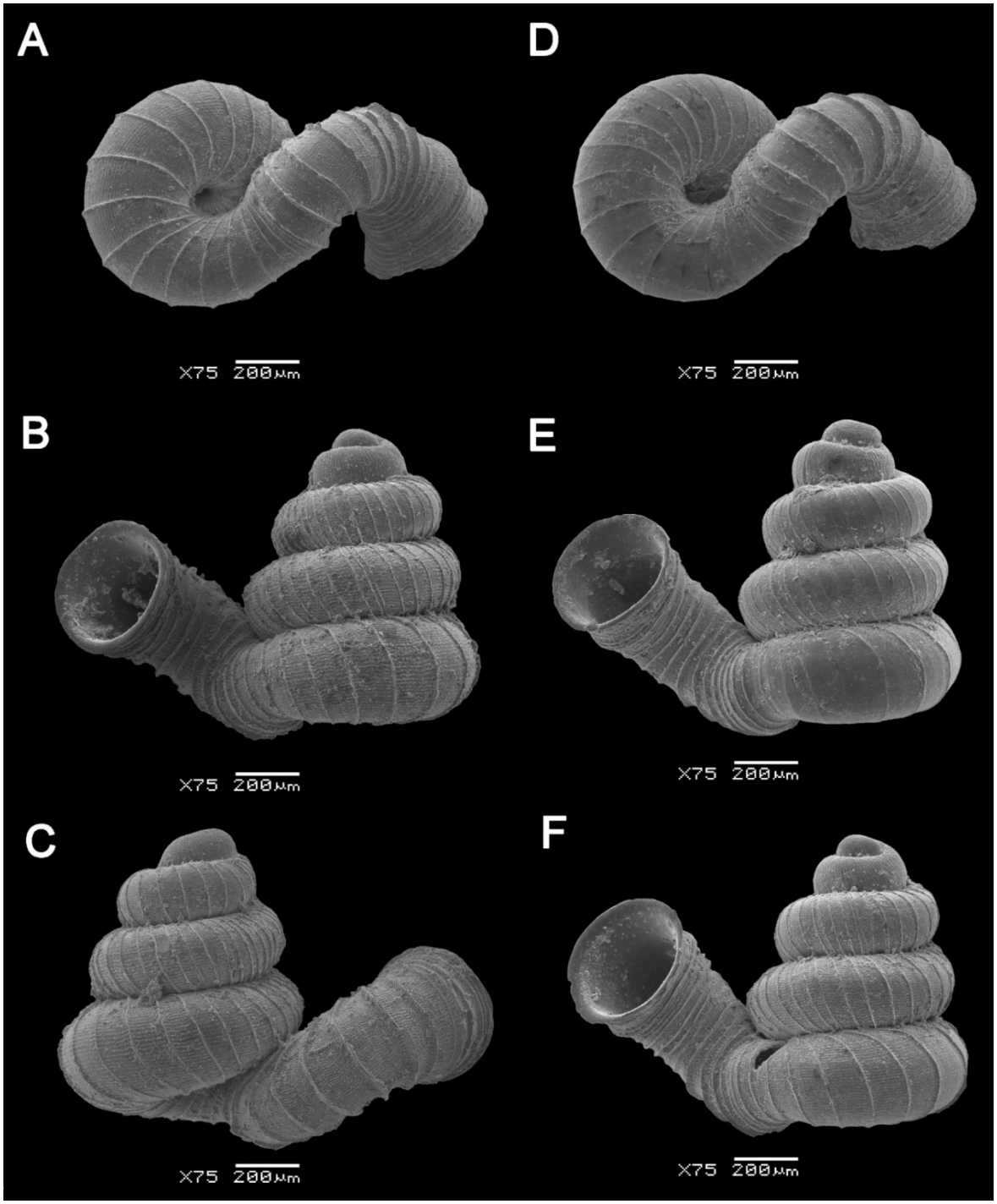


Figure 4.12: *Plectostoma margaretchanae* Marzuki, Liew & Mohd-Azlan, 2021, **A-C.** MZU.MOL.20.05 HOLOTYPE. **A.** Basal view, **B.** Apertural view, **C.** Abapertural view, **D-F.** ME 0227, PARATYPES. **D.** Basal view, **E-F.** Apertural view.

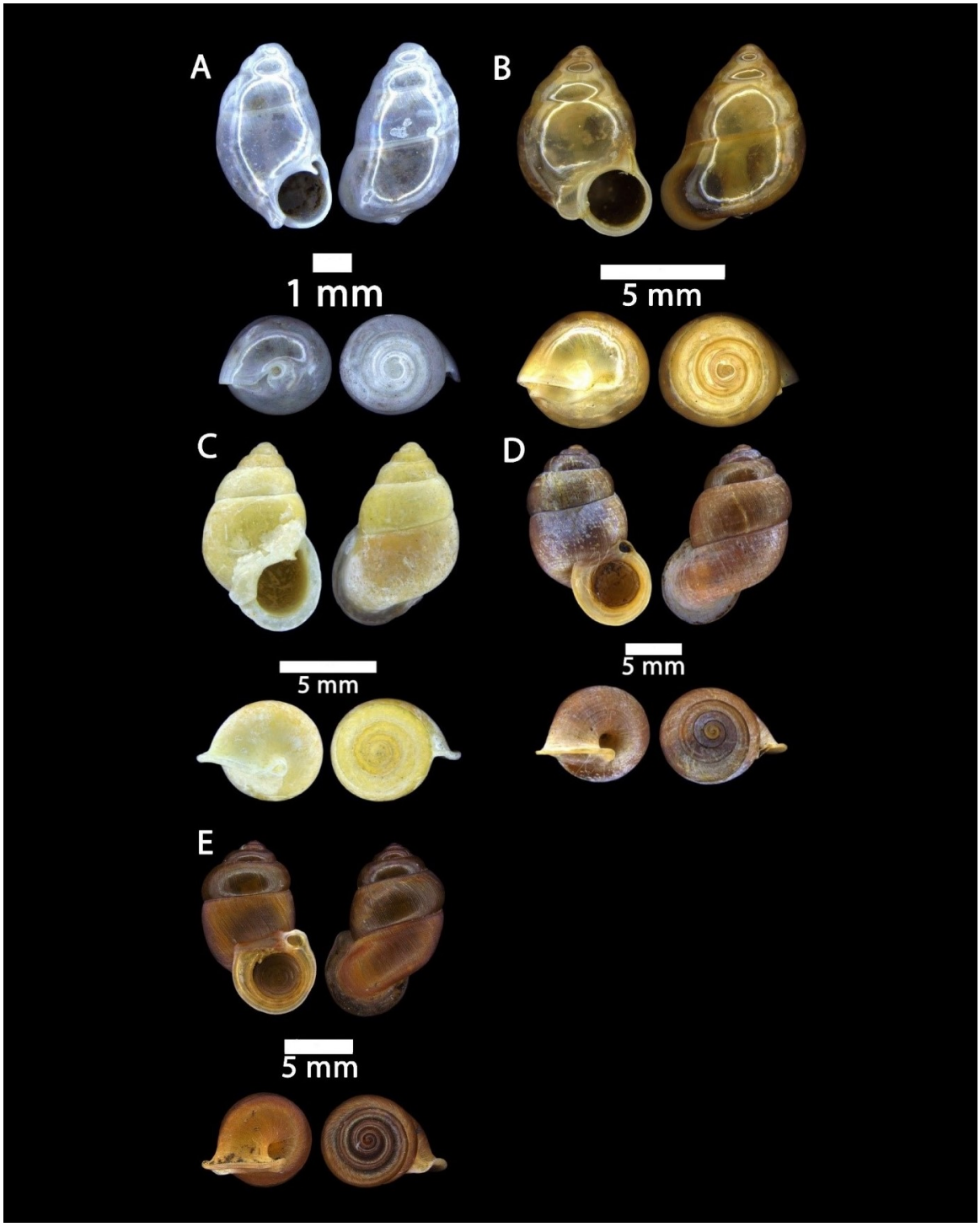


Figure 4.13: A. *Pupina doriae* Godwin-Austen, 1889 ME 8946 Gunung Doya **B.** *Pupina evansi* Godwin-Austen, 1889 ME 9053 Lobang Angin **C.** *Pupina hosei* Godwin-Austen, 1889 ME 1132 Gunung Batu **D.** *Rhaphaulus bombycinus* (L. Pfeiffer, 1855) ME 9556 Lobang Angin **E** *Rhaphaulus pfeifferi* (Issel, 1874) ME 8741 Lobang Angin.

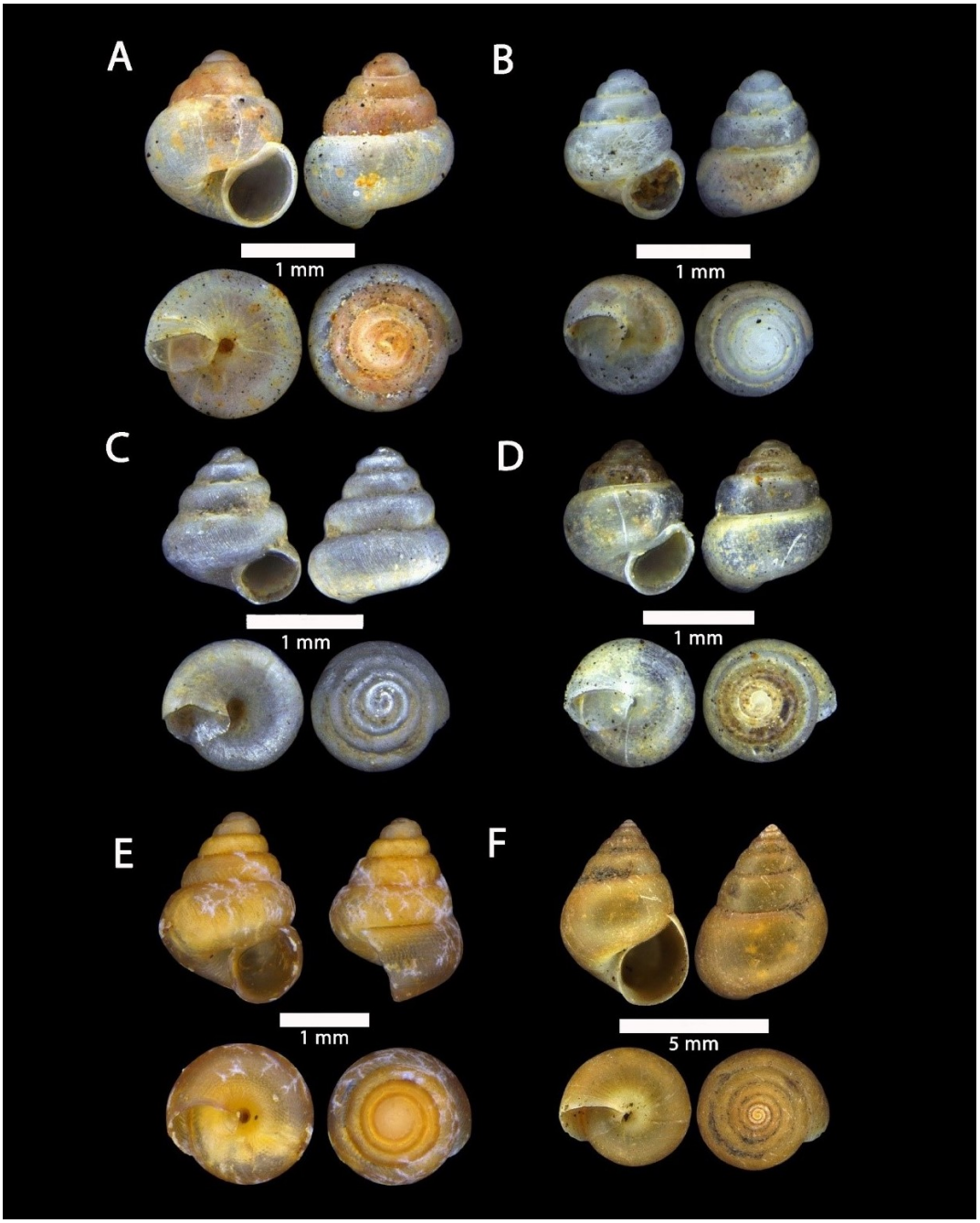


Figure 4.14: A. *Acmella bauensis* Marzuki, Liew & Mohd-Azlan, 2021, MZU.MOL.20.01 HOLOTYPE Gunung Kapor **B.** *Acmella cyrtoglyphe* Vermeulen, Liew & Schilthuizen, 2015 ME 8960 Gunung Doya [not in natural colour, shell surface coated with platinum for examination under scanning electron microscope] **C.** *Acmella nana* Vermeulen, Liew & Schilthuizen, 2015 ME 8497 Gunung Kapor **D.** *Acmella ovoidea* Vermeulen, Liew & Schilthuizen, 2015 ME 2215 Gunung Batu **E.** *Anaglyphula sauroderma* Vermeulen, Liew & Schilthuizen, 2015 ME 6910 Gunung Doya **F.** *Solenomphala scalaris* (Heude, 1882) ME 8810 Gunung Batu.

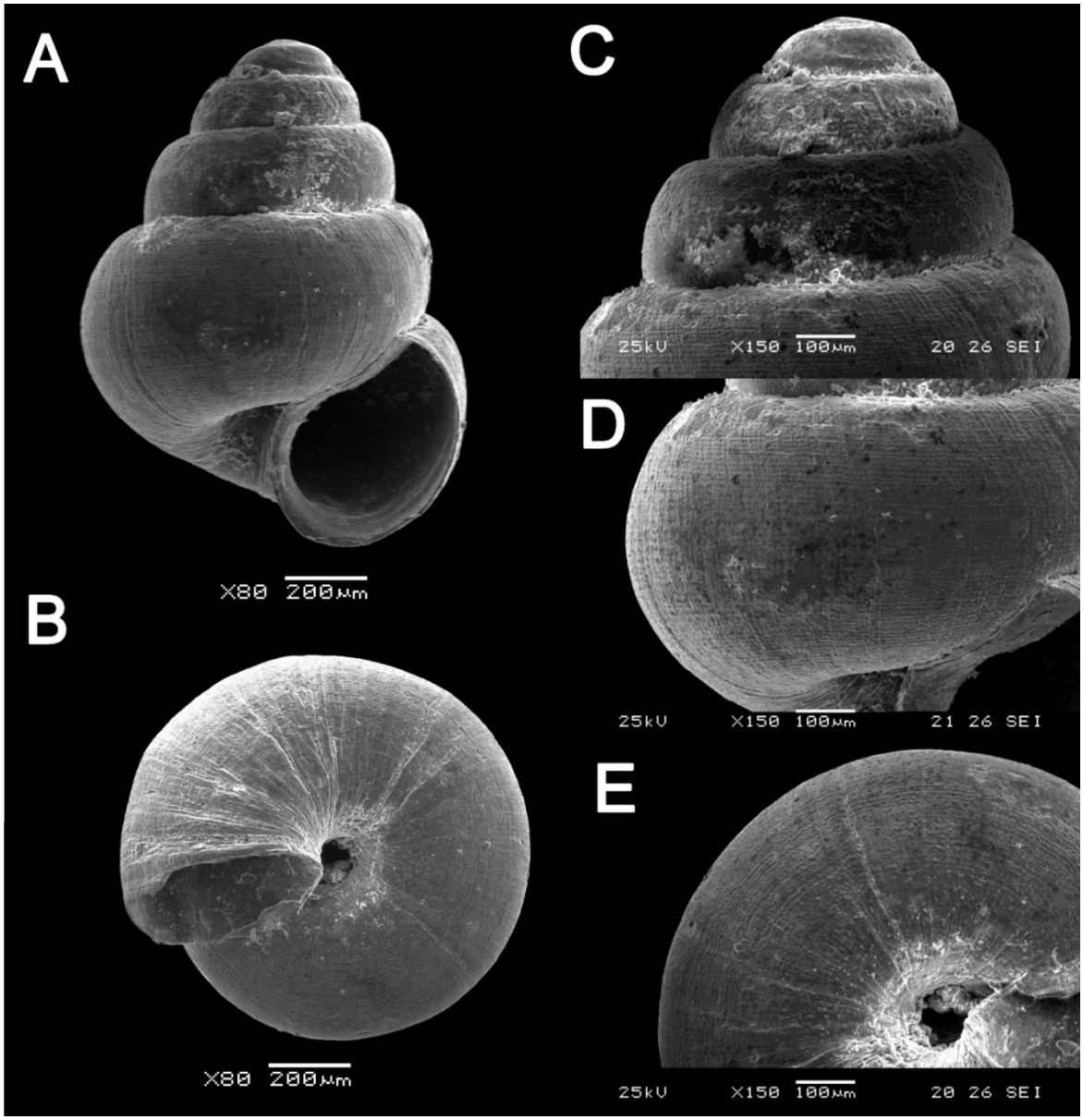


Figure 4.15: *Acmella bauensis* Marzuki, Liew & Mohd-Azlan, 2021. **A-F.** MZU.MOL.20.01 HOLOTYPE. **A.** Apertural view, **B.** Basal view, **C.** Enlargement of the apical side showing the apex, **D.** Enlargement of the body whorl showing the shell sculpture, **E.** Enlargement of the basal side of the shell.

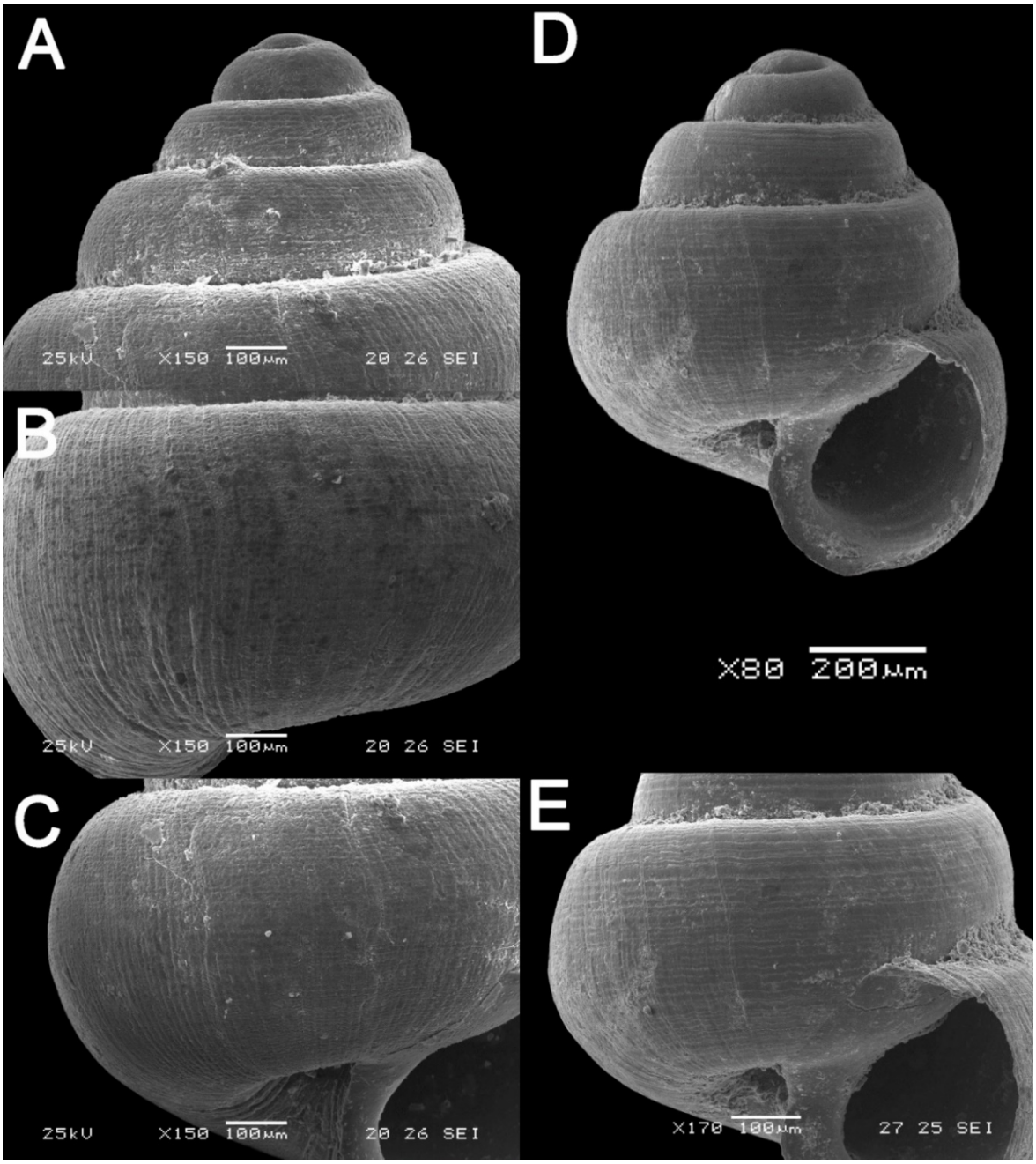


Figure 4.16: *Acmella bauensis* Marzuki, Liew & Mohd-Azlan, 2021. **A-C.** ME0002340 PARATYPE. **A.** Enlargement of the apical side showing the apex, **B.** Enlargement of the body whorl (abapertural side) showing the shell sculpture, **C.** Enlargement of the body whorl (apertural side) showing the shell sculpture. *Acmella nana* Vermeulen, Liew, & Schilthuizen, 2015. **D-E.** ME0009091 SPECIMEN. **D.** Apertural view, **E.** Enlargement of the body whorl (apertural side) showing the shell sculpture.

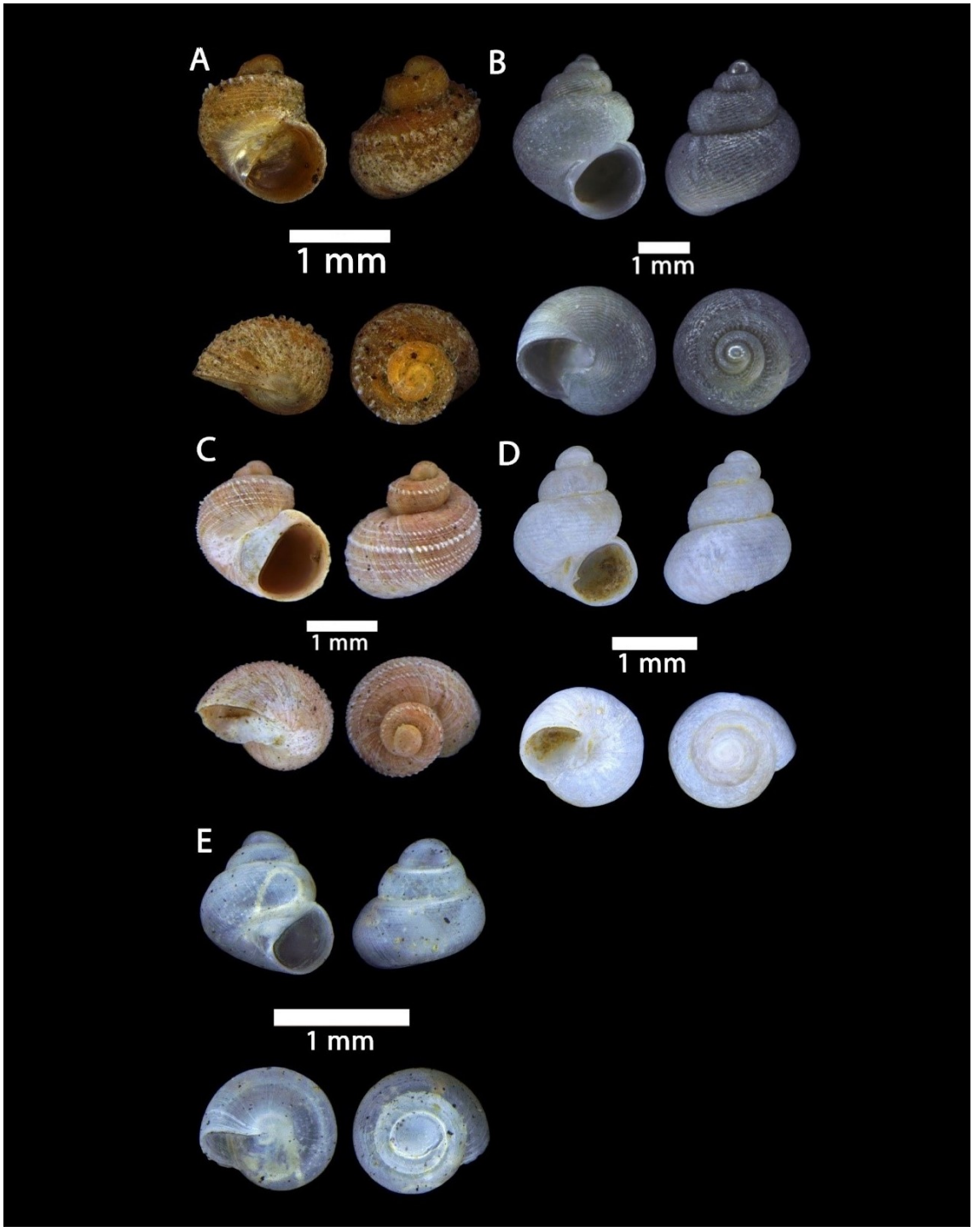


Figure 4.17: A. *Georissa bauensis* Khalik, Hendricks, Vermeulen & Schilthuizen, 2018 ME 8731 Lobang Angin **B.** *Georissa everetti* E. A. Smith, 1895 ME 0906 Gunung Batu [not in natural colour, shell surface coated with platinum for examination under scanning electron microscope] **C.** *Georissa hosei* Godwin-Austen, 1889 ME 8498 Gunung Kapor **D.** *Georissa hungerfordi* Godwin-Austen, 1889, ME 11472 Gunung Kapor **E.** *Georissa leucococca* Vermeulen, Liew & Schilthuizen, 2015 ME 9496 Gunung Doya.

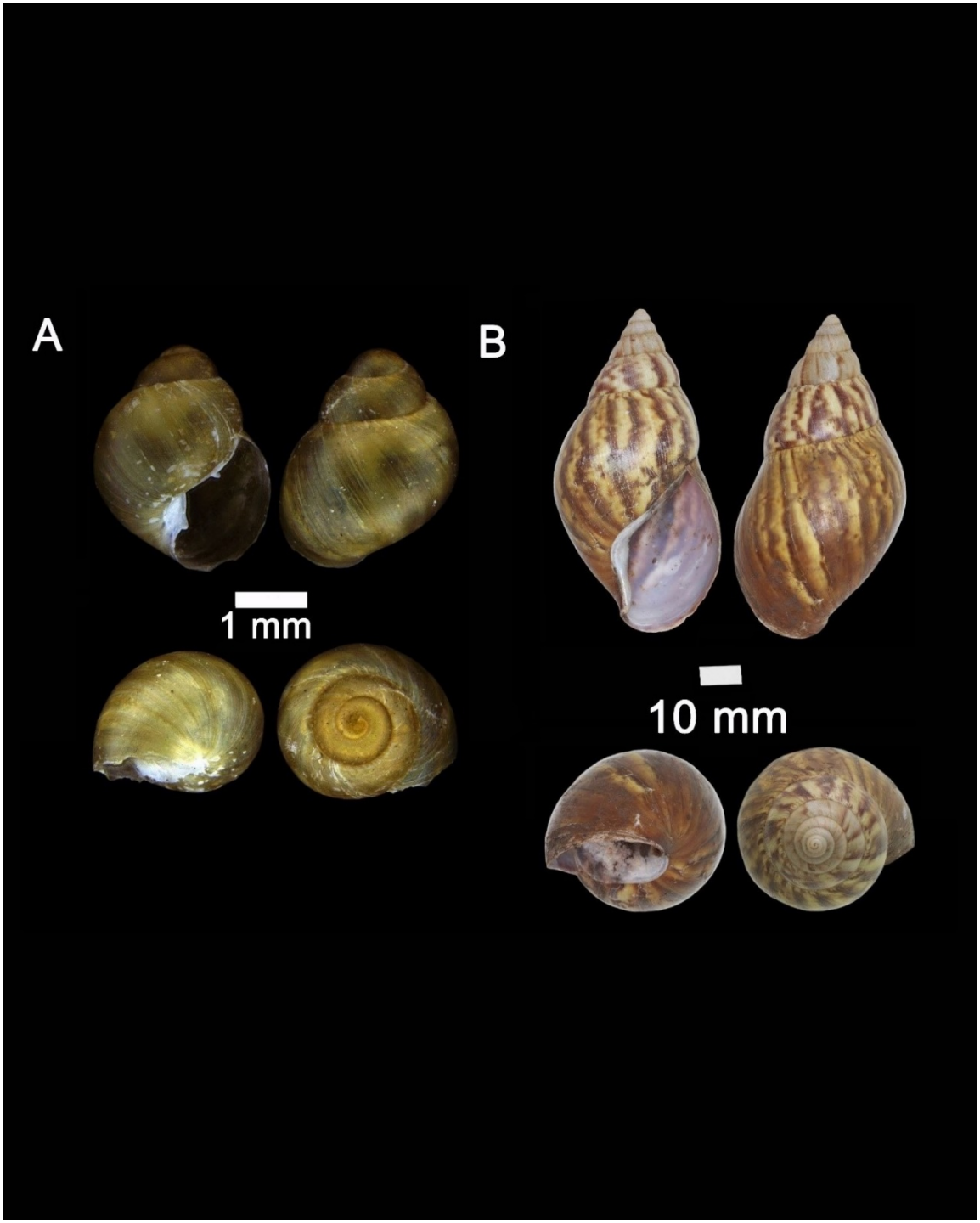


Figure 4.18: A. *Elasmias sundanum* (Möllendorff, 1897) ME 8982 Lobang Angin **B.** *Lissachatina fulica* (Bowdich, 1822) ME 9241 Gunung Kapor.

