



Faculty of Resource Science and Technology

**Geographic Distribution and Potential Conservation Strategies for the
Genus *Japonia* in Sarawak, Malaysia**

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Geographic Distribution and Potential Conservation Strategies for the Genus
Japonia in Sarawak, Malaysia

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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

This study explores the diversity and distribution of *Japonia* species, a genus of terrestrial gastropods in Sarawak, Malaysia. Due to their limited distribution and specific habitat needs, *Japonia* species are highly sensitive to ecological changes. The study