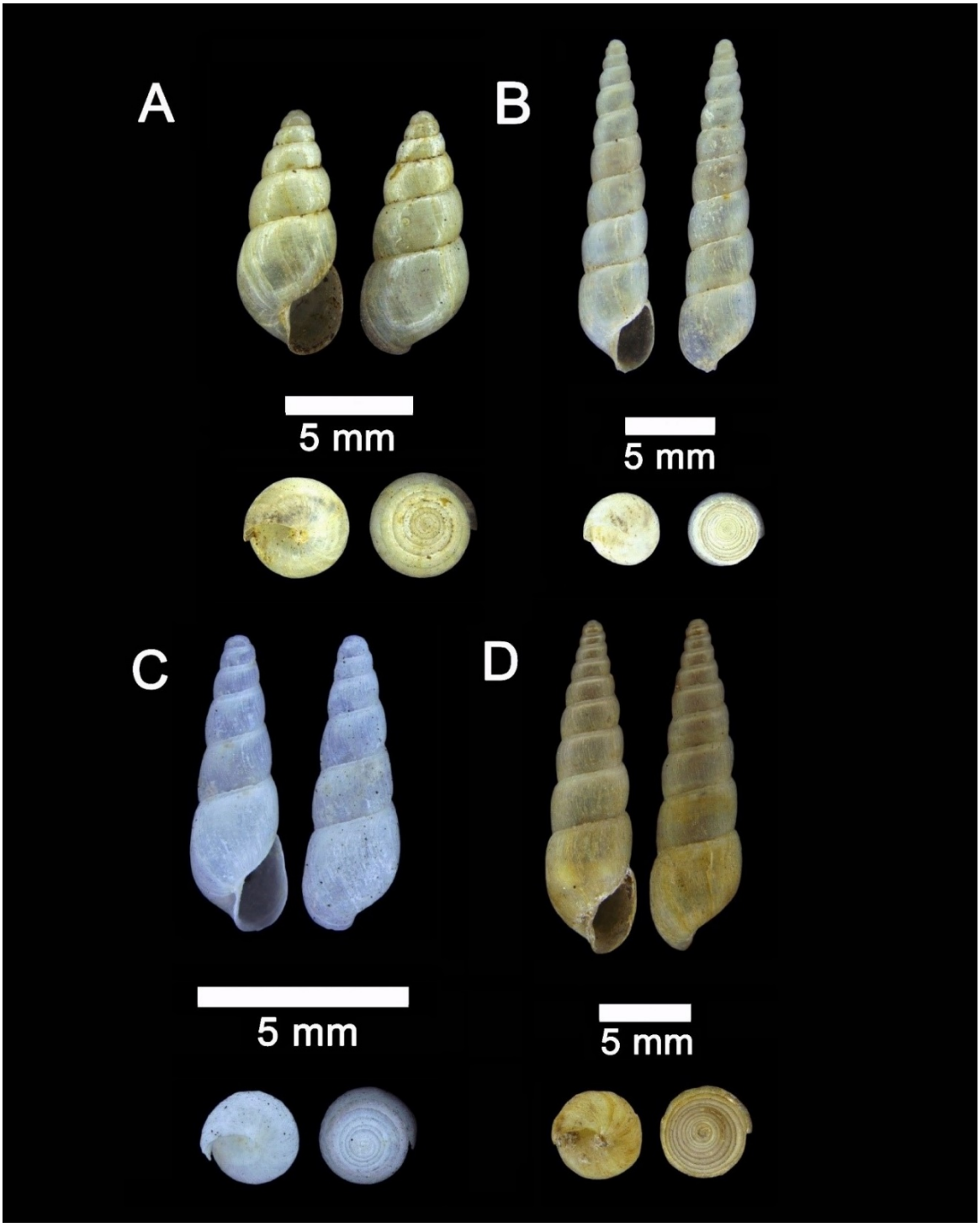


Figure 4.19: A. *Allopeas clavulinum* (Potiez & Michaud, 1838) ME 0753 Gunung Kapor **B.** *Allopeas gracile* (T. Hutton, 1834) ME 2942 Gunung Kapor **C.** *Opeas hannense* (Rang, 1831) ME 9096 Gunung Kapor **D.** *Paropeas achatinaceum* (L. Pfeiffer, 1846) ME 5977 Gunung Kapor.

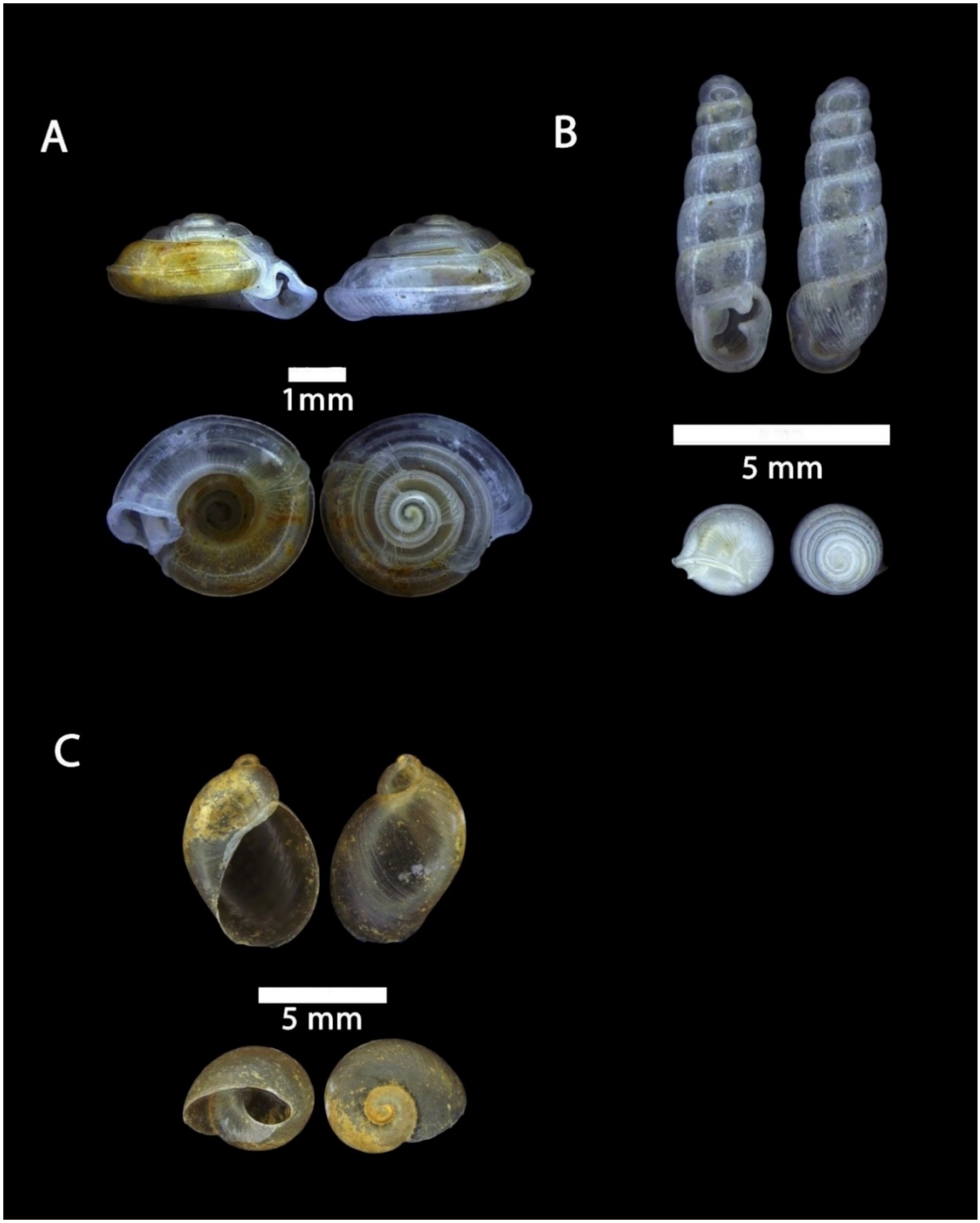


Figure 4.20: A. *Platycochlium sarawakense* Laidlaw, 1950 ME 8993 Gunung Doya **B.** *Gulella bicolor* (T. Hutton, 1834) ME 9095 Gunung Kapor **C.** *Succinea obesa* Martens, 1867 ME 2903 Gunung Batu.

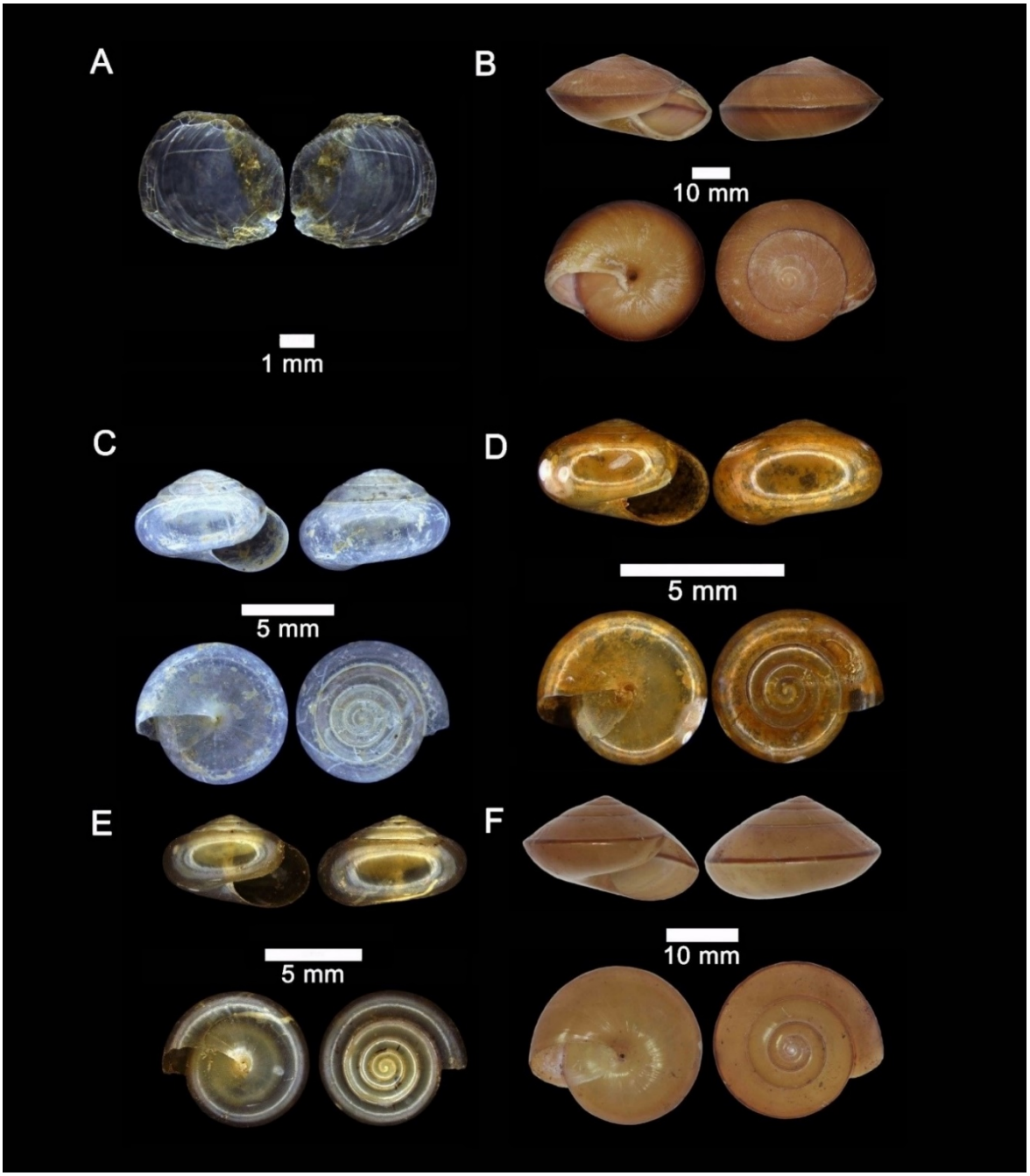


Figure 4.21: A. *Damayantia carinata* Collinge, 1901 ME 9054 Lobang Angin **B.** *Hemiplecta densa* (A. Adams & Reeve, 1850) ME 9241 Gunung Doya **C.** *Macrochlamys infans* (L. Pfeiffer, 1854) ME 2854 Gunung Batu **D.** *Macrochlamys saintjohni* (Godwin-Austen, 1891) ME 9900 Gunung Kapor **E.** *Macrochlamys tersa* (Issel, 1874) ME 9620 Gunung Kapor **F.** *Vitrinula glutinosa* (Metcalfe, 1851) ME 8782 Gunung Kapor.

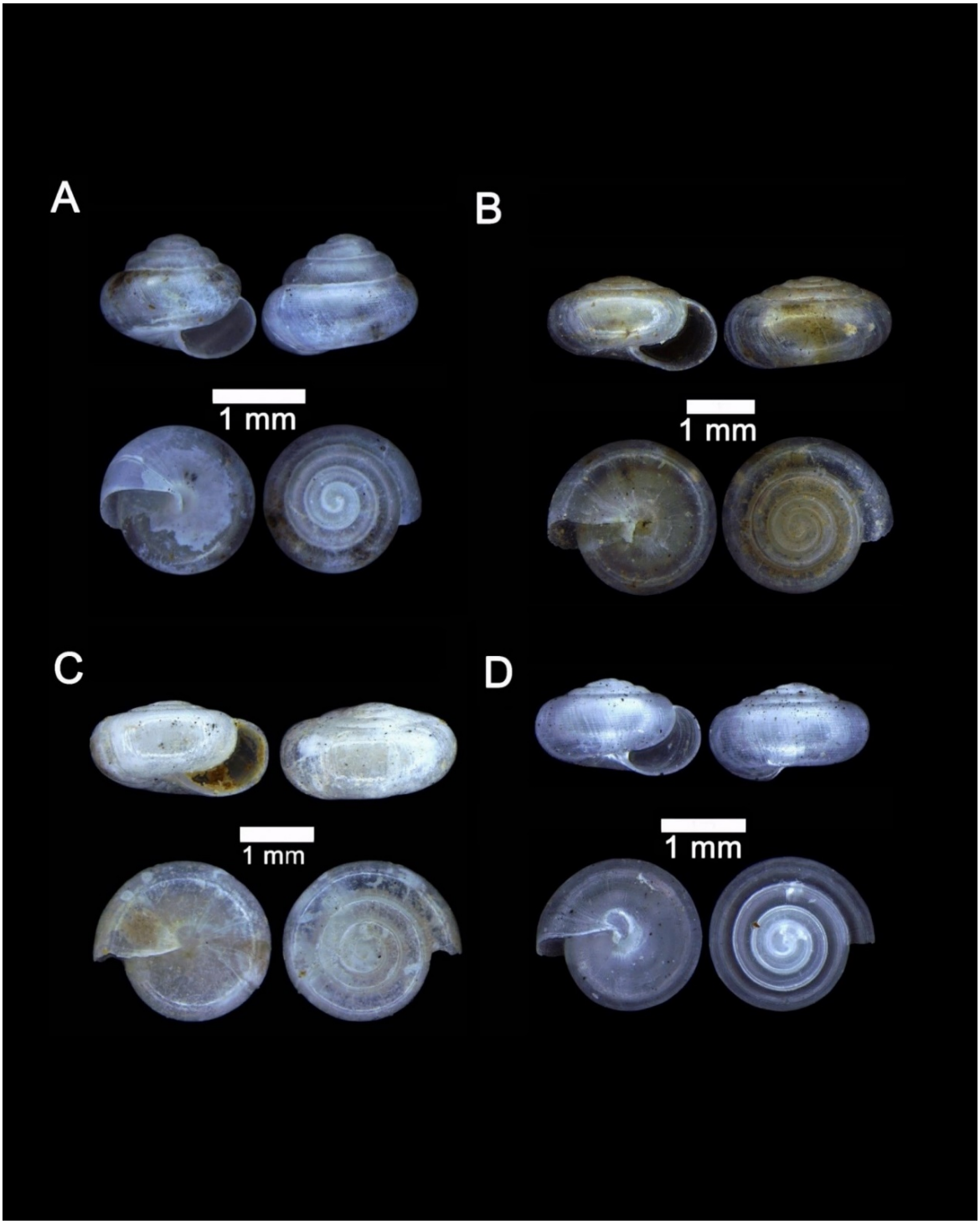


Figure 4.22: A. *Microcystina arabii* Marzuki, Liew & Mohd-Azlan, 2021 MZU.MOL.20.06 HOLOTYPE Gunung Batu **B.** *Microcystina atoni* Marzuki, Liew & Mohd-Azlan, 2021 MZU.MOL.20.11 PARATYPE Gunung Batu **C.** *Microcystina kilat* Marzuki, Liew & Mohd-Azlan, 2021 MZU.MOL.20.19 PARATYPE Gunung Batu **D.** *Microcystina lirata* Marzuki, Liew & Mohd-Azlan, 2021 MZU.MOL.20.15 PARATYPE Gunung Kapor.

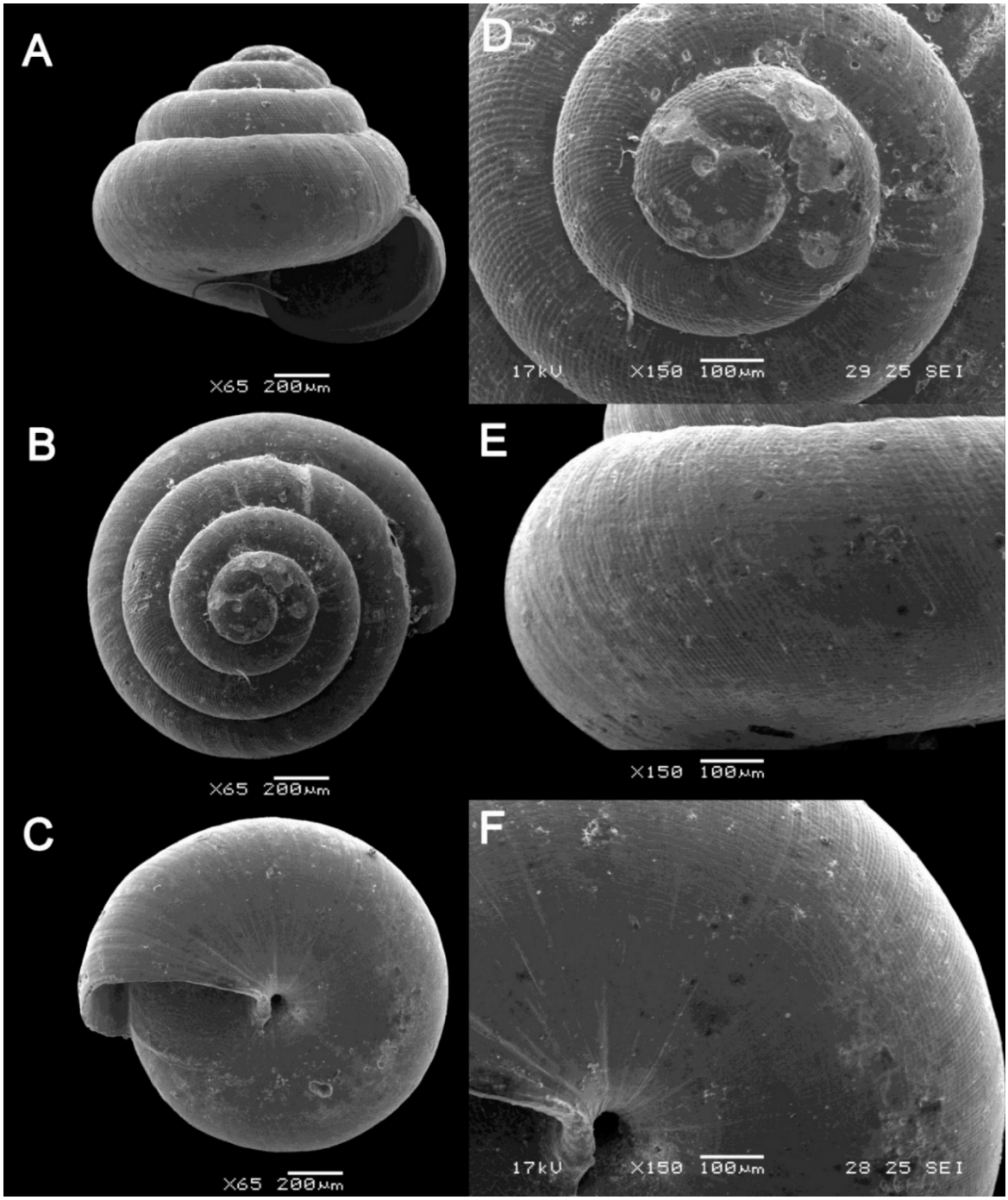


Figure 4.23: *Microcystina arabii* Marzuki, Liew & Mohd-Azlan, 2021. **A-F.** MZU.MOL.20.07 PARATYPE. **A.** Apertural view, **B.** Apical view, **C.** Basal view, **D.** Enlargement of the apical side showing the apex, **E.** Enlargement of the body whorl showing the shell sculpture, **F.** Enlargement of the basal side of the shell.

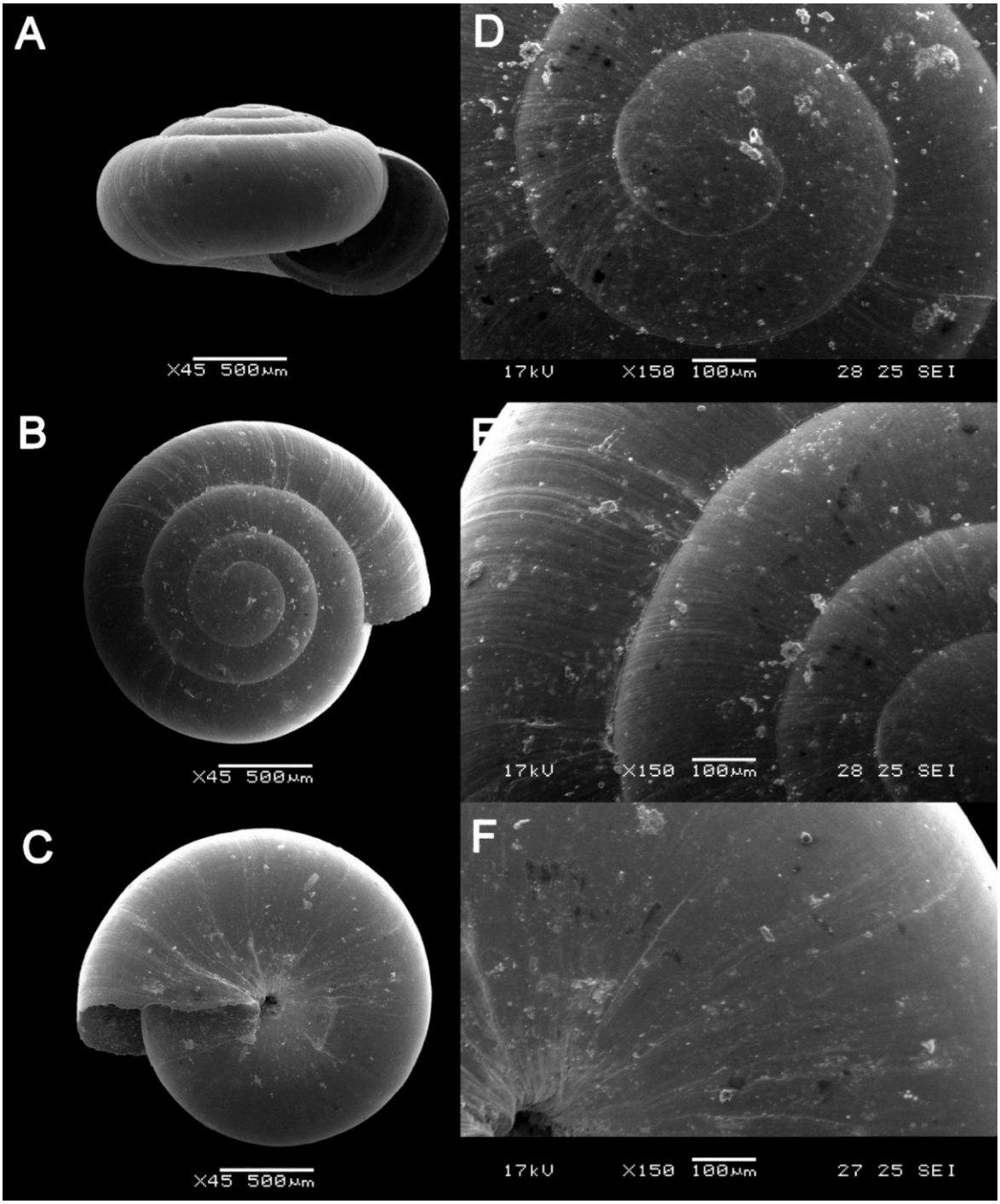


Figure 4.24: *Microcystina atoni* Marzuki, Liew & Mohd-Azlan, 2021. **A-F.** MZU.MOL.20.10 HOLOTYPE. **A.** Apertural view, **B.** Apical view, **C.** Basal view, **D.** Enlargement of the apical side showing the apex, **E.** Enlargement of the teleoconch showing the shell sculpture, **F.** Enlargement of the basal side of the shell.

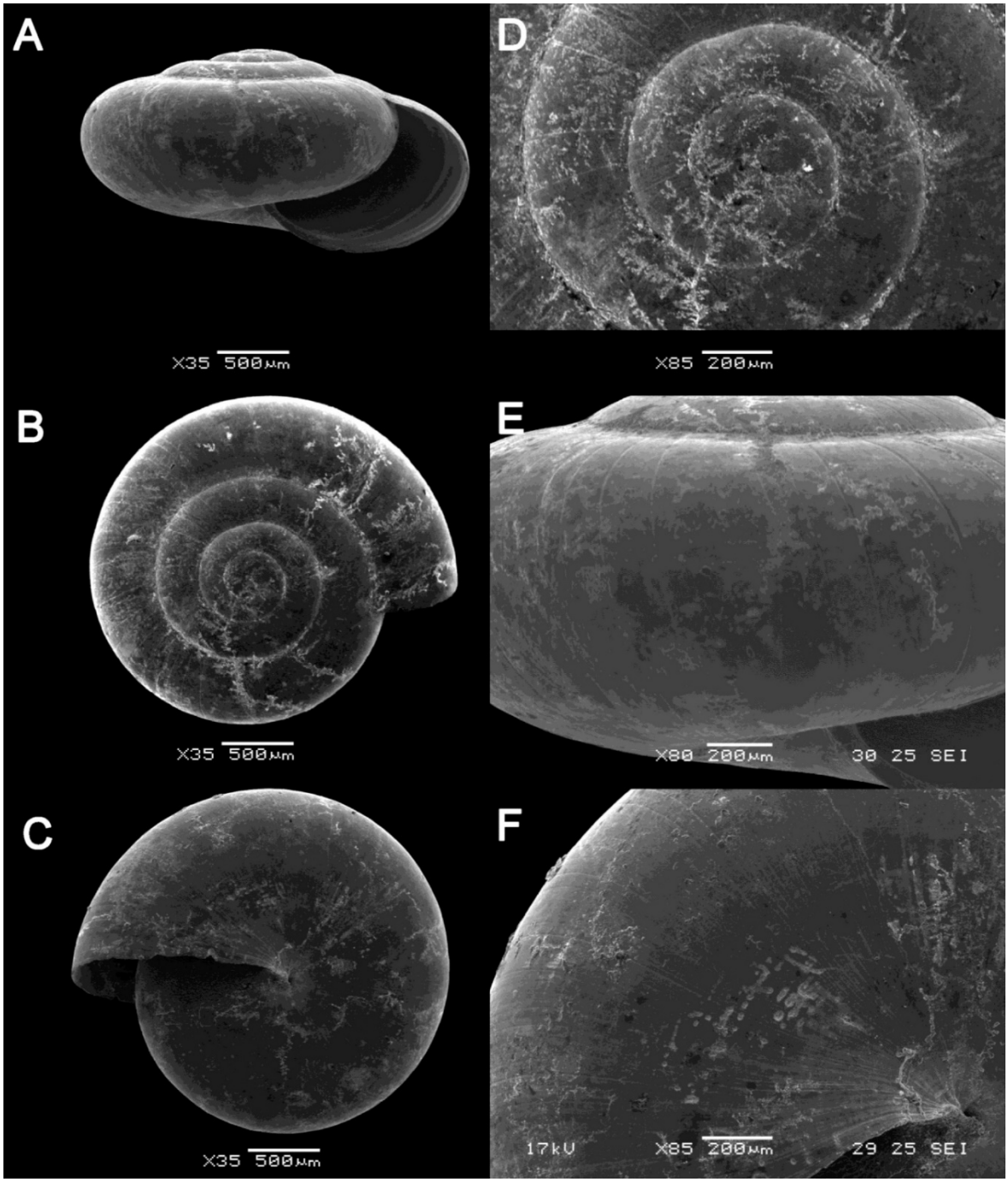


Figure 4.25: *Microcystina kilat* Marzuki, Liew & Mohd-Azlan, 2021. **A-F.** MZU.MOL.20.18 HOLOTYPE. **A.** Apertural view, **B.** Apical view, **C.** Basal view, **D.** Enlargement of the apical side showing the apex, **E.** Enlargement of the body whorl showing the shell sculpture, **F.** Enlargement of the basal side of the shell.

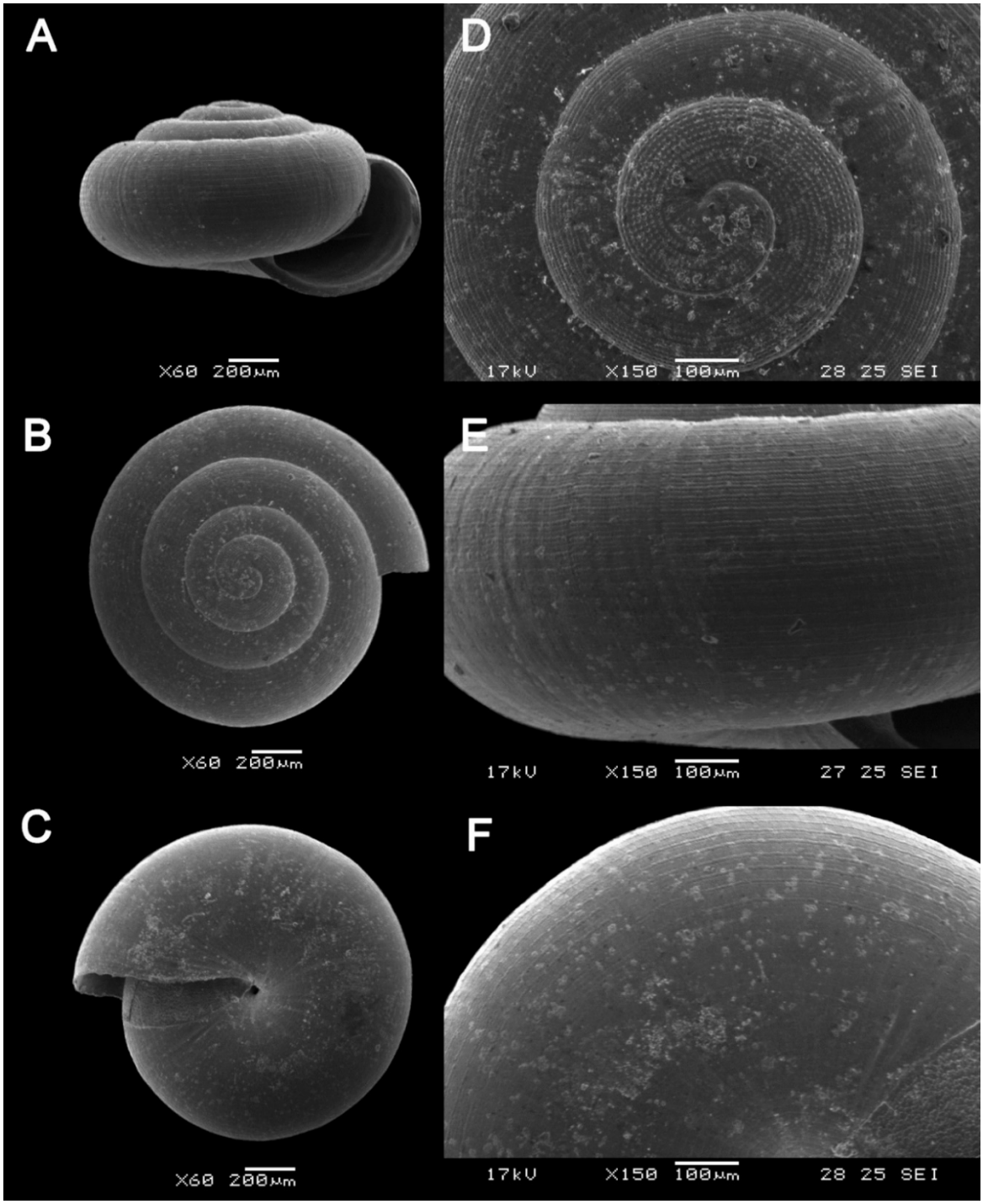


Figure 4.26: *Microcystina lirata* Marzuki, Liew & Mohd-Azlan, 2021. **A-F.** MZU.MOL.20.14 HOLOTYPE. **A.** Apertural view, **B.** Apical view, **C.** Basal view, **D.** Enlargement of the apical side showing the apex, **E.** Enlargement of the body whorl showing the shell sculpture, **F.** Enlargement of the basal side of the shell.

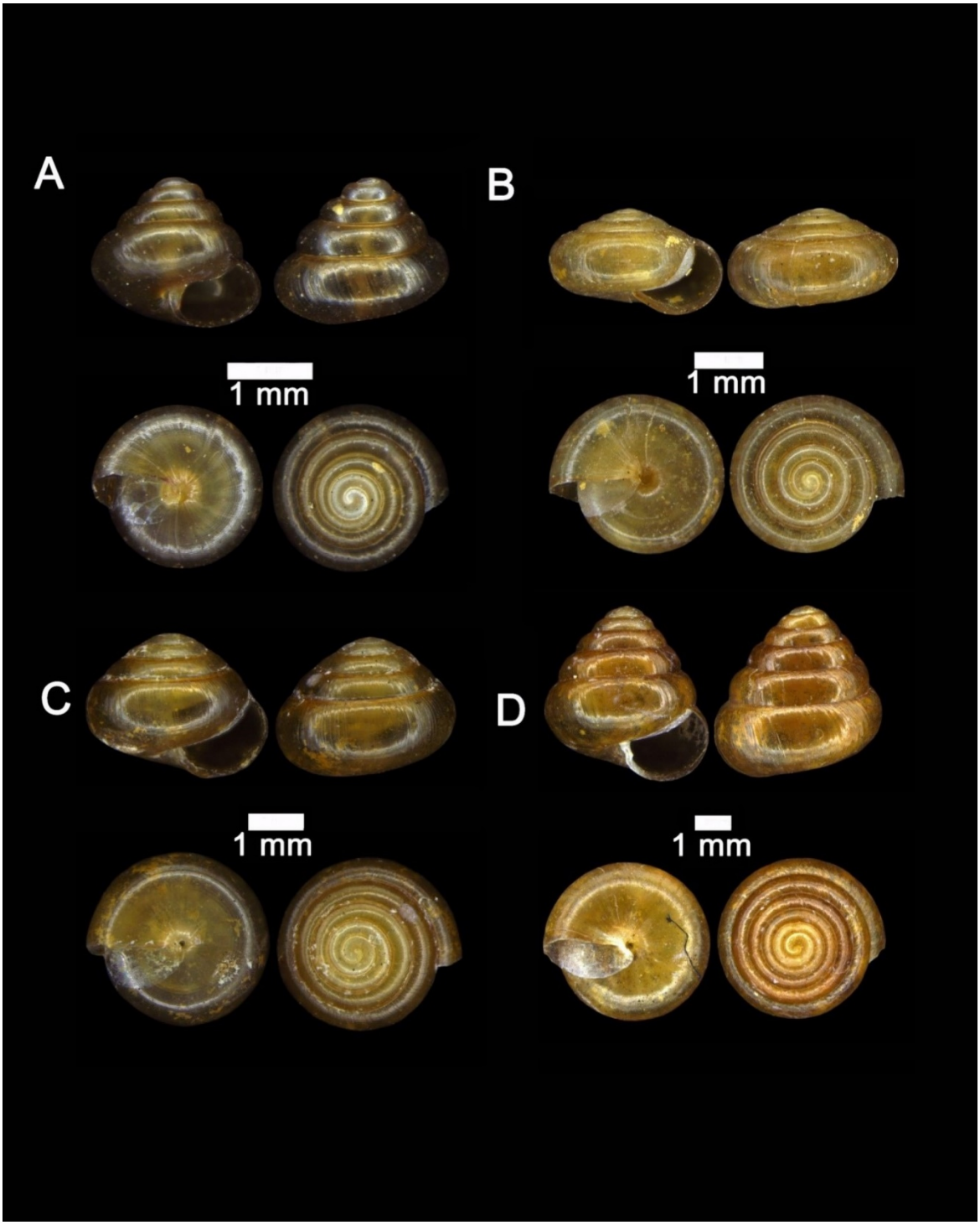


Figure 4.27: A. *Microcystina oswaldbrakeni* Marzuki, Liew & Mohd-Azlan, 2021 MZU.MOL.20.17 PARATYPE Gunung Batu **B.** *Microcystina paripari* Marzuki, Liew & Mohd-Azlan, 2021 ME 1746 PARATYPE Gunung Batu **C.** *Microcystina physotrochus* Vermeulen, Liew & Schilthuizen, 2015 ME 9072 Gunung Kapor **D.** *Microcystina seclusa* Godwin-Austen, 1891 ME 8153 Gunung Kapor.

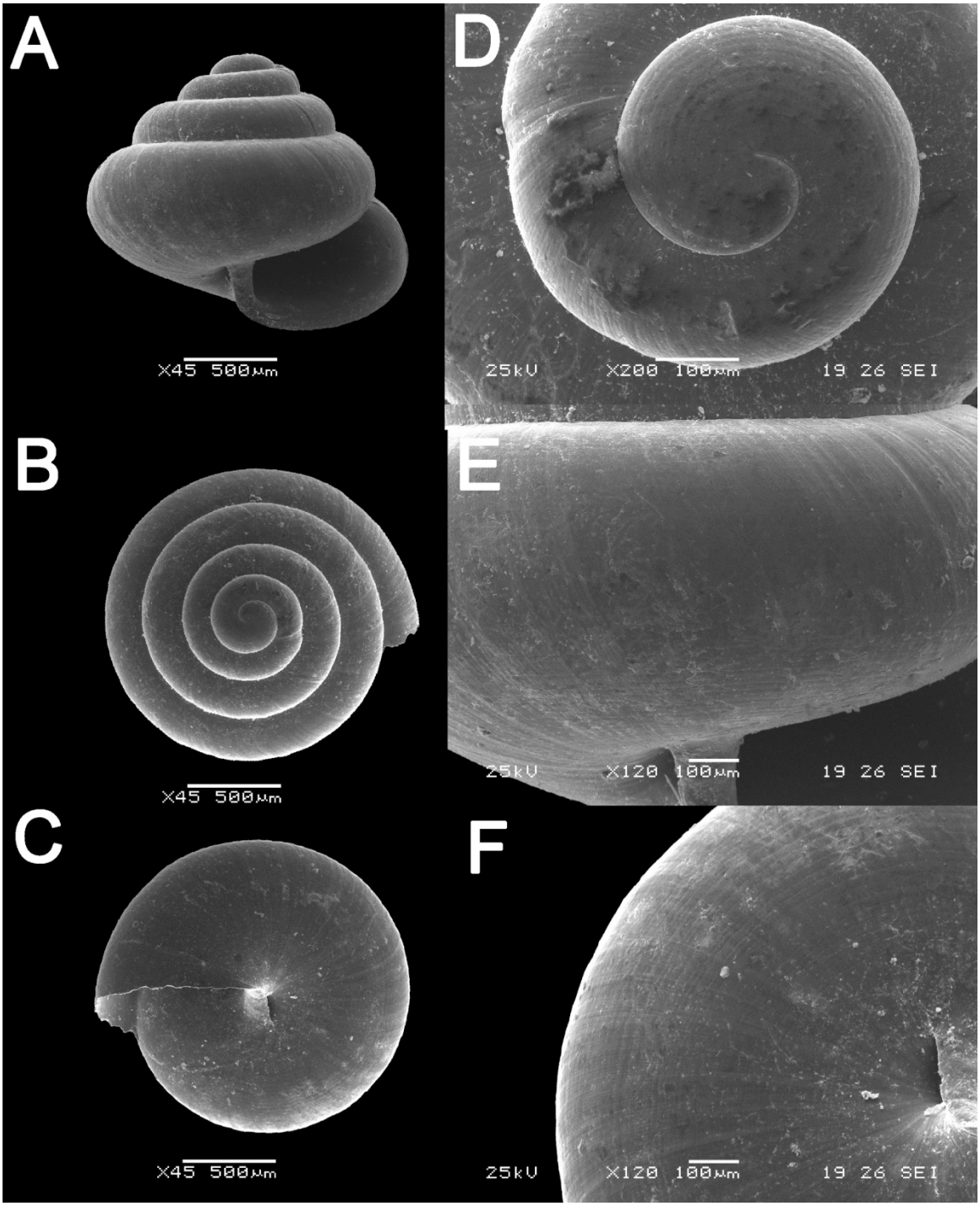


Figure 4.28: *Microcystina oswaldbrakeni* Marzuki, Liew & Mohd-Azlan, 2021. **A-F.** MZU.MOL.20.16 HOLOTYPE. **A.** Apertural view, **B.** Apical view, **C.** Basal view, **D.** Enlargement of the apical side showing the apex, **E.** Enlargement of the teleoconch showing the shell sculpture, **F.** Enlargement of the basal side of the shell.

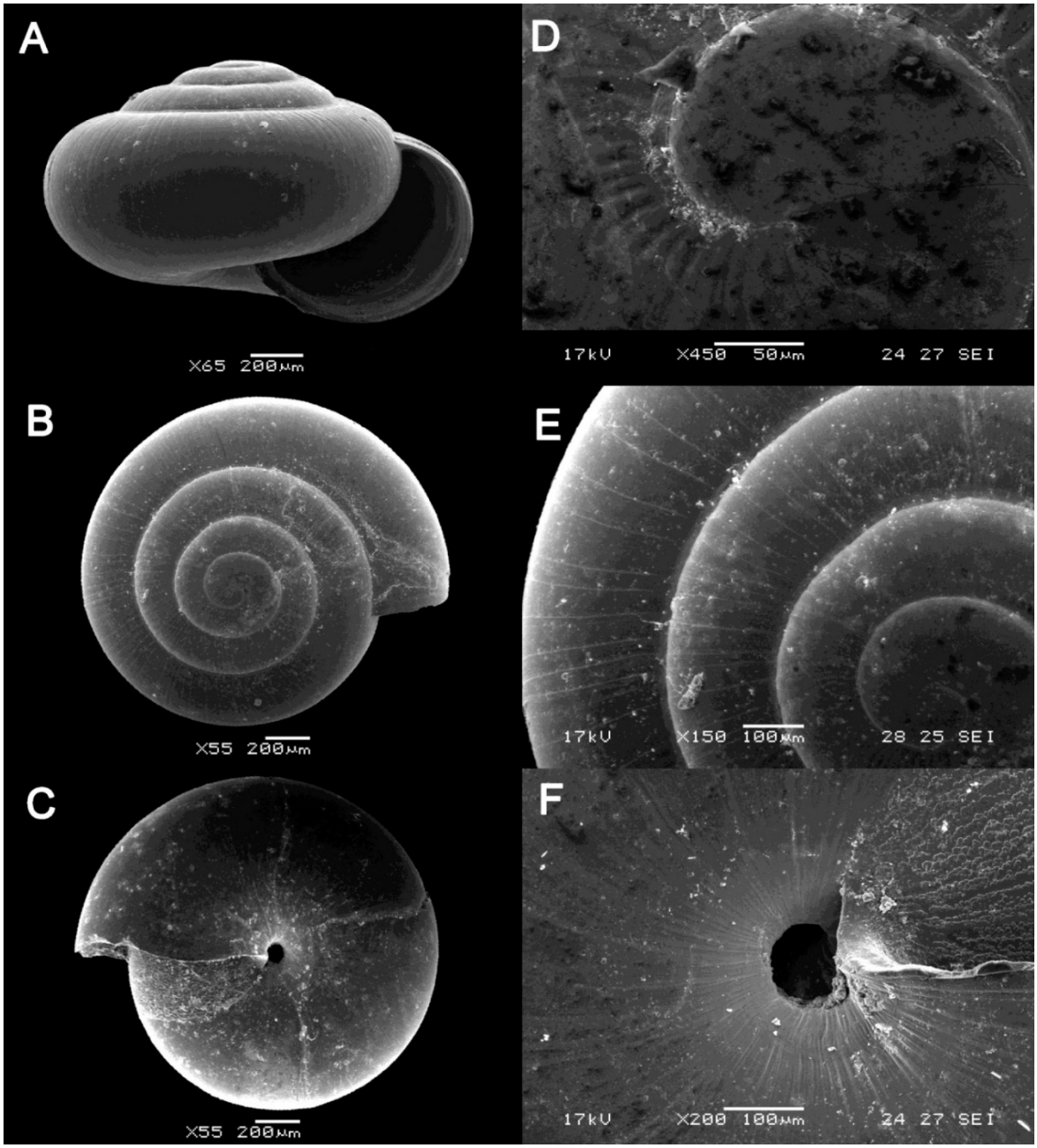


Figure 4.29: *Microcystina paripari* Marzuki, Liew & Mohd-Azlan, 2021. **A-F.** MZU.MOL.20.12 HOLOTYPE. **A.** Apertural view, **B.** Apical view, **C.** Basal view, **D.** Enlargement of the apical side showing the apex, **E.** Enlargement of the teleoconch showing the shell sculpture, **F.** Enlargement of the basal side of the shell.

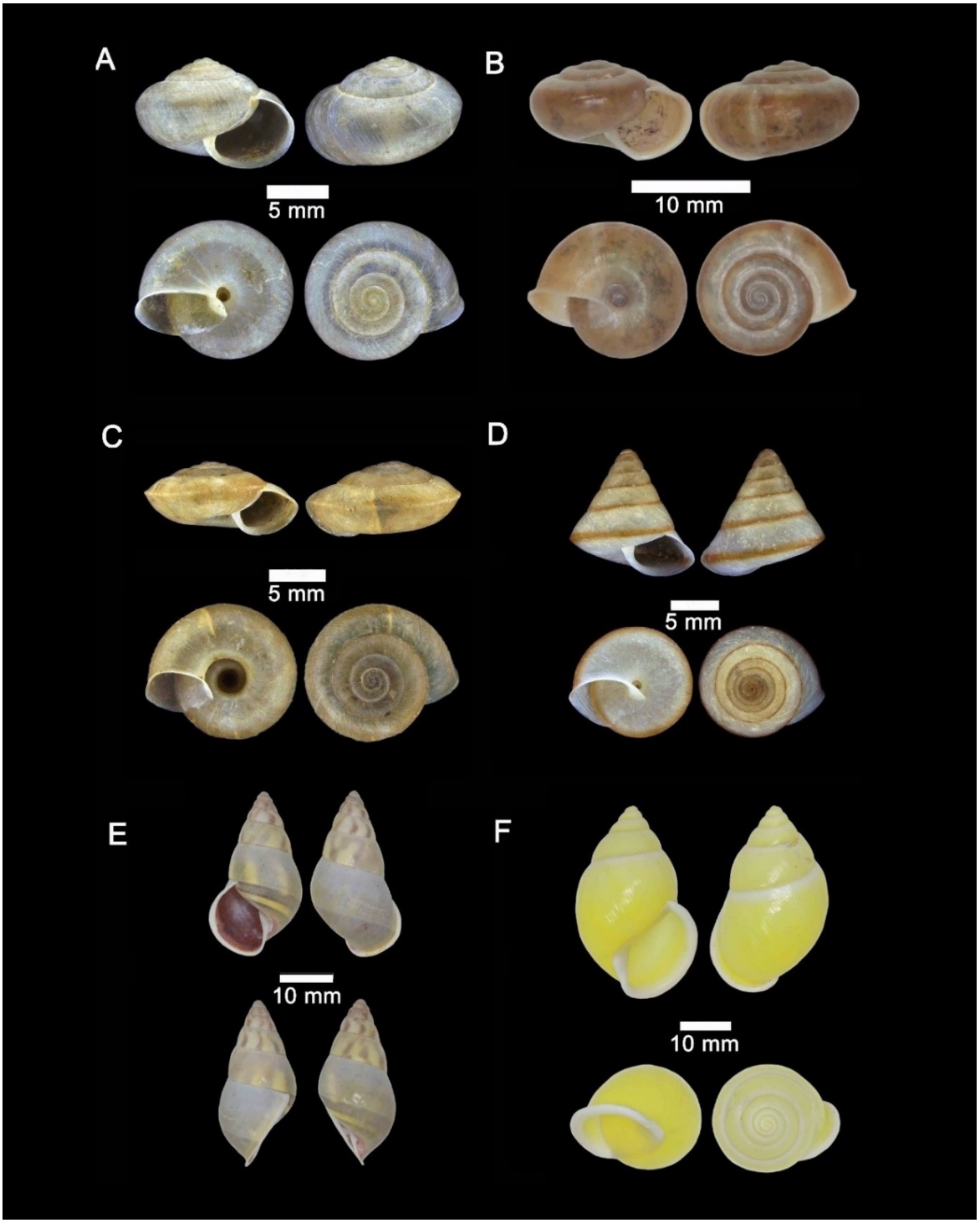


Figure 4.30: A. *Bradybaena similaris* (Férussac, 1821) ME 4906 Gunung Batu **B.** *Chloritis tomentosa* (L. Pfeiffer, 1854) ME 8917 Gunung Doya **C.** *Landouria winteriana* (L. Pfeiffer, 1842) ME 8078 Gunung Kapor **D.** *Ganesella acris* (Benson, 1859) ME 8963 Gunung Kapor **E.** *Amphidromus angulatus* Fulton, 1896 ME 4632 Gunung Kapor **F.** *Amphidromus epidemiae* Wang, 2021 ME 8756 Gunung Kapor.

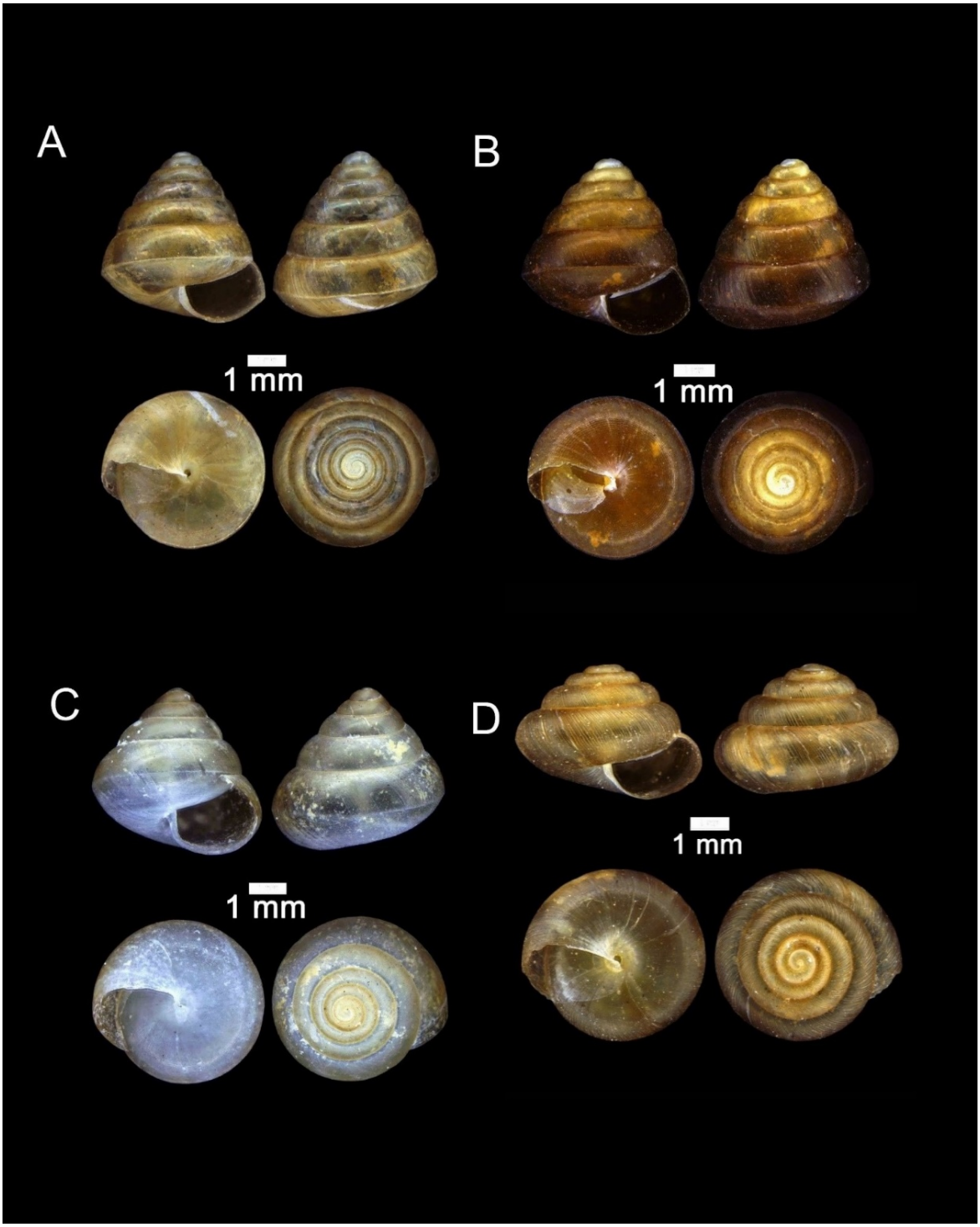


Figure 4.31: A. *Kaliella barrakporensis* (L. Pfeiffer, 1852) ME 9009 Gunung Kapor **B.** *Kaliella busauensis* (E. A. Smith, 1895) ME 1892 Gunung **C.** *Kaliella calculosa* (Gould, 1852) ME 1863 Gunung Kapor **D.** *Kaliella doliolum* (L. Pfeiffer, 1846) ME 9074 Gunung Kapor.

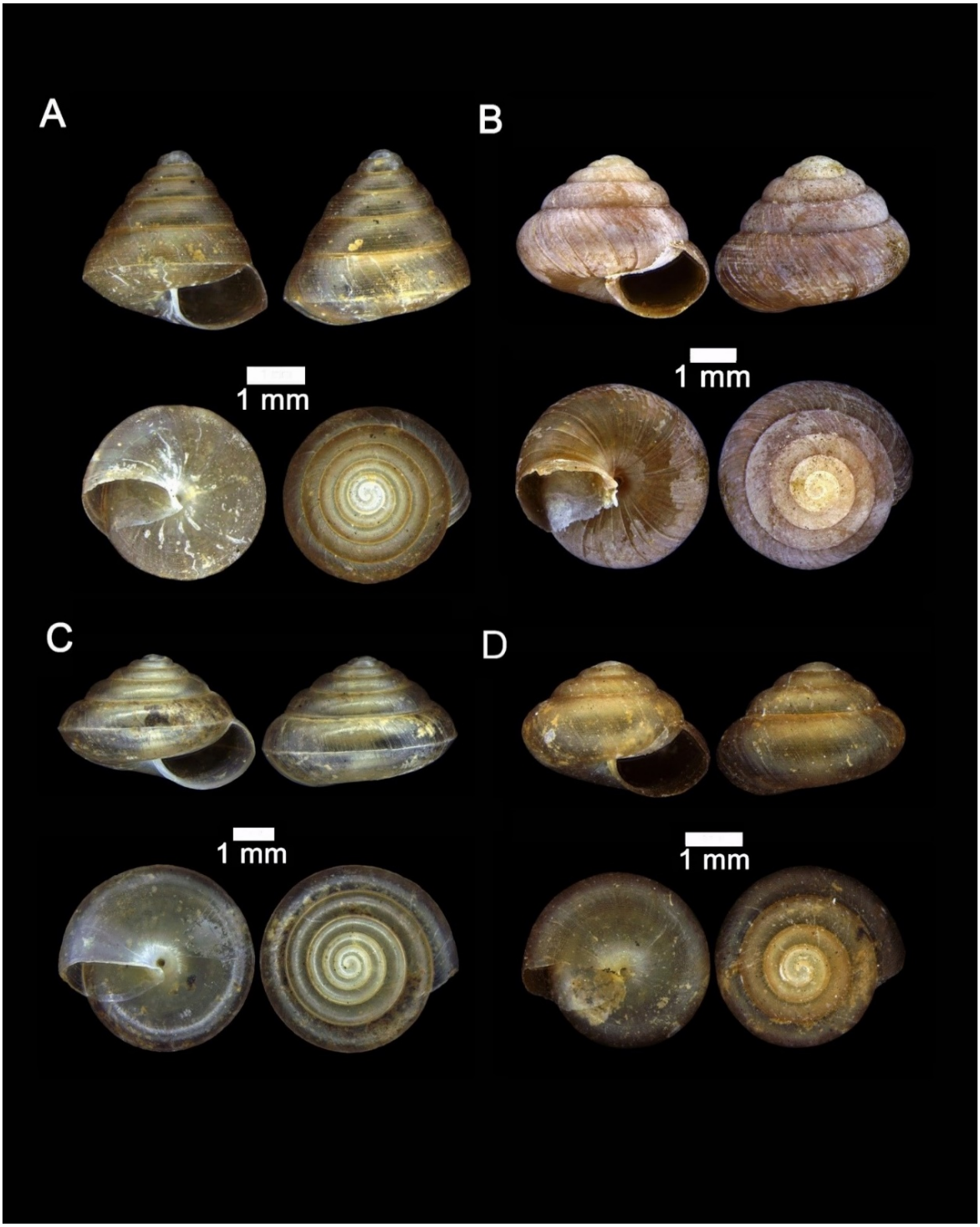


Figure 4.32: A. *Kaliella microconus* (Mousson, 1865) ME 1855 Gunung Batu **B.** *Kaliella micula* (Mousson, 1857) ME 9650 Gunung Kapor **C.** *Kaliella platyconus* (Möllendorff, 1897) ME 8814 Gunung Batu **D.** *Kaliella scandens* (Cox, 1871) ME 1928 Gunung Kapor.

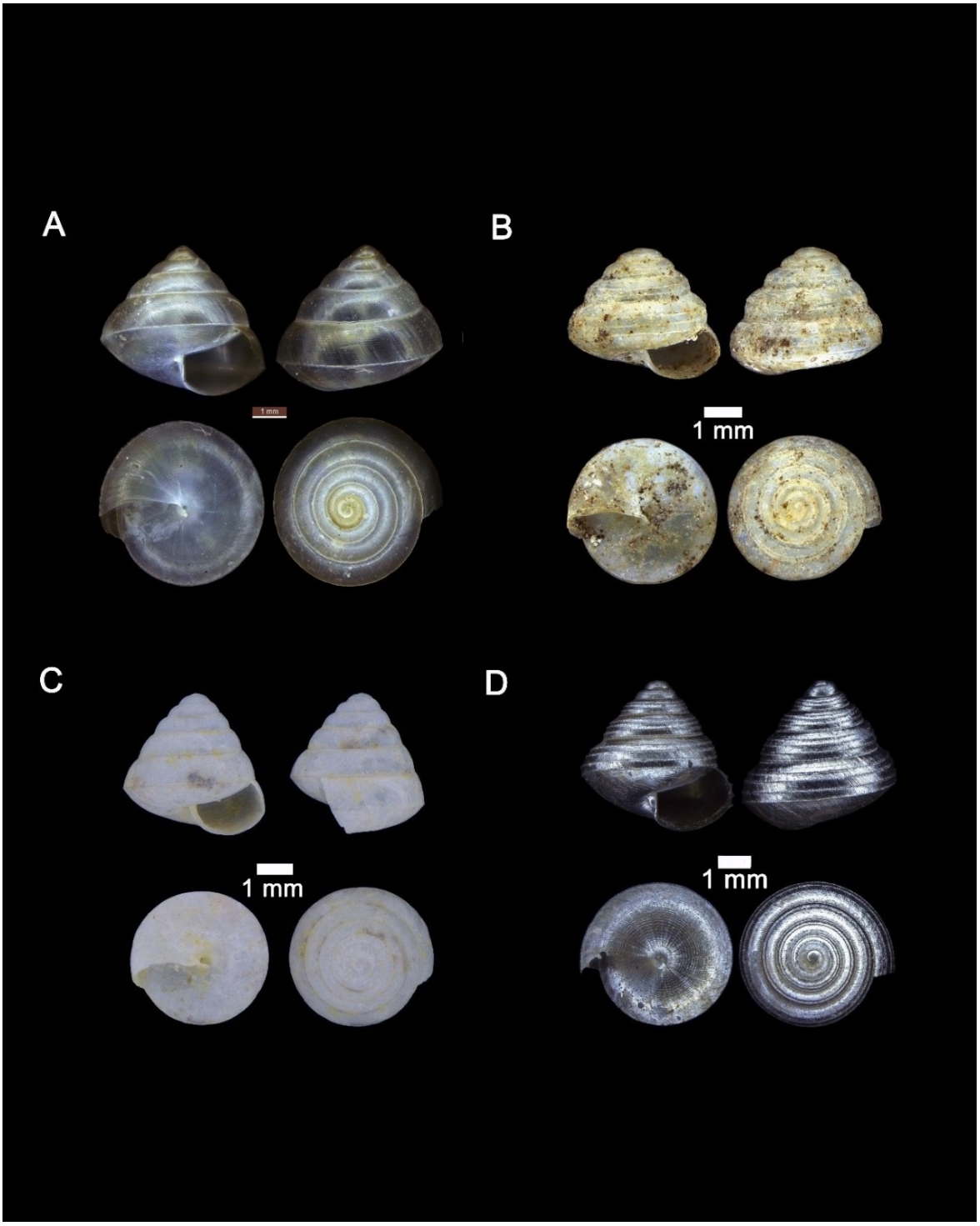


Figure 4.33: A. *Kaliella angulata* (Issel, 1874) ME 8747 Bukit Lobang Angin **B.** *Philalanka jambusanensis* Marzuki, Liew & Mohd-Azlan, 2021 ME 1879 PARATYPE Gunung Batu **C.** *Philalanka kusana* (Aldrich, 1889) ME 5897 Gunung Batu **D.** *Philalanka moluensis* (Smith, 1893) ME 0443 Gunung Doya [not in natural colour, shell surface coated with platinum for examination under scanning electron microscope].

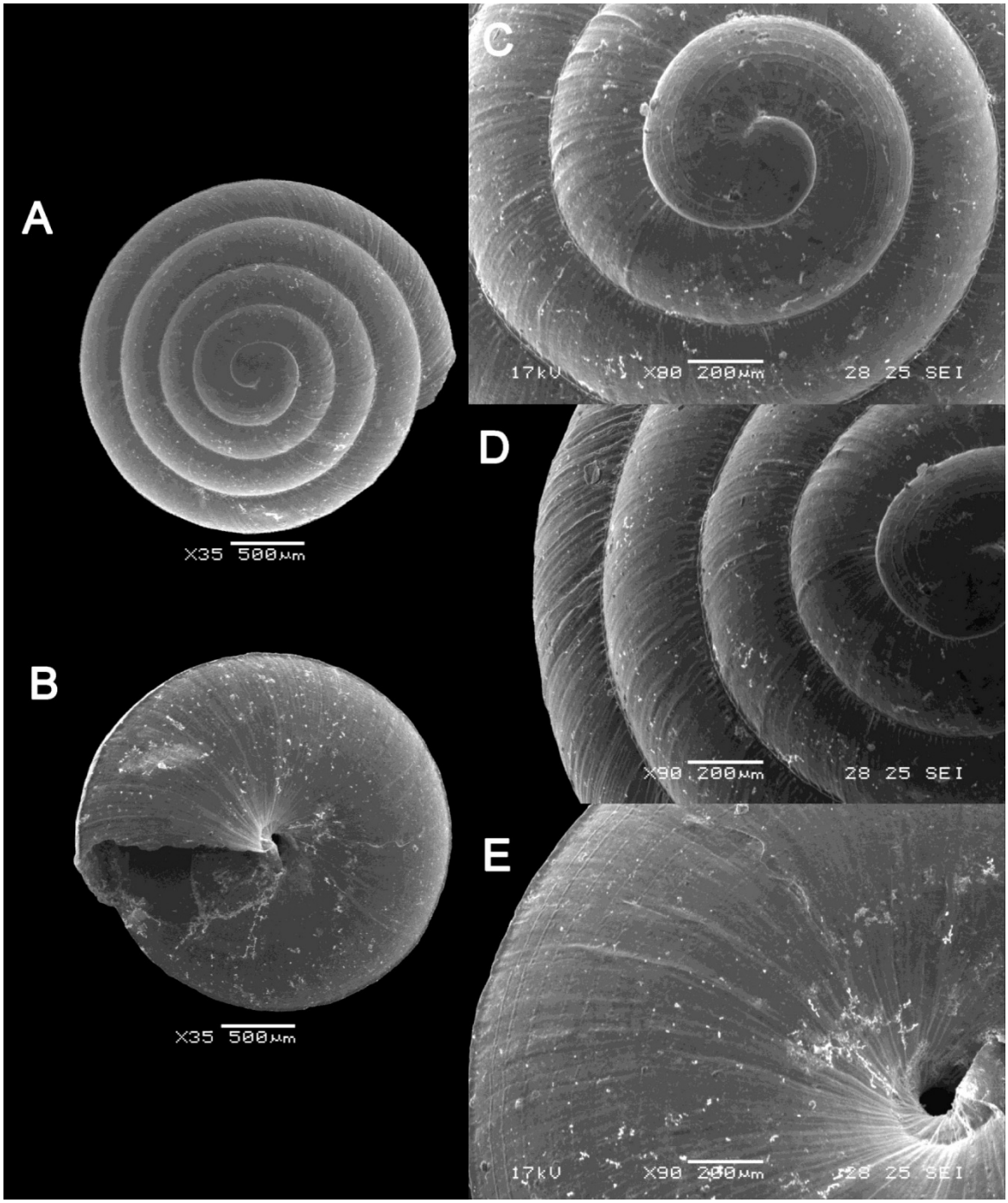


Figure 4.34: *Philalanka jambusanensis* Marzuki, Liew & Mohd-Azlan, 2021. **A-E.** MZU.MOL.20.20 HOLOTYPE. **A.** Apical view, **B.** Basal view, **C.** Enlargement of the apical side showing the apex, **D.** Enlargement of the teleoconch showing the shell sculpture, **E.** Enlargement of the basal side of the shell.

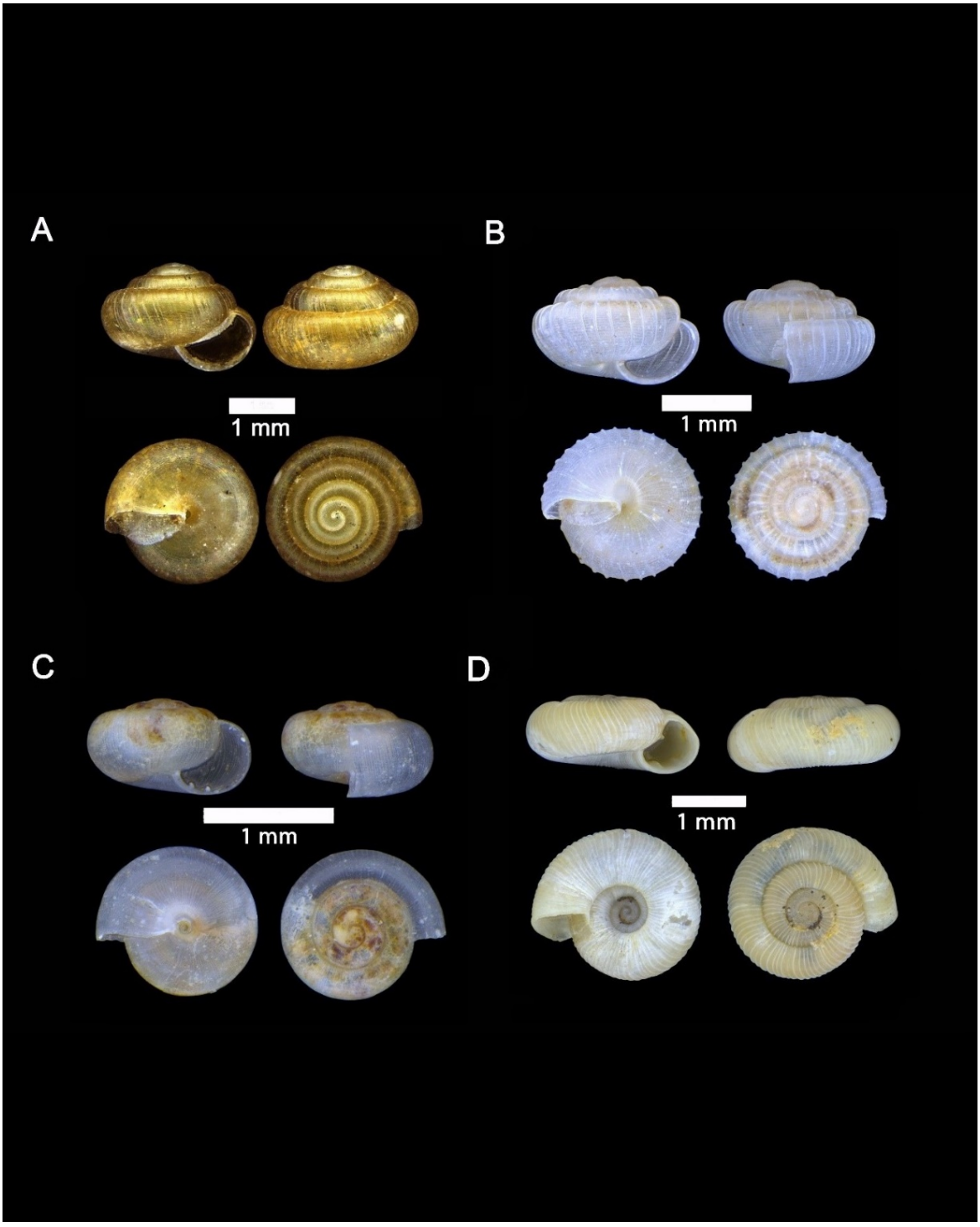


Figure 4.35: A. *Paralaoma angusta* Vermeulen, Liew & Schilthuizen, 2015 ME 9641 Gunung Kapor **B.** *Paralaoma sarawakensis* Marzuki, Liew & Mohd-Azlan, 2021 ME 2269 PARATYPE Gunung Doya **C.** *Sundacharopa argos* Vermeulen & Liew, 2022 ME 8593 Gunung Doya **D.** *Beilania philippinensis* (C. Semper, 1874) ME 10290 Gunung Batu.

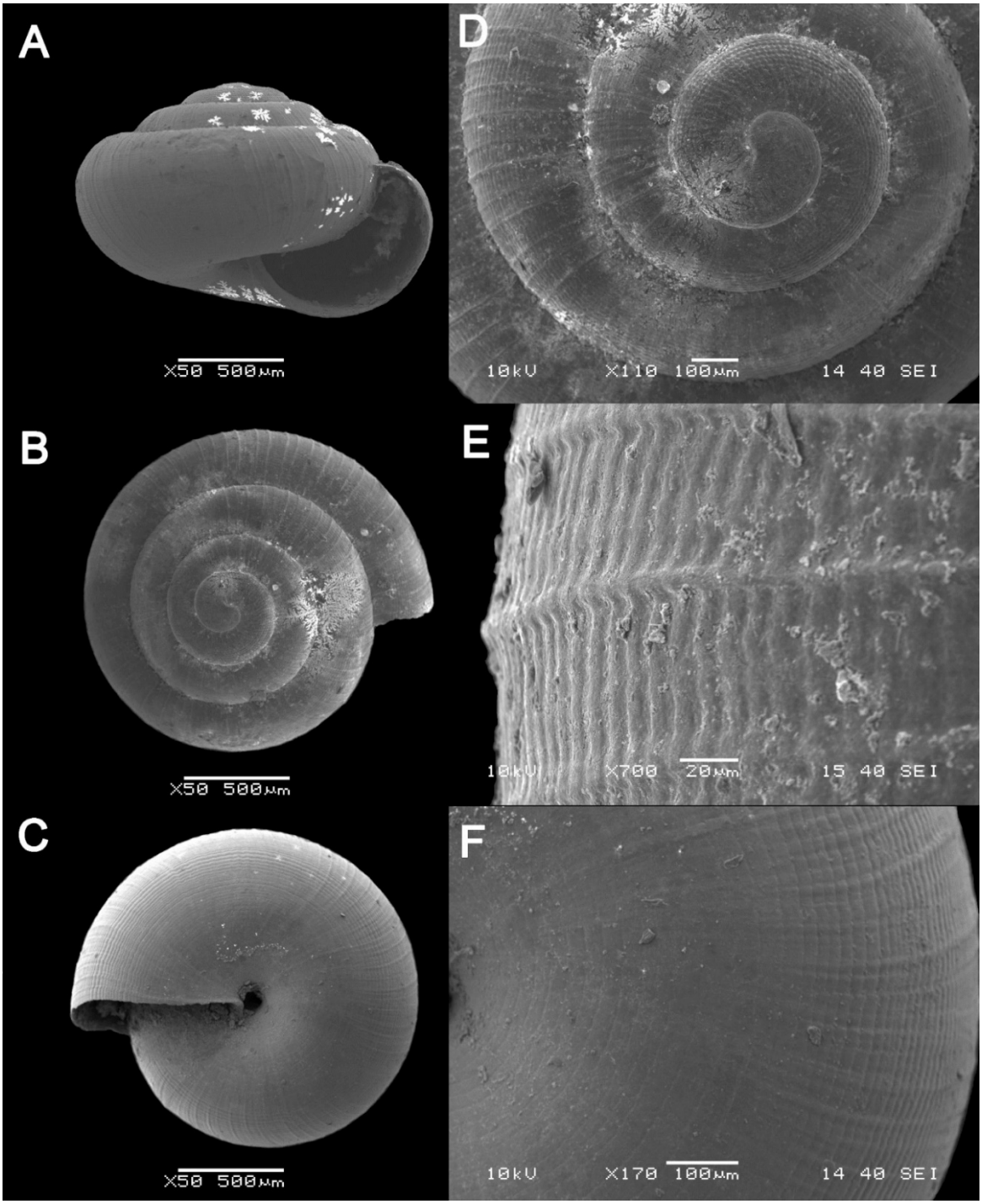


Figure 4.36: *Paralaoma angusta* Vermeulen, Liew & Schilthuizen, 2015. **A-F.** ME 1763. **A.** Apertural view, **B.** Apical view, **C.** Basal view, **D.** Enlargement of the apical side showing the apex, **E.** Enlargement of the body whorl showing the shell sculpture, **F.** Enlargement of the basal side of the shell.

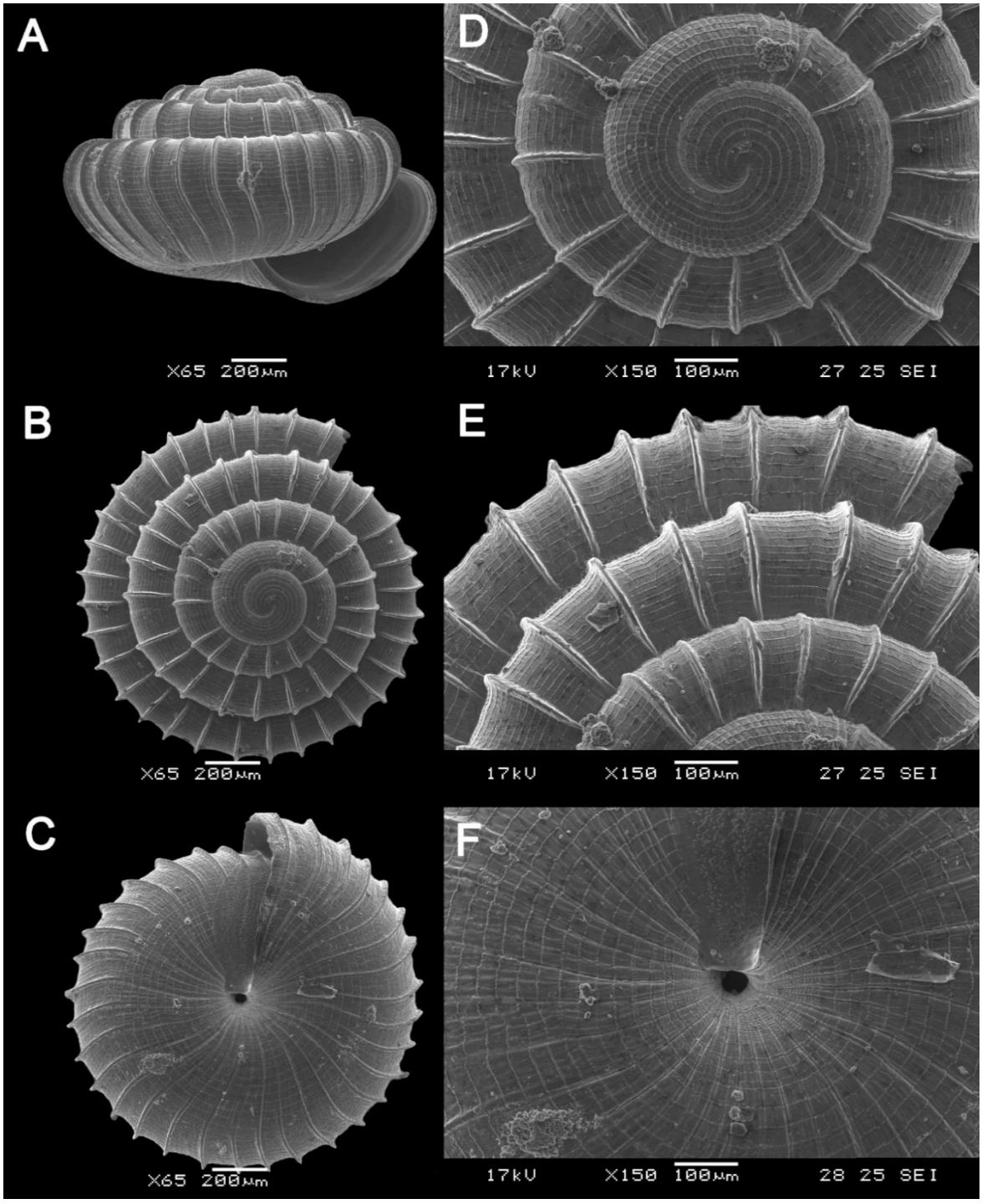


Figure 4.37: *Paralaoma sarawakensis* Marzuki, Liew & Mohd-Azlan, 2021. **A-F.** MZU.MOL.20.21 HOLOTYPE. **A.** Apertural view, **B.** Apical view, **C.** Basal view, **D.** Enlargement of the apical side showing the apex, **E.** Enlargement of the teleoconch showing the shell sculpture, **F.** Enlargement of the basal side of the shell.

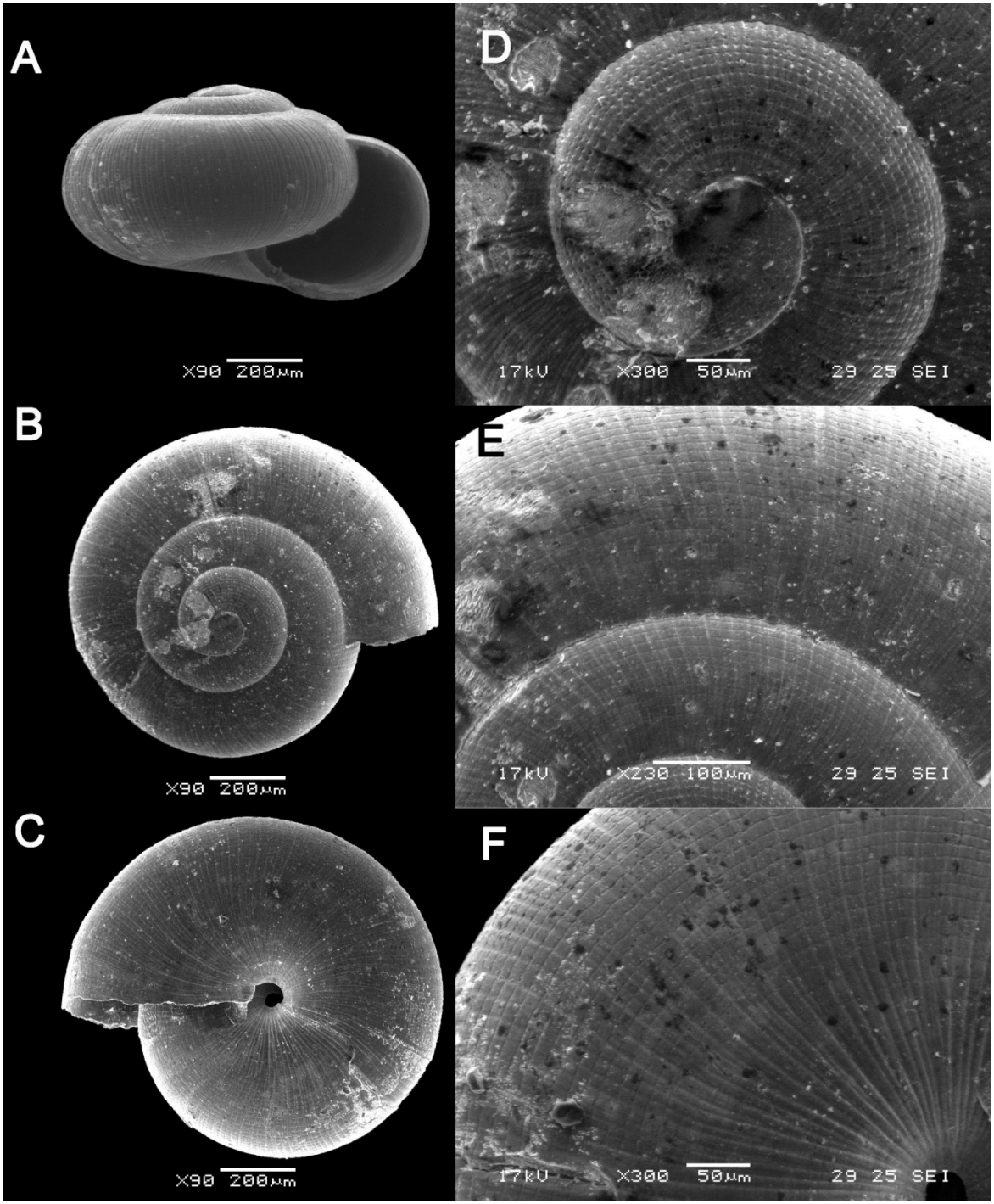


Figure 4.38: *Sundacharopa argos* Vermeulen & Liew, 2022. **A-F.** MZU.MOL.20.08. **A.** Apertural view, **B.** Apical view, **C.** Basal view, **D.** Enlargement of the apical side showing the apex, **E.** Enlargement of the teleoconch showing the shell sculpture, **F.** Enlargement of the basal side of the shell.

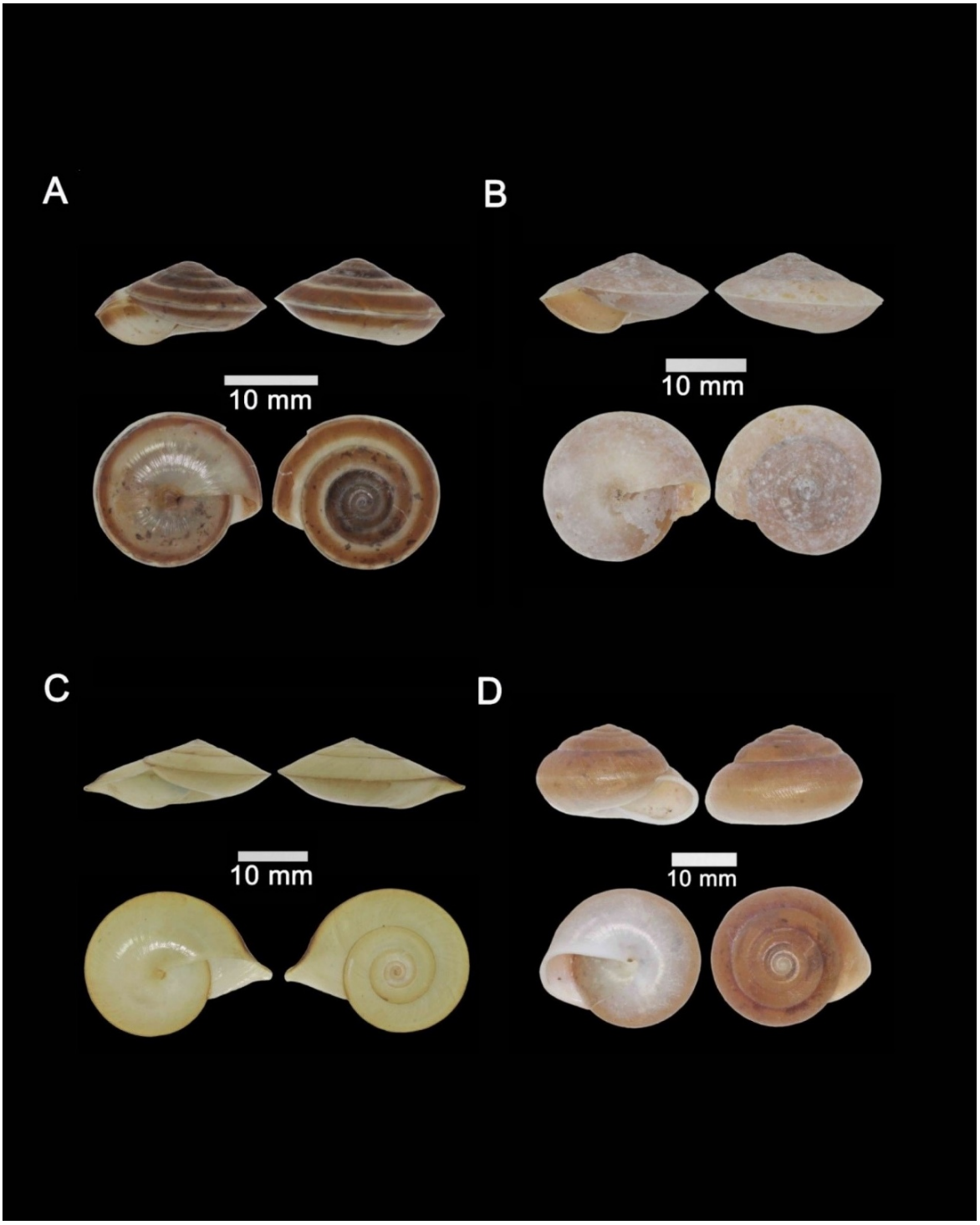


Figure 4.39: A. *Dyakia busanensis* Godwin-Austen, 1891 ME 9015 Gunung Doya **B.** *Dyakia subdebilis* E. A. Smith, 1895 ME 1602 Gunung Kapor **C.** *Rhinocochlis nasuta* (Metcalfe, 1851) ME 8740 Lobang Angin **D.** *Elaphroconcha striata* (Gray, 1834) ME 8792 Gunung Kapor.

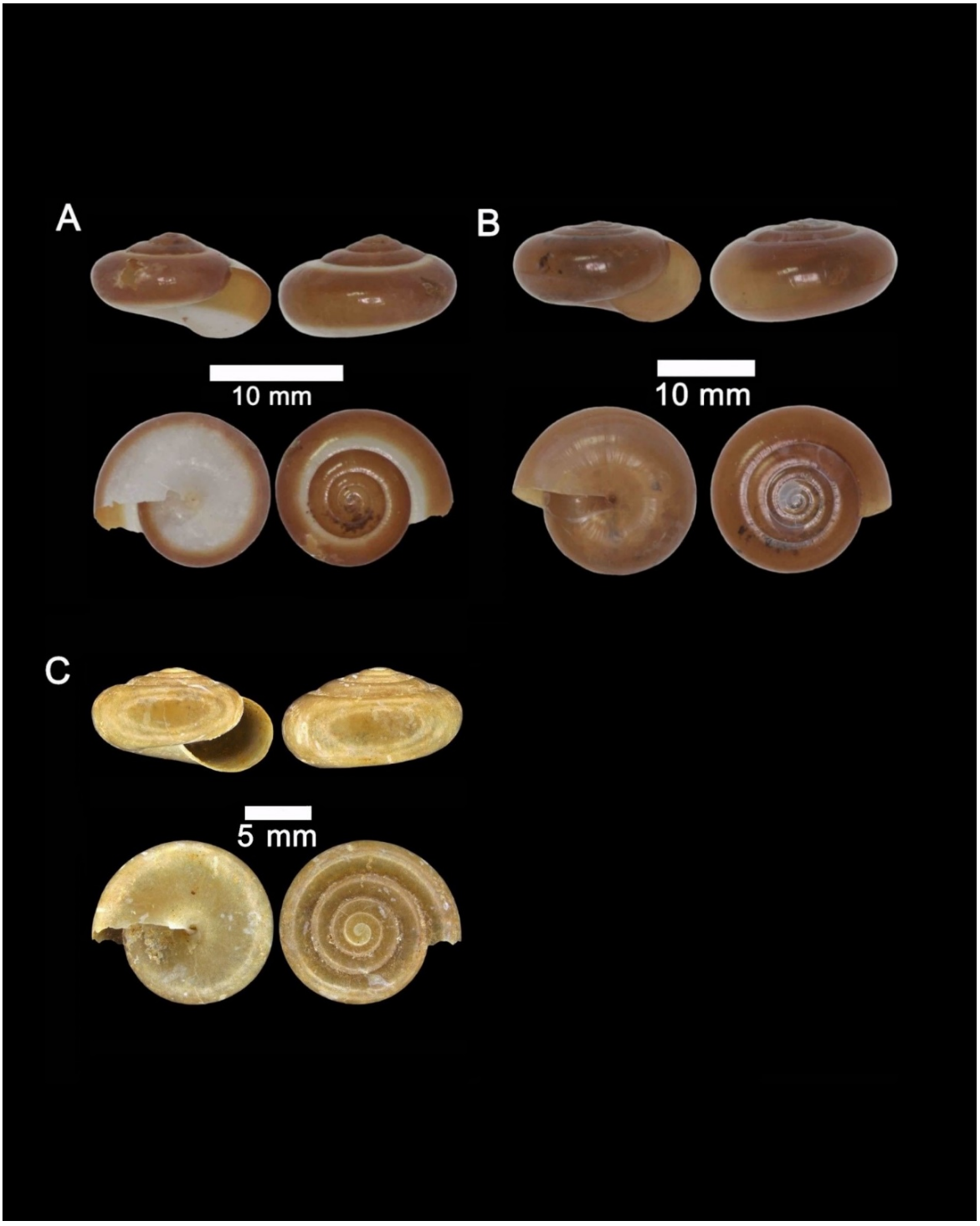


Figure 4.40: A. *Everettia cutteri* (H. Adams, 1870) ME 8968 Gunung Doya Kapor **B.** *Everettia microrhytida* Marzuki, Liew & Mohd-Azlan, 2021 MZU.MOL.20.25 HOLOTYPE Gunung Batu **C.** *Everettia minuta* Marzuki, Liew & Mohd-Azlan, 2021 MZU.MOL.20.23 HOLOTYPE Gunung.

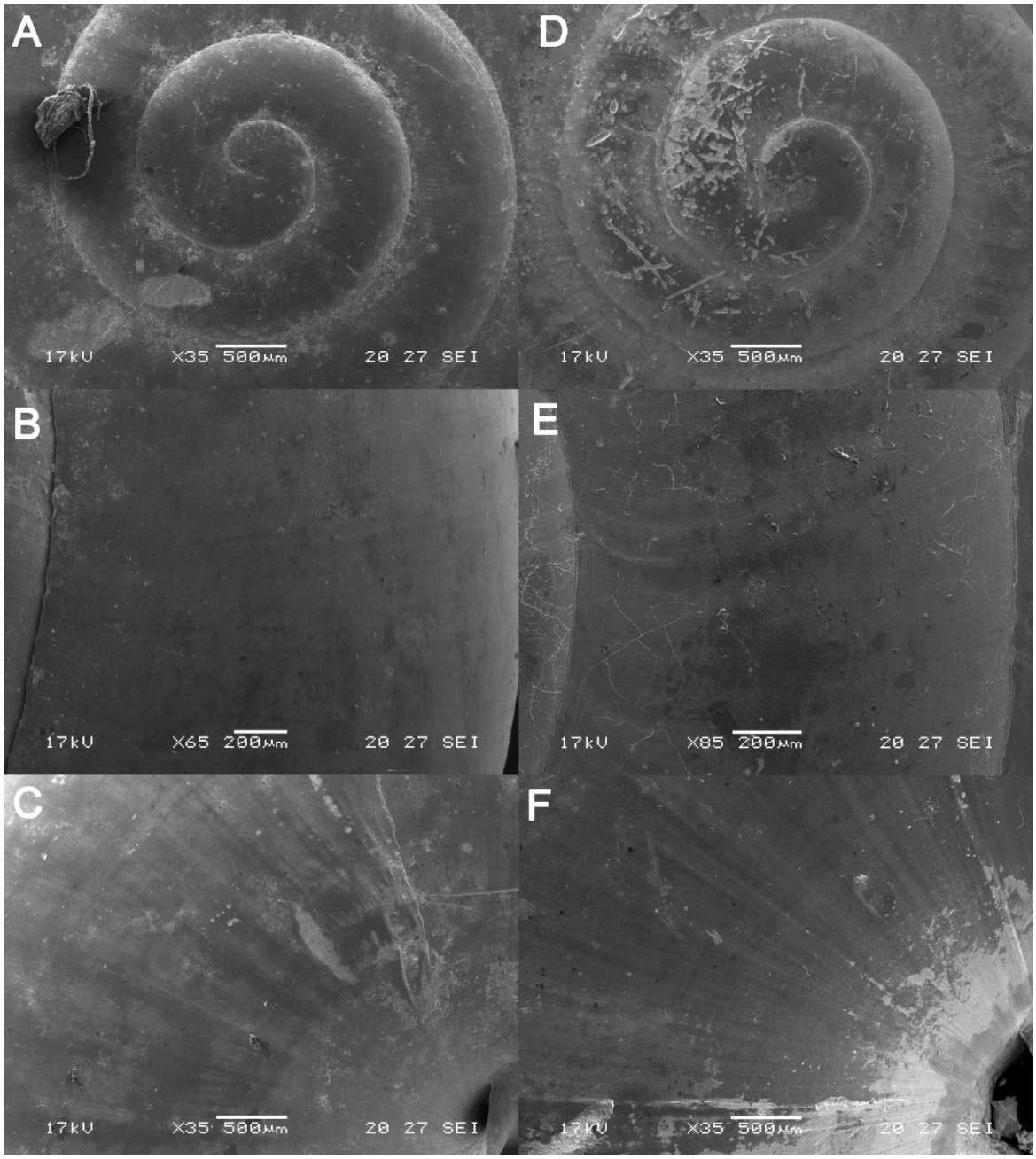


Figure 4.41: *Everettia* spp. **A-C.** *Everettia minuta* Marzuki, Liew & Mohd-Azlan, 2021 MZU.MOL.20.24 PARATYPE. **A.** Enlargement of the apical side showing the apex, **B.** Enlargement of the teleoconch showing the shell sculpture, **C.** Enlargement of the basal side of the shell. **D-F.** *Everettia microrhytida* Marzuki, Liew & Mohd-Azlan, 2021 MZU.MOL.20.26 PARATYPE. **D.** Enlargement of the apical side showing the apex, **E.** Enlargement of the teleoconch showing the shell sculpture, **F.** Enlargement of the basal side of the shell.

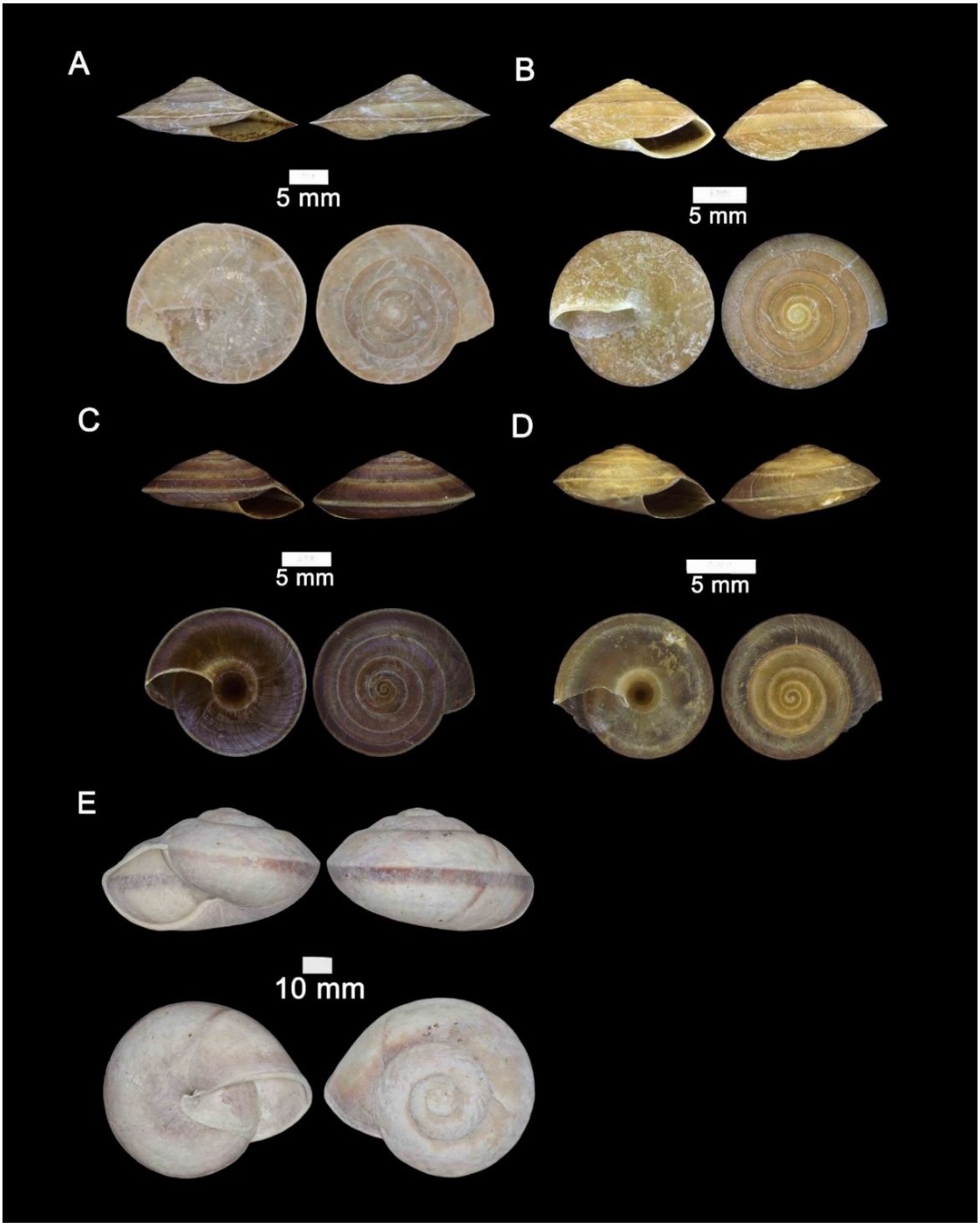


Figure 4.42: A. *Geotrochus conicoides* (Metcalfe, 1851) ME 8911 Gunung Doya **B.** *Geotrochus subscalaris* Vermeulen, Liew & Schilthuizen, 2015 ME 1636 Gunung Kapor **C.** *Videna bicolor* (Martens, 1864) ME 8732 Lobang Angin **D.** *Videna nepiadelphos* Vermeulen & Liew, 2022 ME 8972 Gunung Kapor **E.** *Exrhysota brookei* (A. Adams & Reeve, 1848) ME 8790 Gunung Kapor.

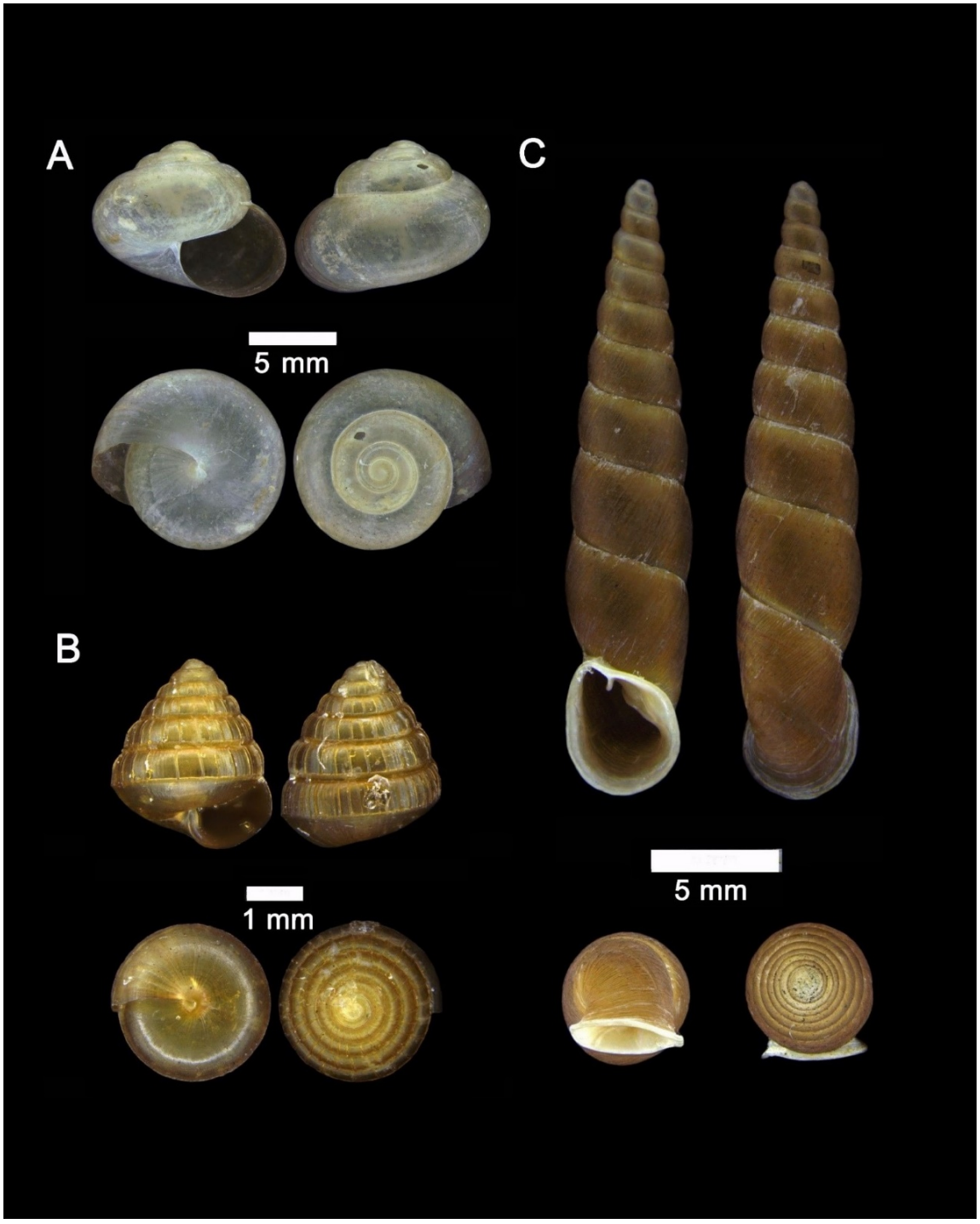


Figure 4.43: A. *Helicarion dyakanum* (Godwin-Austen, 1891) ME 8770 Gunung Kapor **B.** *Rahula raricostulata* (E. A. Smith, 1893) ME 8938 Lobang Angin **C.** *Phaedusa borneensis* (Pfeiffer, 1854) ME 8784 Gunung Kapor.

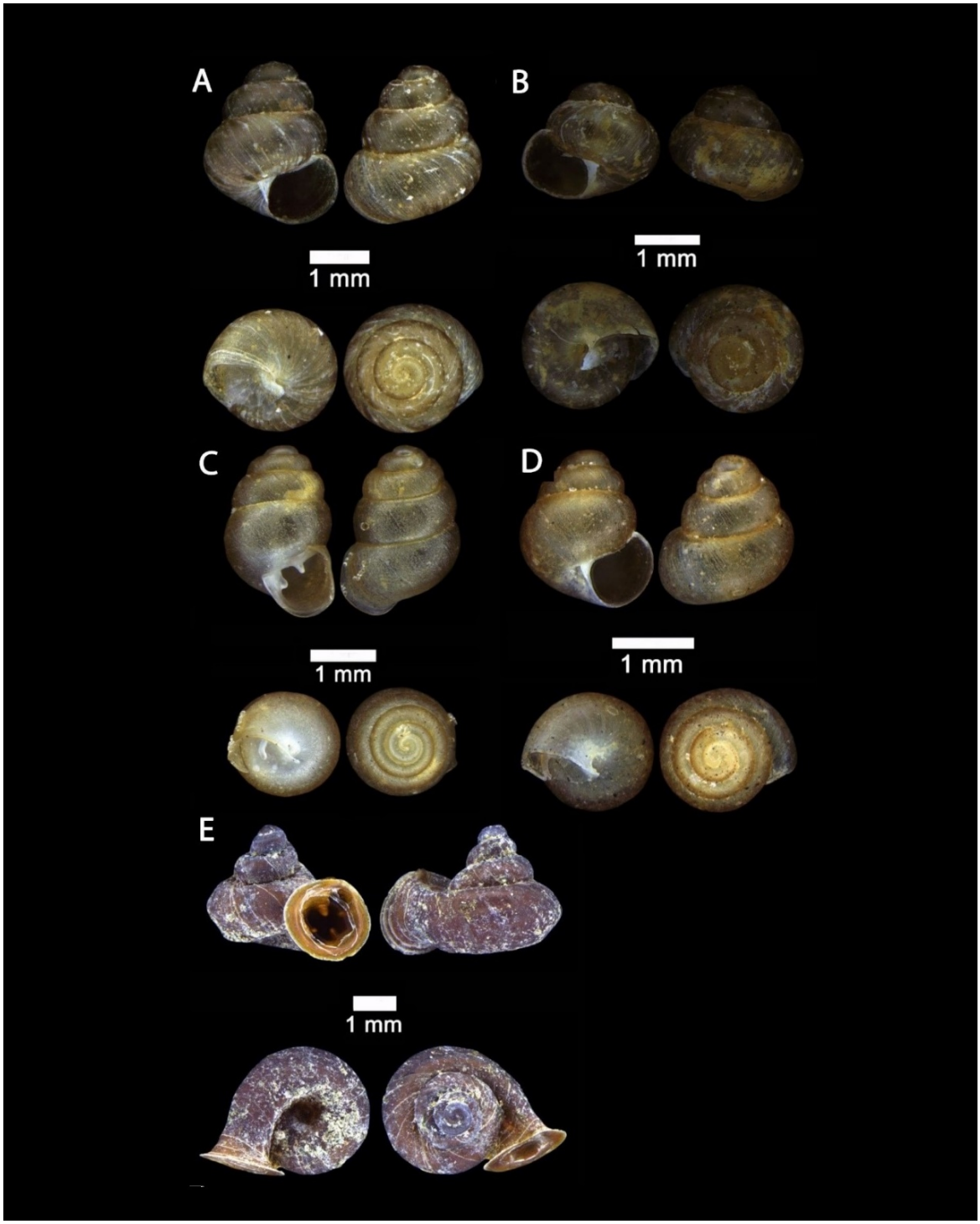


Figure 4.44: A. *Ptychopatula dioscoricola* (C. B. Adams, 1845) ME 9070 Gunung Kapor **B.** *Ptychopatula orcella* (Stoliczka, 1873) ME 8925 Gunung Doya **D.** *Pupisoma moleculina* (van Benthem-Jutting, 1940) ME 9051 Gunung Kapor **C.** *Pupisoma pulvisculum* (Issel, 1874) ME 9055 Gunung Kapor **E.** *Boysidia salpinx* F. G. Thompson & Dance, 1983 ME 8781 Gunung Kapor.

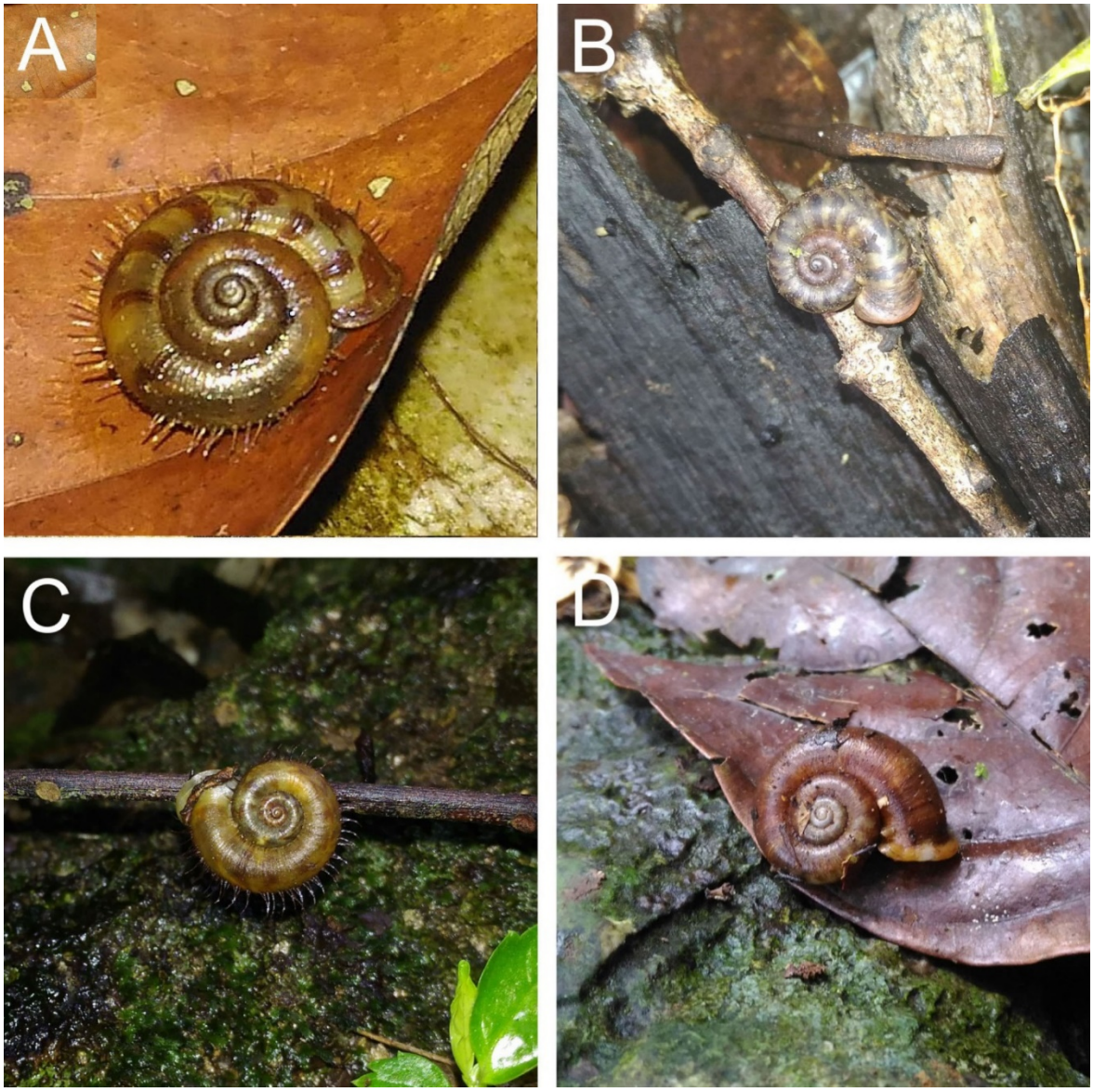


Figure 4.45: Living snails from Bau. **A.** *Japonia barbata* (L. Pfeiffer, 1855) ME 8768 Gunung Kapor **B.** *Opisthophorus euryomphalus* (L. Pfeiffer, 1856) ME 8779 Gunung Kapor **C.** *Opisthophorus biciliatus* Mousson, 1849 ME 8754 Gunung Kapor **D.** *Opisthophorus birostris* (L. Pfeiffer, 1854) ME 8755 Gunung Kapor. All not to scale.



Figure 4.46: Living snails from Bau. **A.** *Cyclophorus perdix borneensis* (Metcalfe, 1851) ME 8753 Gunung Kapor **B.** *Platyrhaphe linita* (Godwin-Austen, 1889) ME 9700 Gunung Doya **C.** *Stomacosmethis sadongensis* (E. A. Smith, 1895) ME 8761 Gunung Kapor **D.** *Pincerna globosa* (H. Adams, 1870) ME 8749 Lobang Angin. All not to scale.

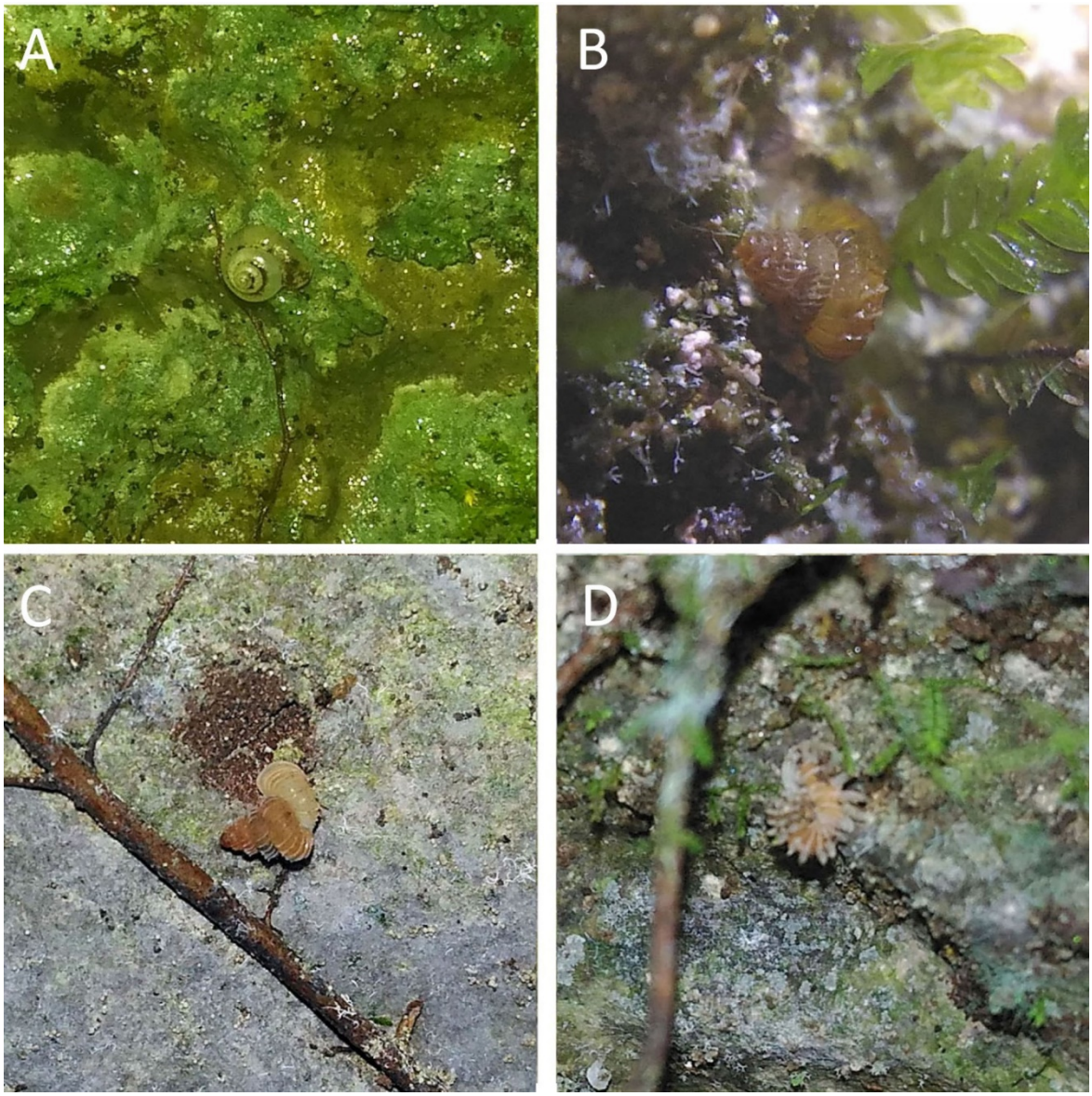


Figure 4.47: Living snails from Bau. **A.** *Chamalycaeus specus* (Godwin-Austen, 1889) ME 11867 Lobang Angin **B.** *Plectostoma wallacei wallacei* Ancey, 1887 ME 8767 Gunung Kapor **C.** *Plectostoma austeni* (E. A. Smith, 1894) ME 8794 Gunung Batu **D.** *Plectostoma everetti* (E. A. Smith, 1893) ME 8793 Gunung Batu. All not to scale.

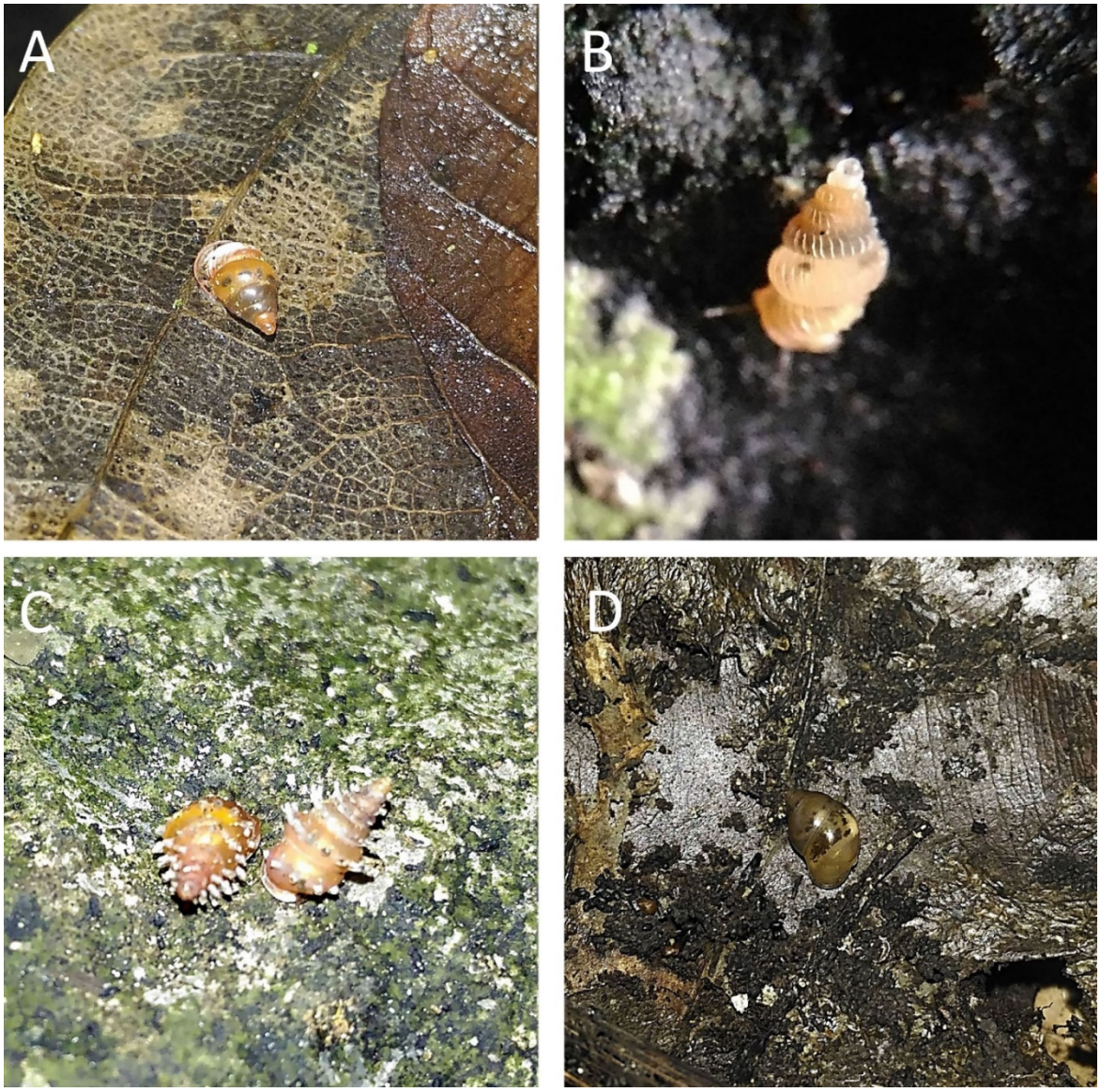


Figure 4.48: Living snails from Bau. **A.** *Diplommatina adversa* (H. Adams & A. Adams, 1851) ME 8766 Gunung Kapor **B.** *Diplommatina concinna* H. Adams, 1872 ME 9137 Gunung Kapor **C.** *Diplommatina spinosa* Godwin-Austen, 1889 ME 8801 Gunung Batu **D.** *Pupina evansi* Godwin-Austen, 1889 ME 9053 Lobang Angin. All not to scale.

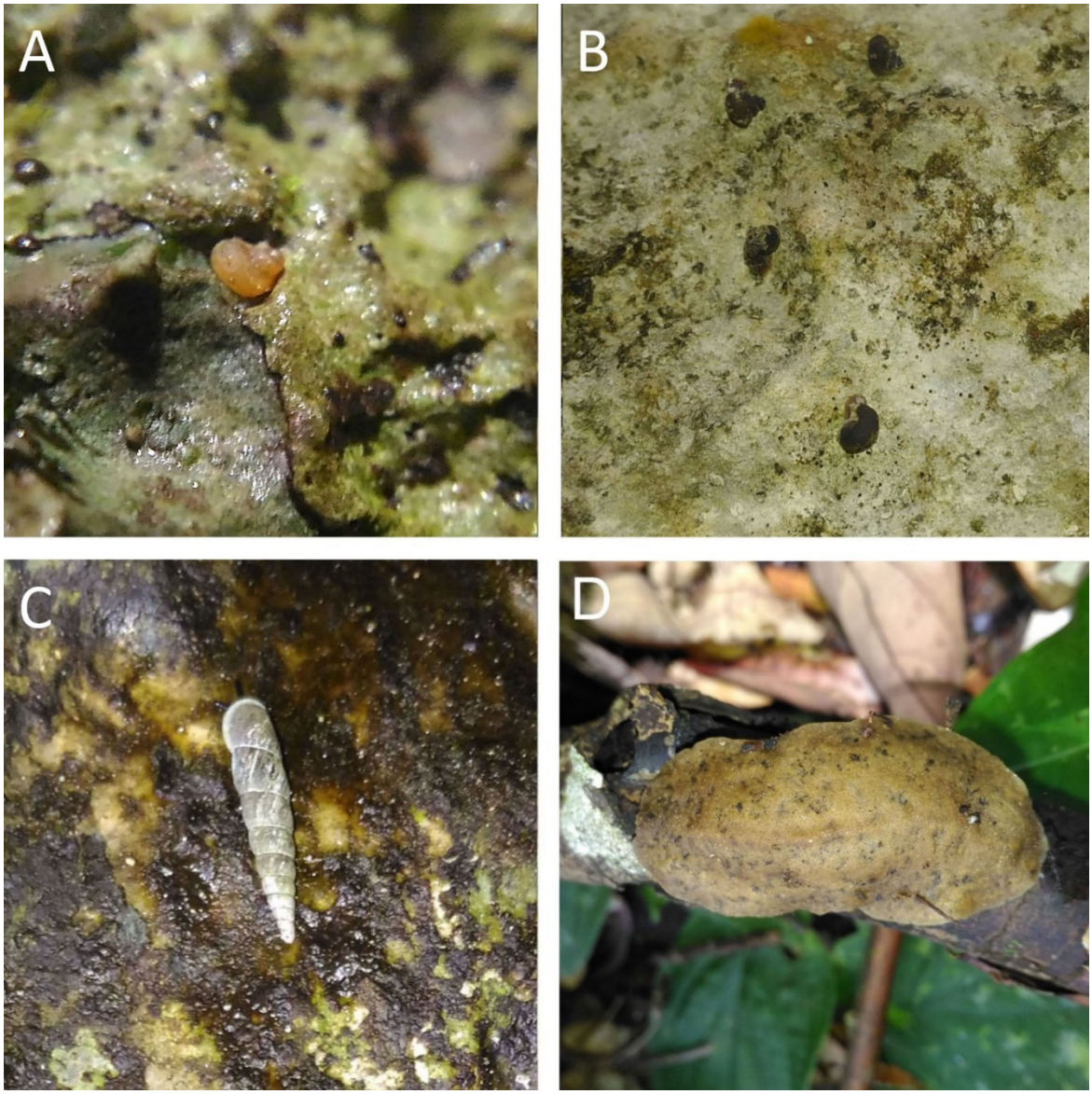


Figure 4.49: Living snails from Bau. **A.** *Georissa bauensis* Khalik, Hendricks, Vermeulen & Schilthuizen, 2018 ME 8731 Lobang Angin **B.** *Boysidia salpinx* Thompson & Dance, 1983 ME 8781 Gunung Kapor **C.** *Phaedusa borneensis* (L. Pfeiffer, 1854) ME 8784 Gunung Kapor **D.** *Valiguna flava* (Heynemann, 1885) Uncat. Gunung Kapor. All not to scale.

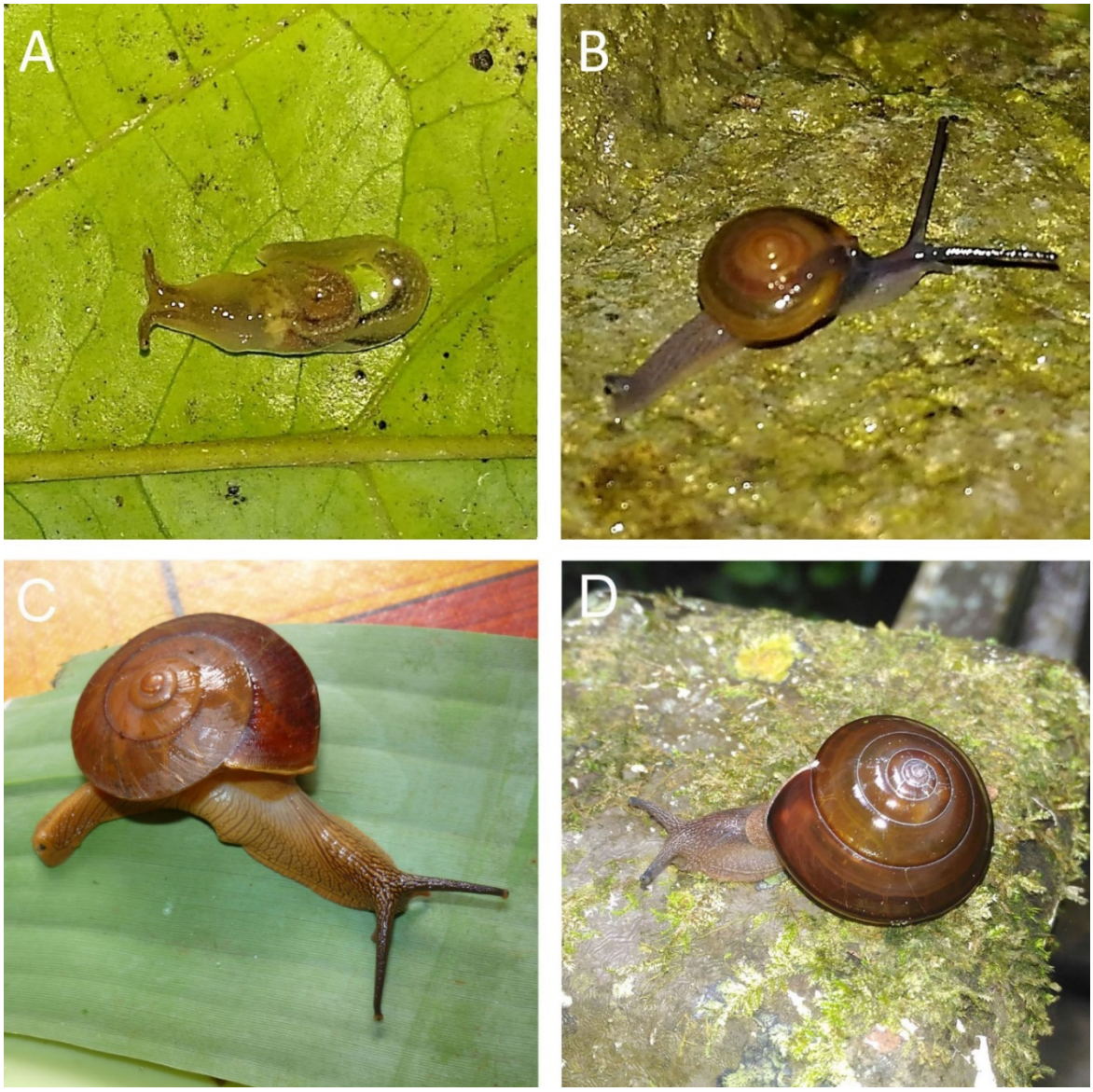


Figure 4.50: Living snails from Bau. **A.** *Damayantia carinata* Collinge, 1901 Uncat. Gunung Kapor **B.** *Macrochlamys tersa* (Issel, 1874) ME 8966 Gunung Kapor **C.** *Hemiplecta densa* (A. Adams & Reeve, 1850) ME 4724 Gunung Kapor **D.** *Vitrinula glutinosa* (Metcalfe, 1851) ME 8750 Lobang Angin. All not to scale.

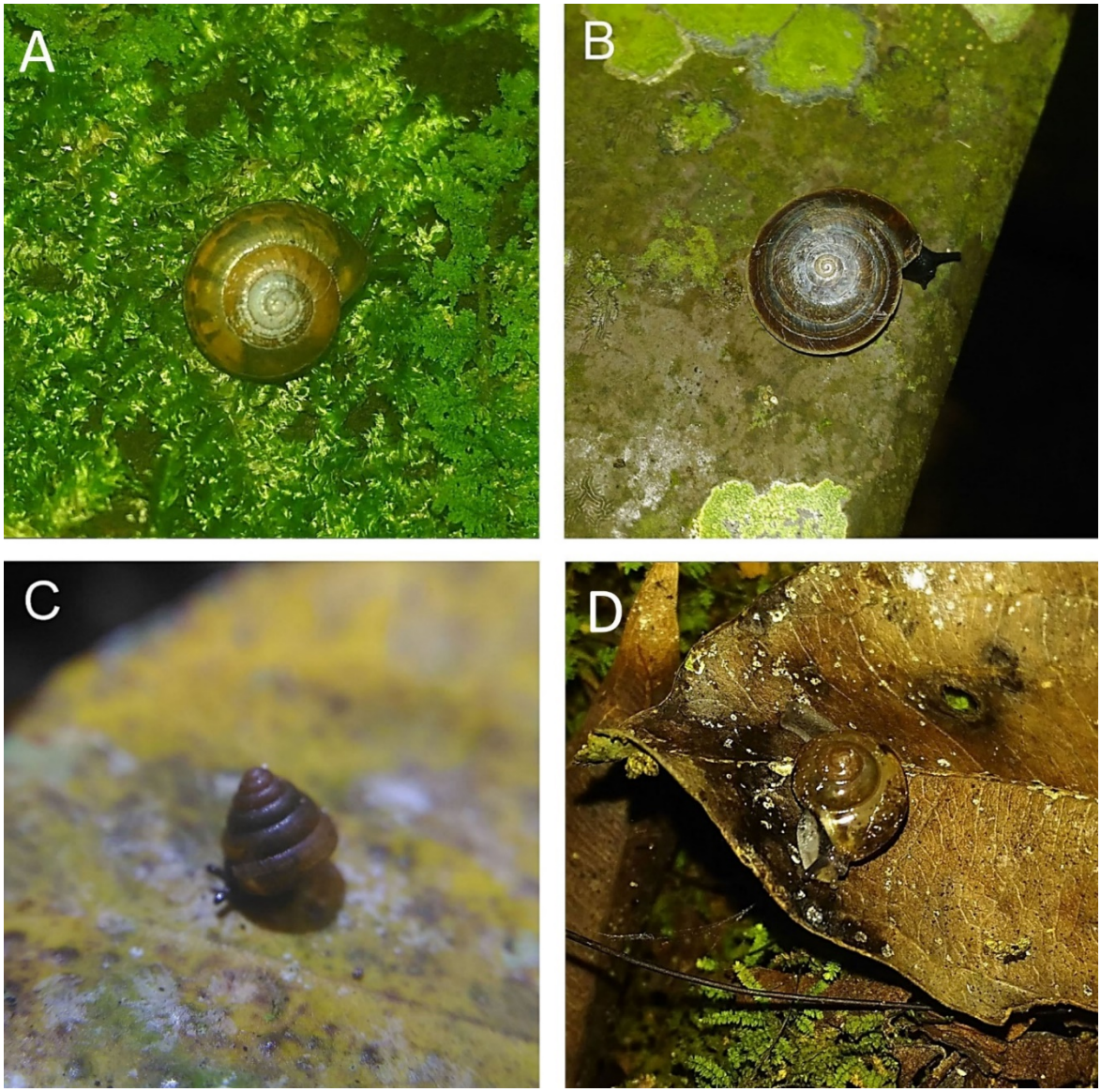


Figure 4.51: Living snails from Bau. **A.** *Videna nepiadelphos* Vermeulen & Liew, 2022 ME 8984 Lobang Angin **B.** *Videna bicolor* (Martens, 1864) ME 8732 Lobang Angin **C.** *Kaliella barrakporensis* (L. Pfeiffer, 1852) ME 9026 Gunung Kapor **D.** *Helicarion dyakanum* (Godwin-Austen, 1891) ME 8969 Gunung Kapor. All not to scale.

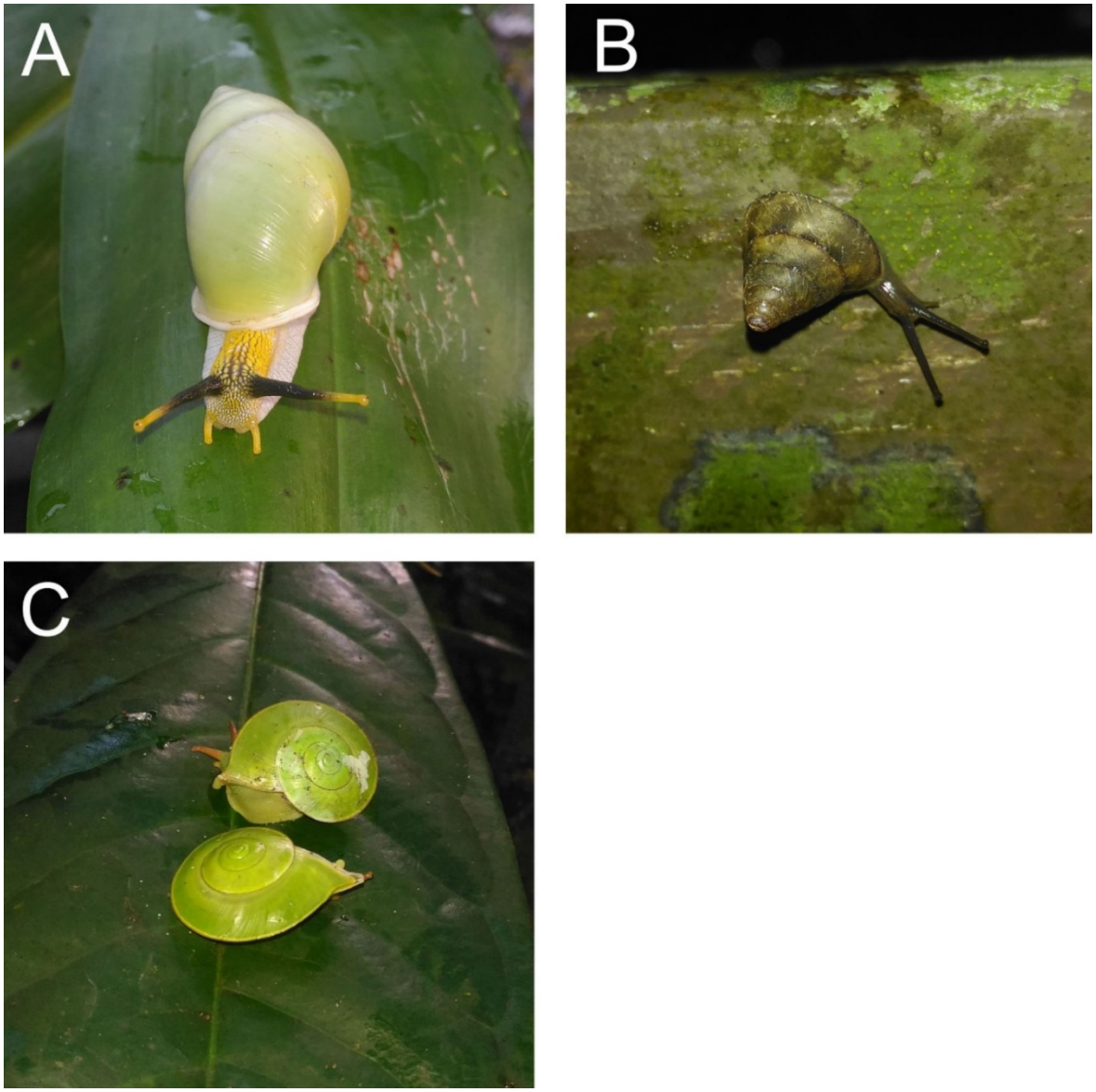


Figure 4.52: Living snails from Bau. **A.** *Amphidromus epidemiae* Wang, 2021 ME 8756 Gunung Kapor **B.** *Ganesella acris* (Benson, 1859) ME 8977 Lobang Angin **C.** *Rhinocochlis nasuta* (Metcalfe, 1851) ME 8885 Lobang Angin. All not to scale.



Figure 4.53: Living snails from Bau. **A.** *Paropeas achatinaceum* (L. Pfeiffer, 1846) ME 8785 Gunung Kapor **B.** *Allopeas gracile* (T. Hutton, 1834) ME 2942 Gunung Kapor. All not to scale.

4.2 The species richness estimates and sampling effectiveness: live-taken snail versus empty shell

Sampling effectiveness and richness estimates analysis were done to see the sample coverage and diversity estimates based on live-taken snail and empty shell data taken from Bau. The sample coverage and diversity estimates are taken from 45 small plots on each hill between the live-taken snail and empty shell as the sample is analyzed and summarized in Appendix C-F.

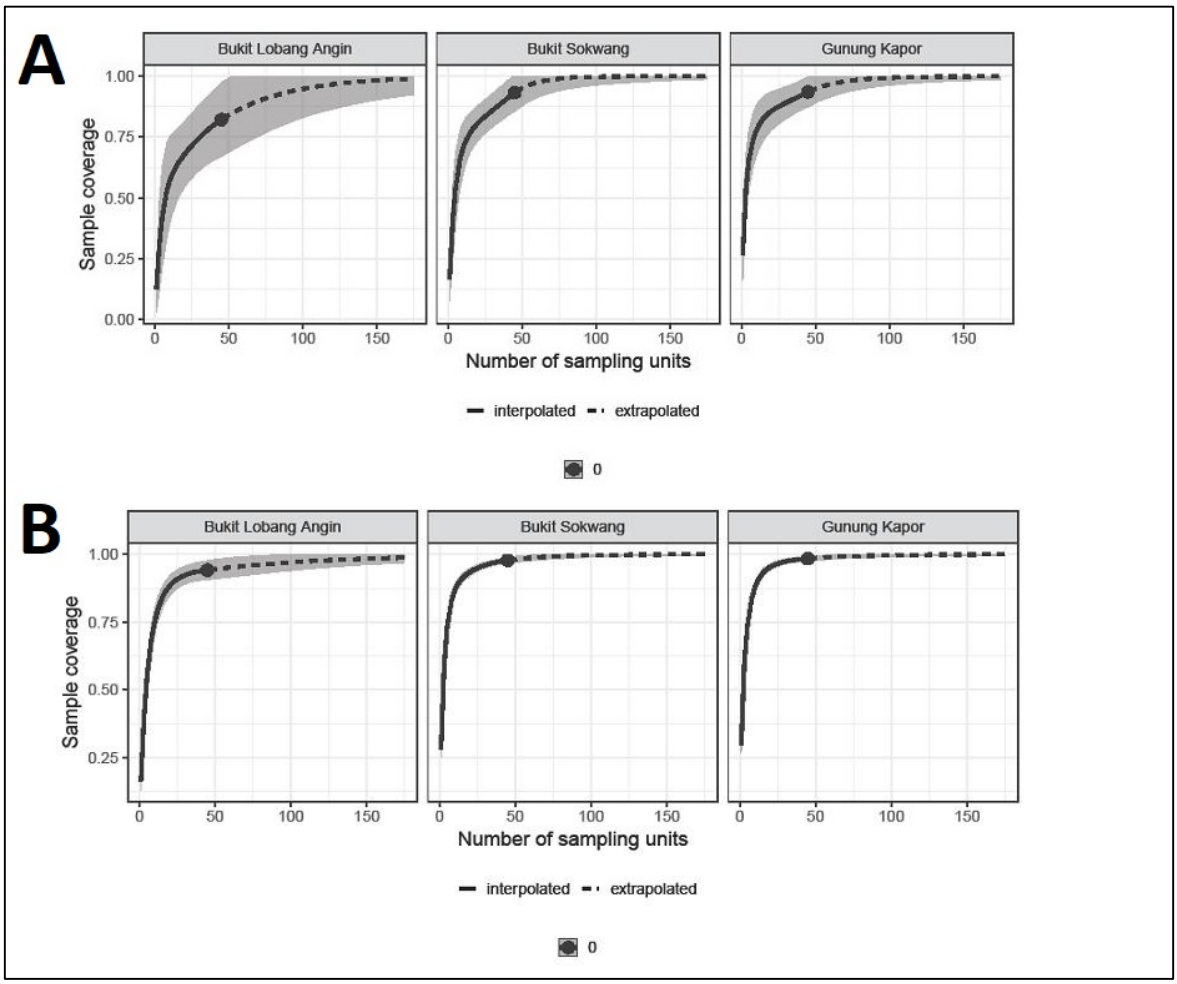


Figure 4.54: A. Estimated species richness according to sample coverage using live-taken snail; **B**. Estimated species richness according to sample coverage using empty shell. Shaded areas represent 95% confidence intervals, and dashed lines represent extrapolated data.

Based on the sample coverage (Figure 4.54) at hill scales, the gap between the lower control limit and upper control limit for samples taken from live-taken snails is slightly higher than the empty shell. However, the sample coverage's completeness ratios for both live-taken snail and empty shell samples from 45 small plots are very high (Sampling coverage = 0.94-0.98 for the empty shell, 0.82-0.93 for the live-taken snail) indicating high sampling effectiveness.

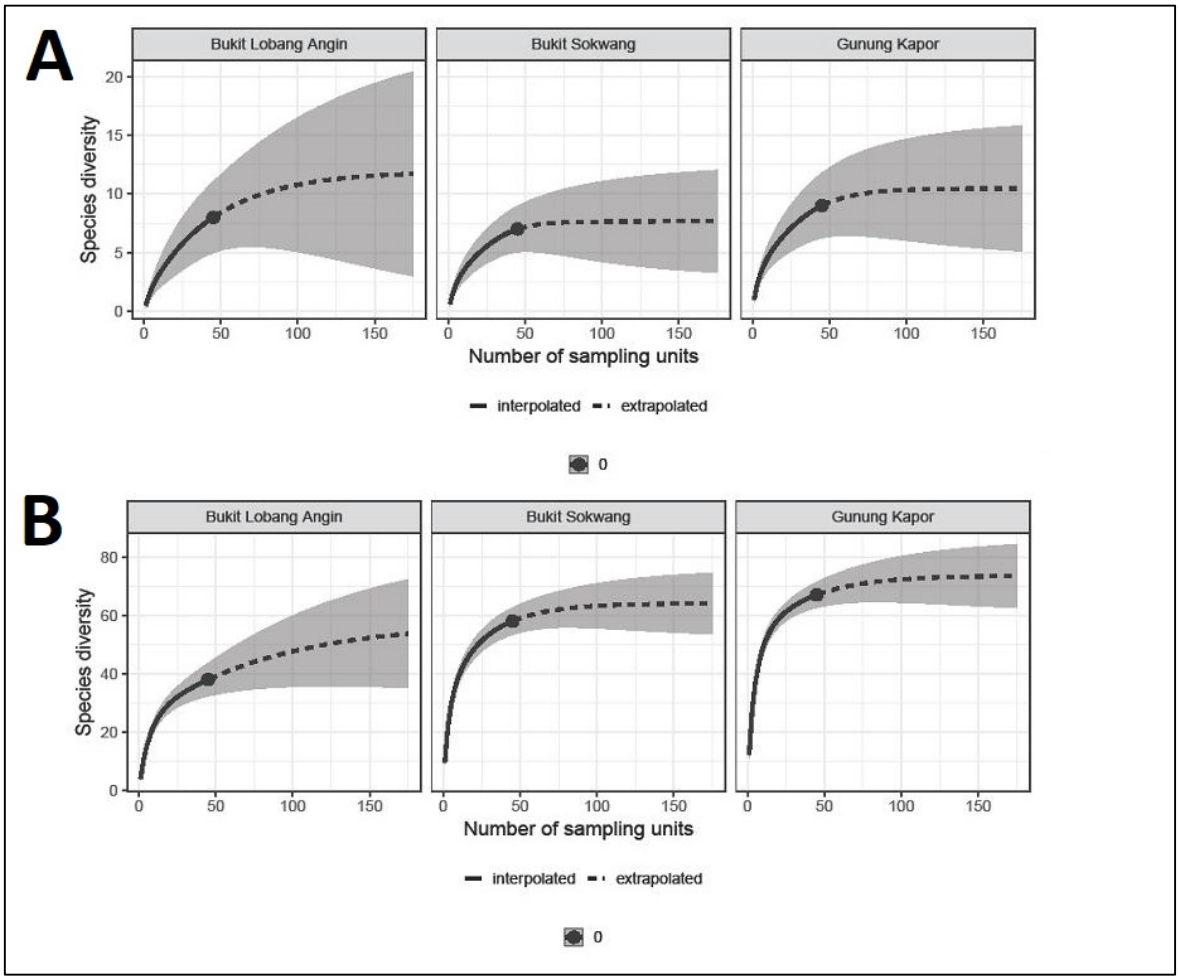


Figure 4.55: A. Species richness estimates for a rarefied and extrapolated sample with respect to the number of sampling units using live-taken snail; **B.** Species richness estimates for a rarefied and extrapolated sample with respect to the number of sampling units using empty shell. Shaded areas represent 95% confidence intervals, and dashed lines represent extrapolated data.

Despite high completeness ratios for both live-taken snail and empty shell samples at hill scales, somehow, species diversity (figure 4.55) from live-taken snails appears low compared to the empty shell. The species counted from the live-taken snail samples (8-9 species @ 22-45 individuals per hill) are lower than the species observed from the empty shell samples (38-67 species @ 187-559 individuals per hill) (see Appendix C, D, and E). According to diversity estimates, 58 species were observed with estimated 64 species using empty shell samples while only 7 species with estimated 8 species were observed using live-taken snails in C1H1 while 67 species were observed with estimated 74 species using empty shell samples while only 9 species with estimated 10 species observed using live-taken snail in C1H2. On the other hand, 38 species were observed with estimated 58 species using empty shell samples while only 8 species with estimated 12 species were observed using live-taken snails in C1H3.

The same outcome also follows at the cluster scales (figure 4.56). There are about 95 living individuals together with 1187 empty shells collected from 135 small plots in Bau. High completeness ratios (Sampling coverage = 0.99 for empty shell, 0.95 for live-taken snail) indicated high sampling effectiveness for both live-taken snail and empty shell samples at cluster scale. However, the species counted from the live-taken snail samples (17 species @ 95 individuals) are lower than the species observed from the empty shell samples (84 species @ 1187 individuals), which is similar to the hill scale (= Bukit Sokwang, Gunung Kapor and Bukit Lobang Angin) (see Appendix F). Species diversity from live-taken snail is very low compare to the empty shell even though high completeness ratios for live-taken snail and empty shell samples both at cluster scales. According to diversity estimates, 84 species were observed with estimated 90 species using empty shell samples while only 17 species with estimated 19 species were observed using live-taken snails in Bau.

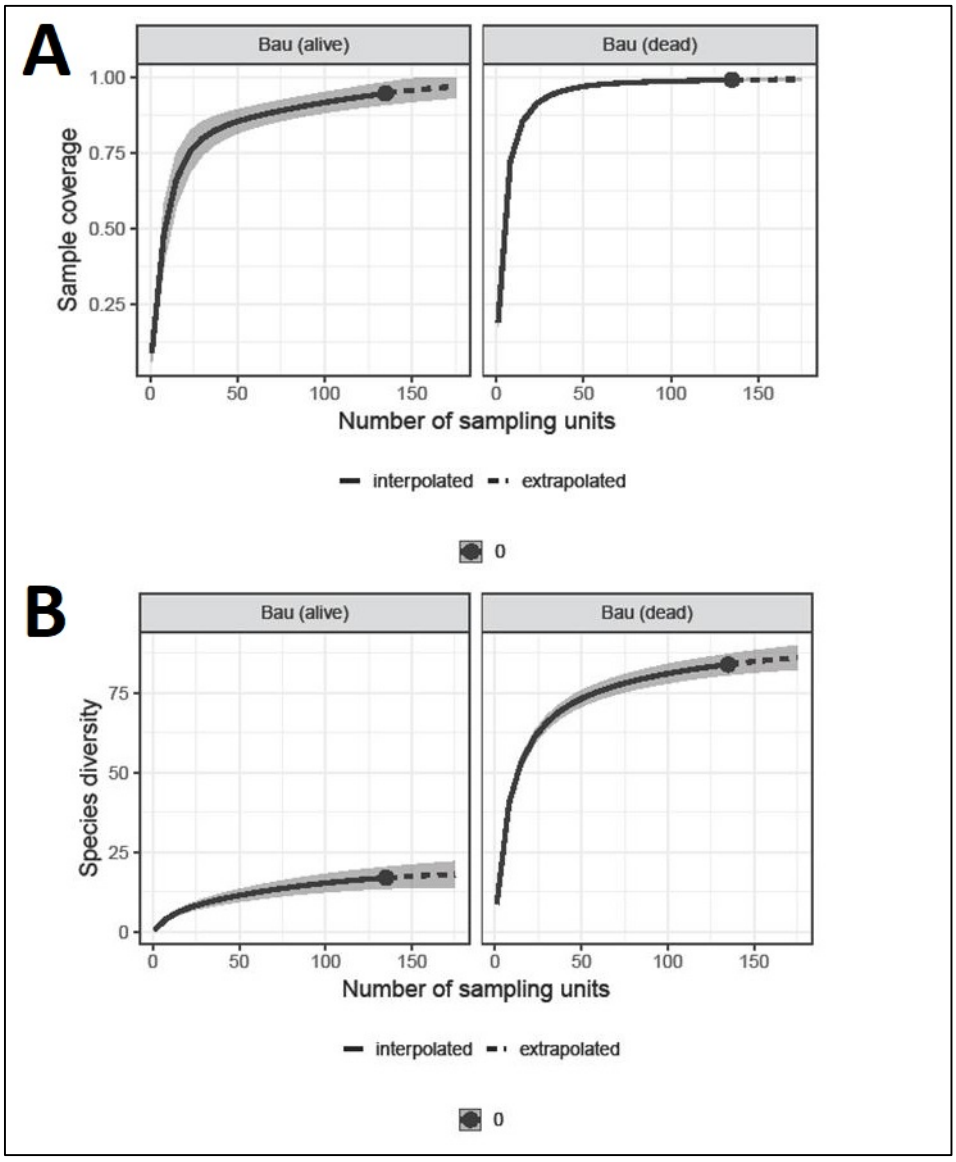


Figure 4.56: A. Comparison between live-taken snail versus empty shell on estimated species richness according to sample coverage in Bau limestone hill cluster. **B.** Comparison between live-taken snail versus empty shell on species richness estimates for a rarefied and extrapolated sample with respect to the number of sampling units in Bau limestone hill cluster. Shaded areas represent 95% confidence intervals, and dashed lines represent extrapolated data.

4.3 The associations between land snail species and microhabitats

Cluster analysis was done to see the relationship between species community and assemblages based on presence-absence (figure 4.57A) and abundance (figure 4.57B) data of 17 live-taken land snail species from Bau. According to the species richness data (figure 56a), there are three main clusters involved. All clusters are not corresponding to the microhabitat, but more to the locality: Cluster 1 ranges mostly from Bukit Lobang Angin (C1H3), Cluster 2 ranges mostly from Bukit Sokwang (C1H1), and Cluster 3 ranges mostly from Gunung Kapor (C1H2). Presence-absence data are used to determine species richness and suitable for monitoring the land snail populations at large scales, to identify high-value habitats and specific species of conservation concern. But, this data lacks the actual living population in the particular area. According to the abundance data (figure 56b), there are also 3 main clusters involved. Similar to presence-absence data, all clusters do also not correspond to the microhabitat, but more to locality: Cluster 1 ranges mostly from Bukit Sokwang (C1H1), Cluster 2 ranges mostly from Gunung Kapor (C1H2), and Cluster 3 ranges mostly from Bukit Lobang Angin (C1H3).

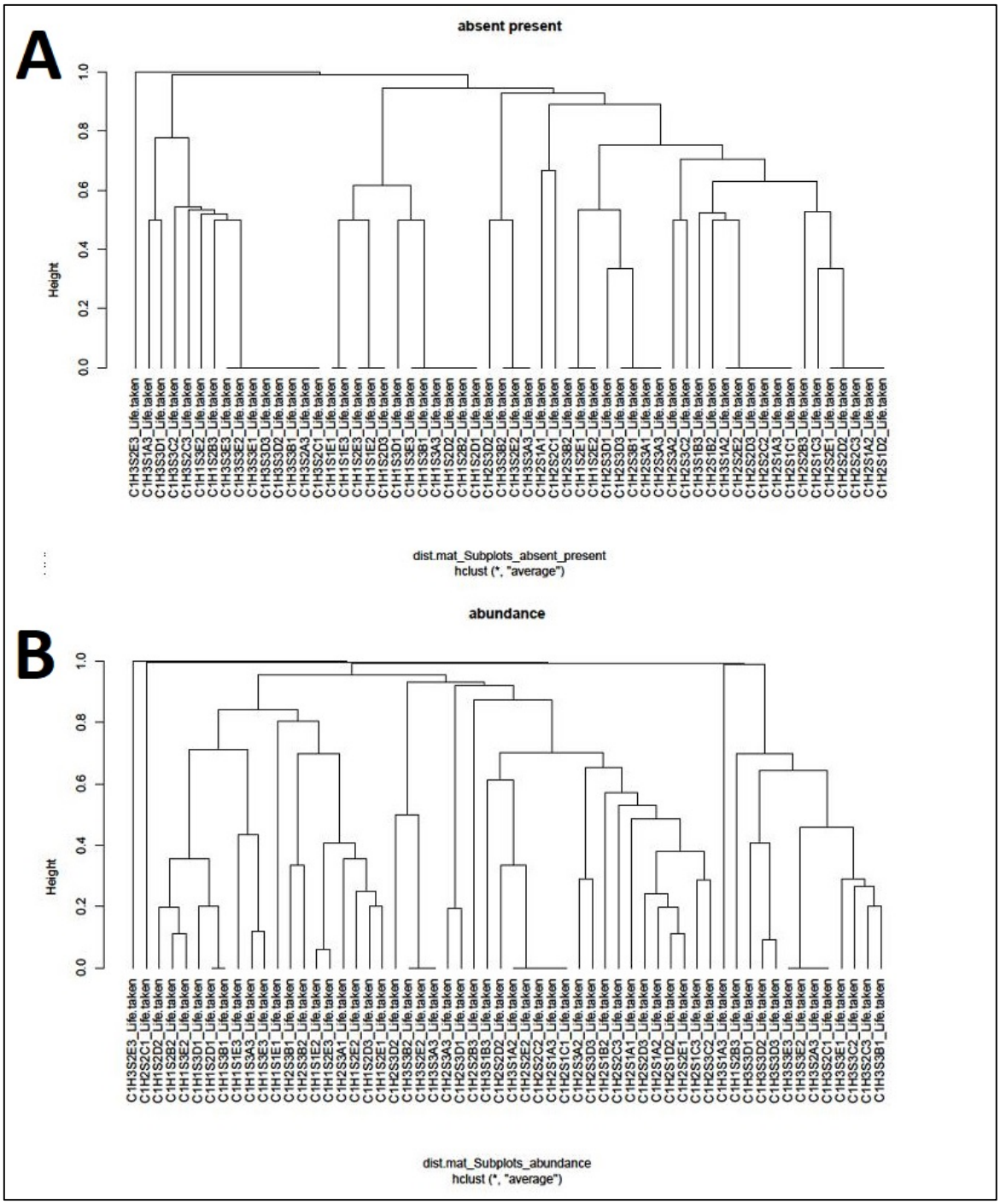


Figure 4.57: A. Cluster analysis of species community and assemblages based on presence-absence data of 17 live-taken land snail species from Bau; **B.** Cluster analysis of species community and assemblages based on abundance data of 17 live-taken land snail species from Bau.

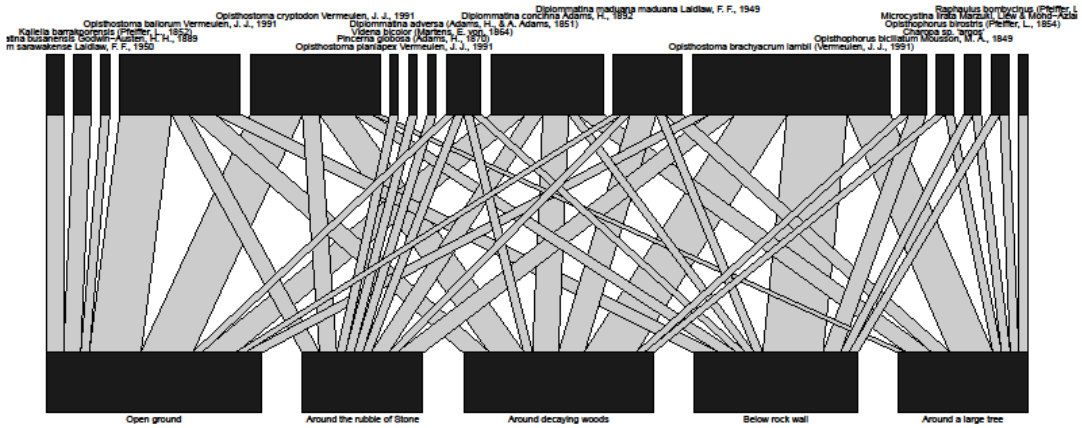


Figure 4.58: Weighted network of land snail species and microhabitats sampled at Bau limestone hill cluster. The upper level shows the 17 species of live-taken land snail. The lower level indicates the five (5) microhabitat (open ground, around the rubble of stone, around decaying woods, below the rock walls and around a large tree) and the relative density of each species is illustrated by the width of its block.

In this study, we quantify the associations between land snail species and microhabitats sampled at the Bau limestone hill cluster using a bipartite weighted network (figure 4.58). In total, the 43 bipartite weighted networks were constructed from 427 individuals from 17 species of live-taken land snails. Land snail species richness was about equivalent in all five microhabitats (8-9 species per microhabitat). *Opisthostoma cryptodon*, *O. brachyacrum lambii*, *Diplommatina maduana maduana*, and *D. concinna* prefer all microhabitats. *Opisthostoma ballorum* and *Diplommatina adversa* prefer open all microhabitats except leaf litter around a large tree. *Microcystina lirata* and *Opisthophorus birostris* prefer leaf litter below the rock walls and around a large tree. *Sundacharopa argos* prefer leaf litter around decaying woods and around a large tree. *Opisthophorus biciliatum* prefer leaf litter around decaying woods and below the rock walls. *Platycochlium*

sarawakense, *Diplommatina busanensis*, and *Kaliella barrakporensis* prefer only leaf litter in the open ground. *Opisthostoma planiapex*, *Pincerna globosa*, and *Videna bicolor* prefer only leaf litter around the rubble of stone. *Rhaphaulus pfeifferi* prefers only leaf litter around a large tree.

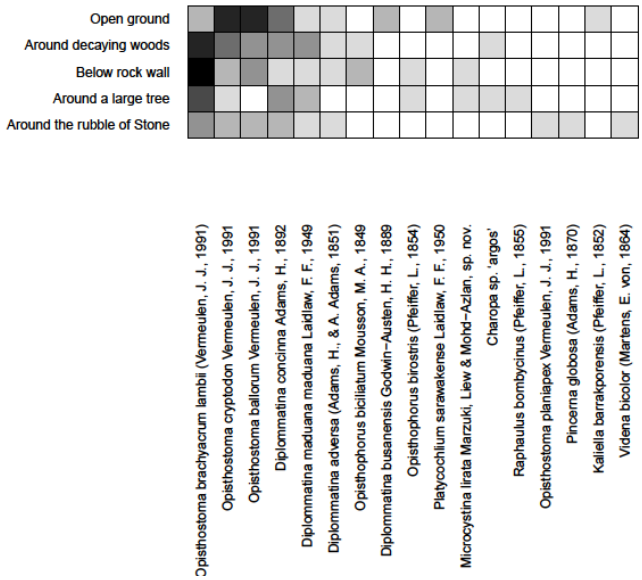


Figure 4.59: A visualisation of the adjacency matrix of land snail species and microhabitats sampled at Bau limestone hill cluster. The x-axis shows the 17 species of live-taken land snail. The y-axis indicates the five (5) microhabitat (open ground, around the rubble of stone, around decaying woods, below the rock walls and around a large tree) and the relative density of each species is illustrated by the tone of its cell.

The associations between land snail species and microhabitats sampled at the Bau limestone hill cluster were simplified using an adjacency matrix (Figure 4.59). Although 17 species are generally leaf litter dweller, surprisingly each species prefer different microhabitats. *Opisthostoma brachyacrum lambii* prefer to leaf litter below the rock walls, around decaying woods, and around a large tree yet less preferred to leaf litter in the open ground and around the rubble of stone. *Opisthostoma cryptodon* and *O. ballorum* prefer to

leaf litter in the open ground and around decaying woods but less preferred to leaf litter around a large tree.

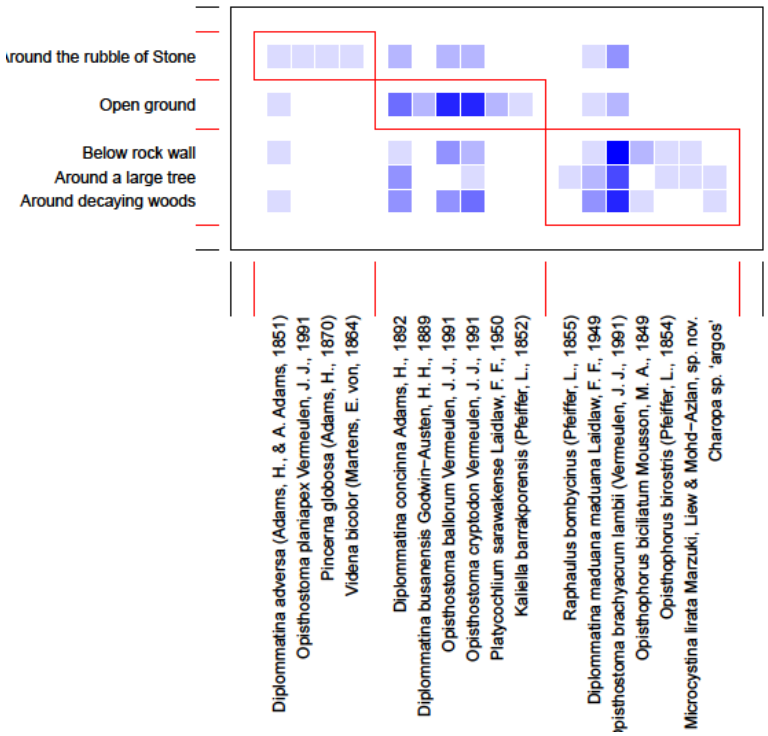


Figure 4.60: Interaction matrix featuring nested modules for the data of land snail species and microhabitats sampled at Bau limestone hill cluster. The x-axis shows the 17 species of live-taken land snail. The y-axis indicates the five (5) microhabitat (open ground, around the rubble of stone, around decaying woods, below rock wall and around a large tree) and the relative density of each species is illustrated by the tone of its cell.

Figure 4.60 show the interaction matrix featuring nested modules for the data of land snail species and microhabitats sampled at the Bau limestone hill cluster. Coloured boxes delineate the three (3) modules. Module 1 involved a group of land snails which prefer more to the leaf- litter around the rubble of stone; *Diplommatina adversa*, *Opisthostoma planiapex*, *Pincerna globosa*, and *Videna bicolor*. Module 2 involved a group of land snails which prefer more to the leaf litter in the open ground; *Diplommatina concinna*, *D.*

busauensis, *O. ballorum*, *O. cryptodon*, *Platycochlium sarawakense*, and *Kaliella barrakporensis*. The rest of the land snail under module 3 prefers leaf litter below rock wall, around a large tree, and around decaying woods.

CHAPTER 5

DISCUSSION

5.1 Land snail species composition in Bau limestone hill clusters and implication to species conservation

5.1.1 Land snail species diversity and composition

To our knowledge, this is the first study to have well documented inventory of land snails for Bau limestone hills. The survey taken from Bau reported 122 species of land snails from 58 genera and 24 families. Among these snails, 18 land snail species are considered new species following this study with 13 new species were described in Marzuki et al. (2021).

Limestone hills in Borneo are a hotspot for land snail diversity and thus have been the focus of land snail diversity studies (Vermeulen 1991a, 1991b, 1993, 1994, 1996). Some of the earliest work on land snails in Borneo were initiated at Sarawak's limestone hills. Recently, a few land snail inventory studies were conducted in several limestone hills and clusters in Sarawak, for example, in Bukit Sarang (83 species), the Bau-Serian limestone range (148 species), Gunung Mulu (97 species) and Niah (108 species) (Vermeulen & Junau 2007). However, these comprehensive reports lack a systematic checklist with proper illustrations for every species (see Vermeulen & Junau, 2007), or with provisional working species names (see Vermeulen, 2003). This problem had made it challenging to update current checklists because the taxa list from the previous report cannot be used to compare with recently collected specimens. To address this knowledge gap, an annotated checklist with traceable specimens and proper illustrations for every species is crucial to amend the existing understanding of land snails in Bau and Sarawak in general.

The land snail species compositions between Bau, Niah, and Mulu are very different. Despite the fact that Bau, Niah and Mulu limestone hills are home to 239 land snail species, only seven percent of the land snail species occur in all three hills (Vermeulen, 1993). These similarities figure give an impression of the biodiversity richness on the Borneo limestone hill areas. The faunas of Bau limestone hills include a large number of land snail species that are site endemics. A total of 45 out of 122 species are assumed to be site endemic in Bau limestone hills (37% of the local fauna) which exhibits the distinctiveness of the biodiversity of the area. Surprisingly, previous study also reveals the similar pattern on site endemic land snail in Niah, Mulu and Bukit Sarang (Vermeulen, 2003; Vermeulen & Junau, 2007). For this reason, the land snail species inventories are necessary for all 264 limestone outcrops in Sarawak to investigate and explore the land snail diversity for the future conservation and management of limestone regions.

Although dissimilarities in terms of species compositions, however, in term of the genera and families' compositions are more or less similar between Bau, Niah, and Mulu (Vermeulen, 1993). This is not surprising because the land snails from all three regions collected in relatively similar habitats and environments. The limestone habitat is well-known for its high species endemism and diversity compare to the non-limestone tropical forest on acidic soil (Vermeulen & Whitten, 1999). Malacological inventory surveys done in Lanjak Entimau, Penrissen, and Gunung Santubong only result in between 9 and 43 species (Liew & Huong, 2015; Shilthuizen, 2016; Marzuki et al., 2019). In terms of species richness, the land snail from limestone hill clusters in Sarawak (e.g. Bau, Niah, and Mulu) are remarkably diverse than Sukolilo Karst in Java (n= 33 species) (Nurinsiyah, 2015) and the entire Bali island (n= 94 species) (Vermeulen & Whitten, 1998).

Land snail diversity study were done by Clements et al. (2008) from limestone outcrops (n = 16) at western and eastern side of Titiwangsa Range and resulted high number of land snail species (n = 198 species). However, the surveys covered almost all major limestone hill clusters in Peninsular Malaysia. The most recent surveys in Peninsular Malaysia were done by Foon et al. (2017) in Kinta Valley, Perak, Malaysia. Even though the species and families number of land snails collected from Kinta Valley (n = 112 species and 23 families) and Bau limestone outcrops (n = 122 species and 24 families) are comparable, yet, the number of limestone outcrops surveyed in Bau (n = 8) significantly lower than Kinta Valley (n = 12). Furthermore, Bau limestone hills are significantly more diverse than Kinta Valley in terms of the genera number.

Another recent study was also taken in Sabah States (Malaysian Borneo (Vermeulen & Liew, 2022). There are about 343 species and subspecies of land snails recorded in Sabah state which cover all types of forest. Our study only concentrated on eight limestone outcrops in Bau while other non-calcareous bedrocks in Bau are neglected. Astonishingly, the Bau limestone forest records one-third of the total Sabah land snail species richness (n = 355 taxa). There are about 218 limestone outcrops in Sabah with a base area of around 102.03 km^2 while 264 limestone outcrops in Sarawak with a base area of around 278.36 km^2 (Liew et al., 2021a). Unlike Sabah, most of the Sarawak forests (including calcareous and non-calcareous bedrock) are malacologically unexplored until to date.

Land snail species in limestone habitat in Bau are highly diverse and surpass the land snail richness in the temperate forests despite very low abundance. To our knowledge, we also recorded the world's highest land snail richness within a single sampling site of 20 m x 20 m during a single visit to one of the sampling sites in Bau (n= 66 species) compared to

45 species recorded in the rainforest in Southwestern Cameroon at the same sampling scale (de Winter & Gittenberger, 1998). Solem et al. (1981) recorded up to 60 land snail species per 4 ha temperate forest patch in New Zealand's Manukau Peninsula. Our studies showed the land snail species richness in tropical forests, especially tropical limestone forests in the Bau area are high and surpasses the land snail richness in the temperate forests despite very low abundance.

Our recent survey recorded 73 more taxa compared to the species of land snails that were recorded in the Bau area prior to this study (H. Adams, 1872; Godwin-Austen, 1889; 1891; Smith, 1893; 1895; Thompson & Dance, 1983; Vermeulen, 1991a; 1991b; 1993; 1999). A total of 13 land snails recorded were described as new species by Marzuki et al. (2021). In addition, three other land snails were described as new species in other papers (Wang, 2021; Vermeulen & Liew, 2022). Furthermore, a tiny Cyclophorid snail, hereafter known as *Leprocochlias cingulatus textrinum*, belongs to a new genus and species in which it was erroneously assigned to *Craspedotropis borneensis* (sensu Marzuki et al., 2021). The species will be described in a later publication. To sum up, 18 land snail species are considered new following this study.

However, eight species which previously recorded in Bau were not found in the recent survey (see Appendix B). In this study, we only survey eight out of the total of 29 limestone outcrops (27.6%) in Bau (Liew et al., 2021b). Most of the species, particularly Diplommatinid are site-endemic to a single or few limestone hills which were not surveyed in our recent study. On the other hand, some other species are possibly identical to other existing species in our study.

Shell-bearing land snails need a certain amount of calcium carbonate from limestone for the formation of their shell depending on the species. Most of the species are known for very restricted distribution, especially for karst-dependent species such as Diplommatinids and Hydrocenids. Borneo was recognized for central Diplommatid snail diversity radiation with 178 taxa recorded (Marzuki, 2019; Marzuki et al., 2021; Vermeulen, 1991; 1993; 1994; 1996a; 1996b; Vermeulen et al., 2015; Vermeulen & Liew, 2022; Vermeulen & Khalik, 2021; 2022). Currently, some other genera such as *Microcystina*, *Kaliella*, and *Everettia* are known to be well-diversed in Borneo (Vermeulen & Liew, 2022). *Microcystina* is a genus of small-sized Ariophantid with a wide variety of microhabitats. This genus was formerly underestimated due to a lack of attention. Vermeulen et al. (2015) described five new species out of the total 10 species of *Microcystina* occurring in Sabah state. Albeit the Bau limestone hill cluster is a small fraction of land in Sarawak state, we recorded eight species of *Microcystina* occurring in this area, whereas six species were described as new species. Surprisingly, only one species occurs in both regions.

Land snail generic compositions in Bau are also remarkably unique. *Platycochlium* Laidlaw, 1950, is a genus with three species under the family Diapheridae. This genus is known entirely restricted to Bau-Serian limestone hill clusters (Vermeulen, 1991b). *Platycochlium sarawakense* Laidlaw, 1950 is the only known species found in Bau. Besides *Platycochlium*, three other Diapherid snails hitherto known from Borneo, viz. *Bruggennea* Dance, 1972, *Sinoennea* Kobelt, 1904, and *Diaphera* Albers, 1850 but not found in Bau. *Arinia* H. Adams & A. Adams, 1856, in Borneo comprise 28 species and five subspecies (Vermeulen, 1996; Vermeulen & Liew, 2022; Vermeulen & Khalik, 2022). Surprisingly, there is no record of *Arinia* species in Western Sarawak particularly in Bau until to date. *Teracharopa lenticula* Vermeulen & Junau, 2007, *Niahia oberon* Vermeulen, 1996b, and

Notharinia xenos Vermeulen & Khalik, 2022 are the representative species of the genus *Teracharopa* Maassen, 2000, *Niahia* Vermeulen, 1996, and *Notharinia* Vermeulen, Phung & Truong, 2007 in Sarawak. However, these genera are only recorded in northern Sarawak. On the other hand, *Oospira scalariformis* (Loosjes, 1953) and *Coptocheilus doriae* (Issel, 1874) are the representative species of the genus *Oospira* Blanford, W. T., 1872 and *Coptocheilus* Gould, 1862 in Western Sarawak, however, these species are known to non-calcareous hilly forest near Lundu area.

Slugs and semi-slugs are small groups of gastropods that lack of calcareous shell or with a small disc-shape shell covered partly or entirely by the mantle. In this study, two (semi)slugs species were recorded in Bau limestone hills, namely; *Damayantia carinata* Collinge, 1901 and *Valiguna flava* (Heynemann, 1885). Other (semi)slugs genera viz. *Isselentia* Collinge, 1901, *Philomycus* Rafinesque, 1820, *Wiegmannia* Collinge, 1901, *Ibycus* Heynemann, 1862, *Microparmarion* Simroth, 1893, *Semperula* Grimpe & Hoffmann, 1924, *Filicaulis* Simroth, 1913, *Veronicella* de Blainville, 1817, *Semperoncis* Starobogatov, 1976, and *Atopos* Simroth, 1891 were hitherto recorded in Sarawak but not found in Bau limestone hills. Slugs and semi-slugs are generally known from non-calcareous, mostly at high altitudes region of Borneo, and are infrequently encountered (Schilthuizen & Liew, 2008). Our recent study also agreed with the fact of the absence of these genera in the Bau limestone forest.

Introduced species are important as the bio-indicator for habitat disturbance. There are about eight introduced land snail species encountered in this study; *Solenomphala scalaris* (Heude, 1882), *Elaphroconcha striata* (Gray, 1834), *Bradybaena similaris* (Férussac, 1822), *Gulella bicolor* (Hutton, 1834), *Lissachatina fulica* (Bowdich, 1822),

Opeas hannense (Rang, 1831), *Allopeas clavulinum* (Potiez & Michaud, 1838), and *Allopeas gracile* (Hutton, 1834). *Opeas hannense* is probably recently introduced into Borneo and only known in Borneo in the first quarters of the 2000s (Vermeulen & Liew, 2022). *Subulina octona* (Bruguière, 1792) a well-known introduced land snail species with worldwide circumtropical distribution was not found in Bau limestone hills. *Parmarion martensi* Simroth, 1893, *Philippinella moellendorffi* (Collinge, 1899), and *Laevicaulis alte* (Férussac, 1821) are the introduced slugs and semi-slugs in Borneo which are commonly found in the disturbed vegetation near human residence. However, these species were not found in Bau limestone hills.

Although the land snail diversity in limestone forests appears very high, the species abundance is very low. Most of the land snail species collected in the recent survey are with less than 10 individuals. This is expected as the land snails are not equally distributed within the limestone landscape. Some land snail species in Sarawak are locally abundant and common. For example, more than a thousand individuals of *Opisthostoma brachyacrum lambii* are found in single plots while others are extremely rare at the site.

5.1.2 Implication to species conservation and taxonomy

To date, the malacofauna surveys in Sarawak were predominantly focused on limestone habitats. There are few efforts done to investigate and explore the land snail diversity in non-limestone forests in Sarawak (Schilthuizen, 2016; Marzuki et al., 2019; Liew & Huong, 2015). Non-limestone areas, especially highland regions also proved to contain a very high number of endemic land snail species although less abundant than the limestone area (Vermeulen & Liew, 2022). Our knowledge of the Sarawak land snail is still

developing and estimated the species number will be increased with additional malacofauna exploration in both limestone and non-limestone area.

Limestone forests in Malaysia, particularly tower-like karst isolated from one another and surrounded by the more acidic non-calcareous substrate. Habitat isolation limits the gene flow of the land snail and brings a high level of species endemism (Clements et al., 2008). This study revealed that limestone areas especially in Bau contain very high levels of endemism among the land snail species. Certain groups of land snails in limestone forests particularly calcicole obligate species are known for their low dispersal ability and these groups are limited to this environment and display a high degree of narrow-range endemism (Liew et al., 2021c; Schilthuizen et al., 2005).

5.2 The species richness estimates and sampling effectiveness: live-taken snail versus empty shell

The result shows all sampling efforts by using both live-taken snails and empty shells reached more than 90% coverage with the land snail samples taken from empty shells reaching almost 100%.

We can imply the empty shells used to estimate the density of live-taken snails in limestone habitats which agreed with Thurman et al. (2008) and Stankowski (2014). Besides randomly searching among the vegetation, there is a need to look at areas where a lot of empty shells to increase the chances to get the live-taken snails. Empty shells provide important information for the presence of particular species in terms of temporal and spatial scales which are important for the biogeographical study of species-area relationships (Clement et al., 2008; Říhová et al., 2018).

Shell decaying rates depend on the shell size, soil acidity, and humidity (Říhová et al., 2018). However, most of the empty shells, both larger and smaller shells, found in these study sites appeared in good condition and identifiable since the soil around the limestone hill is alkaline and rich with the calcium content. This favourable condition slows down the breakdown of empty shells in the soil (Schilthuizen & Rutjes, 2001).

Sampling completeness ratios are conceivably used as a substitution for sampling effectiveness to show in case datasets are representative. Previous study shows very high sampling completeness in both Peninsular Malaysia and Sabah limestone hills regardless of the size and number of quadrat sampling done (Liew et al., 2008). In this case, the sampling regimes in limestone hills should be optimized for expected species diversity and abundance (Schilthuizen, 2011). Small plot (0.0004 m^2), which is the smallest scale unit in this study is recommended for studying land snails since we minimize the plot size and increase the sampling effort to maximize the number of plots. This scale is certainly smaller than previously recommended by Clements et al. (2008) and Liew et al. (2008).

Despite very high sampling effectiveness by using a small plot, species richness taken from live-taken snail samples is low compared to the empty shell. Our result shows that less than 20 live-taken land snail species were recorded compared to empty shell samples, five times the number of live-taken specimens recorded. Previous studies in Borneo also reveal a similar pattern to our result. For instance, less than 1% of the snails collected in the pristine and disturbed limestone forests in Sabah were living individuals (Schilthuizen et al., 2005). Most living snails and slugs are extremely difficult to find in tropical forests (Schilthuizen, 2011). For that reason, most of the species in Borneo were recognized only from the empty shell (Vermeulen, 1990). If we look at it from an ecological point of view,

we found that most of the live-taken snails are true leaf litter dwellers. Land snails in limestone forests are unique for their microhabitat requirement. The soil sample may contain very high species richness, but the species composition may contain the species originating from different niches and complex three-dimensional microhabitats (Schilthuizen, 2011). Land snails from the genera *Plectostoma*, *Stomacosmethis*, *Boysidia*, *Phaedusa*, and most *Georissa* are calcicole obligate and live entirely on limestone wall surfaces. Besides, some other genera such as *Videna*, *Damayantia*, *Leptopoma*, *Pincerna,* and *Amphidromus* are tree dwellers and live mostly on the leaf of the tree. These species are absent in the small plots since the sample from this plot is taken entirely from leaf litters and topsoils. Interestingly, there are a few live-taken *Videna* and *Pincerna* found from leaf litters. This is not a surprise because arboreal land snail sometimes climbs down to the ground for protection and dampness (Vermeulen & Whitten, 1998).

5.3 The associations between land snail species and microhabitats

Presence-absence data are used to determine species richness and are suitable for monitoring the land snail populations at large scales, to identify high-value habitats and specific species of conservation concern. But, this data lacks the actual living population in the particular area fact that land snail specimens collected at the small plot scale are collected from leaf litters and top soils. The species composition for the empty shell may contain the species originating from different niches and complex three-dimensional microhabitats (Schilthuizen, 2011).

Microhabitats are known as the main driver to determine the invertebrate community structure. For example, dissimilarity in time-dependent mortality risks that influence development times is associated with the body size of other invertebrate taxonomic groups

such as insects (Wardhaugh et al., 2013). On the other hand, the cave invertebrate communities' structure also responded to the substrate types and heterogeneity (Pacheco et al., 2020). Our study demonstrates the land snail species composition in Bau limestone hills are not corresponding to the microhabitat, but more to its geography. The live-taken snail collected from all five microhabitats is approximately identical to each other although the sampling differs in which area the leaf litter was collected. The live-taken snail collected from a small plot in our study mostly belongs to leaf litter dweller species. But, the species composition slightly changes concerning different localities although the microhabitats are similar to each other. The limestone area in Bau contains very high levels of endemism among the land snail species due to their low dispersal ability. This situation was similar to the observation made by Liew et al. (2020) on the leaf litter dweller snail, *Pollicaria elephas* from Peninsular Malaysia.

Some factors influenced the land snail species diversity and endemism in limestone forests. In previous studies, limestone hill size and the soil type surrounding limestone hill influence the endemism rates among the land snail. The size of the limestone hills on the other hand also seems to be an important determinant of species diversity rates. Larger limestone hills may contain diverse microhabitats that are conducive to land snail speciation (Clements et al., 2008). Most land snail in Bau generally prefers more than one microhabitat in leaf litter. However, not all leaf litter dweller prefers various microhabitats. Some land snail species prefer different microhabitats though these species are true leaf litter dwellers. The difference in land snail composition in each limestone microhabitat may be influenced by factors such as calcium availability and substrate pH. However, calcium availability may not vary significantly in each limestone outcrop (Crowther, 1987). In addition, although the

bedrock was affected by the substrate's pH (soil and leaf litter), the variation among the microhabitats was very small (Crowther, 1982).

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

The inventory of land snails for Bau is well documented in this study. The survey taken from Bau reported 122 species of land snails from 58 genera and 24 families. Among these snails, 18 land snail species are considered new species following this study. Land snail species in limestone habitat in Bau are highly diverse and surpass the land snail richness in the temperate forests despite very low abundance. To our knowledge, we also recorded the world's highest land snail richness within a single sampling site of 20 m x 20 m during a single visit to one of the sampling sites in Bau (n= 66 species).

All sampling efforts by using both live-taken snails and empty shells reached more than 90% coverage with the land snail samples taken from empty shells reaching almost 100% coverage. However, species richness taken from live-taken snail samples is low compared to the empty shell.

All clusters from presence-absence and abundance data in Bau are not corresponding to the microhabitat, but more to the locality. Land snail species richness was about equivalent in all five microhabitats as the living individuals collected from soil samples and the species are mostly leaf litter dwellers.

6.2 Recommendations

The soil samples were collected from the small plot scale resulting in the highest species completeness compared to the previous conventional sampling scale in the limestone hill cluster by increasing the number of sampling plots but reducing the sampling plot size.

However, this sampling method only covers micro-habitat among leaf litter while ignoring the other habitat components which may be important for land snail species. The land snails appear diverse in the limestone hills, but each species may prefer different components of a selected microhabitat. Therefore, the sampling efficiency increased by selecting the small plot through the probable microhabitat rather than a single microhabitat component from the standard plot.

For the ecological study, the number of species in terms of living individuals increased by using subplots (2 m x 2 m, 4 m^2) that represent all the major microhabitats of land snails. In this plot, we can collect the samples not only from leaf litter but also from different niches and complex three-dimensional microhabitats.

Limestone hills in Sarawak are threatened by various habitat degradation activities. However, our land snail inventories only covered 3% of the total limestone outcrops number in Sarawak and very little land snail inventory has been carried out in the non-limestone areas especially the Dipterocarp forest in Sarawak. Our knowledge of the Sarawak land snail is improving and the estimated species number is expected to increase with additional malacofauna exploration in both limestone and non-limestone area.

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APPENDICES

Appendix A: Journal Publications

1. **Marzuki, M. E.** (2019). *Diplommatina azlani*, a new land snail species from Sarawak (Gastropoda: Cyclophoroidea: Diplommatinidae). *Raffles Bulletin of Zoology, 67*, 56-59.
2. **Marzuki, M. E.**, Liew, T. S., & Mohd-Azlan, J. (2021). Land snails & slugs of Bau limestone hills, Sarawak (Malaysia, Borneo), with the descriptions of 13 new species. *ZooKeys, 1035*, 1-113.

Appendix B: Annotated list of species from Bau not found in the ME collection but reported by previous studies.

Taxa reported	Sources	Remarks
Family Diplommatinidae L. Pfeiffer, 1856		
Opisthostoma dihelicton Vermeulen, 1994	Vermeulen, 1994	The species described from southeastern of limestone outcrop South of Bau
Opisthostoma sulcatum Vermeulen, 1994	Vermeulen, 1994	The species described from southeastern of limestone outcrop South of Bau
Plectostoma picsingense (Smith, 1905)	Vermeulen, 1994	The species described from southeastern of limestone outcrop South of Bau
Plectostoma goniostoma (Vermeulen, 1994)	Vermeulen, 1994	The species described from southeastern of limestone outcrop South of Bau
Plectostoma ptychodon (Vermeulen, 1994)	Vermeulen, 1994	The species described from southeastern of limestone outcrop South of Bau
Family Cyclophoridae Gray, 1847		
Craspedotropis borneensis (Godwin-Austen, 1889)	Godwin-Austen, 1889	The species described from "Busau Hills" [=Jambusan Hills, Bau, Sarawak]
Family Ariophantidae Godwin-Austen, 1883		
Microcystina pudens Godwin-Austen, 1891	Godwin-Austen, 1891	The species described from "Busan Hills" [=Jambusan Hills, Bau, Sarawak]
Family Chronidae Thiele, 1931		
Kaliella amussitata (Smith, 1895)	Smith, 1895	The species described from "Busau, West Sarawak" [=Jambusan Hills, Bau, Sarawak]

Appendix C: Diversity estimates with rarefied and extrapolated samples from Bukit Sokwang using empty shell and live-taken snail samples.

Basic data information

Samples	T	U	S.obs	SC	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Empty shell	45	441	58	0.9781	10	8	6	6	0	1	3	2	2	2
Living snail	45	28	7	0.9331	2	3	0	0	0	0	1	0	0	0

Empty shell (dead)

	t	method	order	qD	qD.LCL	qD.UCL	SC	SC.LCL	SC.UCL
1	1	interpolated	0	9.800	9.043	10.557	0.282	0.253	0.312
10	22	interpolated	0	49.703	46.065	53.341	0.942	0.929	0.955
20	45	observed	0	58.000	53.042	62.958	0.978	0.966	0.990
30	107	extrapolated	0	63.444	53.869	73.019	0.998	0.989	1.000
40	175	extrapolated	0	64.052	50.723	77.382	1.000	0.995	1.000

Living snail (alive)

	t	method	order	qD	qD.LCL	qD.UCL	SC	SC.LCL	SC.UCL
1	1	interpolated	0	0.622	0.428	0.817	0.166	0.086	0.245
10	22	interpolated	0	5.206	3.810	6.601	0.819	0.745	0.893
20	45	observed	0	7.000	5.006	8.994	0.933	0.844	1.000
30	107	extrapolated	0	7.641	3.794	11.488	0.999	0.953	1.000
40	175	extrapolated	0	7.652	2.724	12.580	1.000	0.980	1.000

Asymptotic diversity estimates along with related statistics

Sample	Diversity	Observed	Estimator	s.e.	LCL	UCL
Empty shell	Species richness	58.000	64.111	5.071	59.479	83.249
Empty shell	Shannon diversity	40.102	42.914	1.462	40.102	45.779
Empty shell	Simpson diversity	32.846	34.644	1.370	32.846	37.329
Living snail	Species richness	7.000	7.652	1.282	7.055	14.673
Living snail	Shannon diversity	4.510	5.202	0.946	4.510	7.057
Living snail	Simpson diversity	3.379	3.646	0.772	3.379	5.158

Appendix D: Diversity estimates with rarefied and extrapolated samples from Gunung Kapor using empty shell and live-taken snail samples.

Basic data information

Samples	T	U	S.obs	SC	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Empty shell	45	441	58	0.9781	10	8	6	6	0	1	3	2	2	2
Living snail	45	28	7	0.9331	2	3	0	0	0	0	1	0	0	0

Empty shell (dead)

	t	method	order	qD	qD.LCL	qD.UCL	SC	SC.LCL	SC.UCL
1	1	interpolated	0	9.800	9.043	10.557	0.282	0.253	0.312
10	22	interpolated	0	49.703	46.065	53.341	0.942	0.929	0.955
20	45	observed	0	58.000	53.042	62.958	0.978	0.966	0.990
30	107	extrapolated	0	63.444	53.869	73.019	0.998	0.989	1.000
40	175	extrapolated	0	64.052	50.723	77.382	1.000	0.995	1.000

Living snail (alive)

	t	method	order	qD	qD.LCL	qD.UCL	SC	SC.LCL	SC.UCL
1	1	interpolated	0	0.622	0.428	0.817	0.166	0.086	0.245
10	22	interpolated	0	5.206	3.810	6.601	0.819	0.745	0.893
20	45	observed	0	7.000	5.006	8.994	0.933	0.844	1.000
30	107	extrapolated	0	7.641	3.794	11.488	0.999	0.953	1.000
40	175	extrapolated	0	7.652	2.724	12.580	1.000	0.980	1.000

Asymptotic diversity estimates along with related statistics

Sample	Diversity	Observed	Estimator	s.e.	LCL	UCL
Empty shell	Species richness	58.000	64.111	5.071	59.479	83.249
Empty shell	Shannon diversity	40.102	42.914	1.462	40.102	45.779
Empty shell	Simpson diversity	32.846	34.644	1.370	32.846	37.329
Living snail	Species richness	7.000	7.652	1.282	7.055	14.673
Living snail	Shannon diversity	4.510	5.202	0.946	4.510	7.057
Living snail	Simpson diversity	3.379	3.646	0.772	3.379	5.158

Appendix E: Diversity estimates with rarefied and extrapolated samples from Bukit Lobang Angin using empty shell and live-taken snail samples.

Basic data information

Samples	T	U	S.obs	SC	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Empty shell	45	559	67	0.9844	9	6	5	3	5	7	2	3	3	2
Living snail	45	45	9	0.9362	3	3	0	0	0	0	1	1	0	0

Empty shell (dead)

	t	method	order	qD	qD.LCL	qD.UCL	SC	SC.LCL	SC.UCL
1	1	interpolated	0	12.422	11.524	13.321	0.297	0.267	0.326
10	22	interpolated	0	59.818	56.291	63.345	0.959	0.951	0.968
20	45	observed	0	67.000	62.395	71.605	0.984	0.976	0.992
30	107	extrapolated	0	72.563	63.770	81.356	0.998	0.990	1.000
40	175	extrapolated	0	73.464	60.621	86.306	1.000	0.995	1.000

Living snail (alive)

	t	method	order	qD	qD.LCL	qD.UCL	SC	SC.LCL	SC.UCL
1	1	interpolated	0	1.000	0.758	1.242	0.265	0.155	0.374
10	22	interpolated	0	6.692	5.128	8.257	0.864	0.806	0.922
20	45	observed	0	9.000	6.717	11.283	0.936	0.865	1.000
30	107	extrapolated	0	10.373	5.340	15.407	0.996	0.948	1.000
40	175	extrapolated	0	10.462	3.254	17.670	1.000	0.973	1.000

Asymptotic diversity estimates along with related statistics

Sample	Diversity	Observed	Estimator	s.e.	LCL	UCL
Empty shell	Species richness	67.000	73.600	5.764	68.509	95.866
Empty shell	Shannon diversity	48.836	51.819	1.414	49.048	54.590
Empty shell	Simpson diversity	39.791	41.836	1.498	39.791	44.772
Living snail	Species richness	9.000	10.467	2.248	9.170	21.650
Living snail	Shannon diversity	5.059	5.710	0.802	5.059	7.281
Living snail	Simpson diversity	3.559	3.717	0.603	3.559	4.898

Appendix F: Diversity estimates with rarefied and extrapolated samples from Bau limestone hills cluster using empty shell and live-taken snail samples.

Basic data information

Samples	T	U	S.obs	SC	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Empty shell	45	187	38	0.9419	11	3	3	3	6	1	1	1	3	2
Living snail	45	22	8	0.8222	4	2	1	0	0	0	0	0	0	0

Empty shell (dead)

	t	method	order	qD	qD.LCL	qD.UCL	SC	SC.LCL	SC.UCL
1	1	interpolated	0	4.156	3.649	4.662	0.163	0.130	0.196
10	22	interpolated	0	30.869	27.493	34.246	0.896	0.858	0.933
20	45	observed	0	38.000	32.158	43.842	0.942	0.910	0.974
30	107	extrapolated	0	48.532	37.102	59.963	0.973	0.948	0.998
40	175	extrapolated	0	53.744	37.984	69.505	0.988	0.973	1.000

Living snail (alive)

	t	method	order	qD	qD.LCL	qD.UCL	SC	SC.LCL	SC.UCL
1	1	interpolated	0	0.489	0.298	0.680	0.124	0.036	0.212
10	22	interpolated	0	5.320	3.670	6.969	0.694	0.544	0.844
20	45	observed	0	8.000	5.379	10.621	0.822	0.632	1.000
30	107	extrapolated	0	10.940	4.861	17.019	0.956	0.827	1.000
40	175	extrapolated	0	11.700	2.947	20.454	0.990	0.916	1.000

Asymptotic diversity estimates along with related statistics

Sample	Diversity	Observed	Estimator	s.e.	LCL	UCL
Empty shell	Species richness	38.000	57.719	17.050	42.559	123.287
Empty shell	Shannon diversity	27.789	32.243	2.331	27.789	36.810
Empty shell	Simpson diversity	22.900	25.402	1.683	22.900	28.701
Living snail	Species richness	8.000	11.911	5.182	8.544	36.138
Living snail	Shannon diversity	5.034	6.777	1.896	5.034	10.492
Living snail	Simpson diversity	3.408	3.787	1.337	3.408	6.406

Where, T = Sample size, U = Number of incidences, S.obs = Observed species richness, SC = the sample coverage estimate, Q1-Q10 = first ten incidence frequency counts, s.e. = the s.e. of the asymptotic estimator, LCL = Lower confidence limit, UCL = Upper confidence limit, qD = the diversity estimate of Order q, qD.LCL = the 95% lower confidence limits of diversity, qD.UCL = the 95% upper confidence limits of diversity, SC.LCL = the 95% lower confidence limits of sample coverage, SC.UCL = the 95% upper confidence limits of sample coverage.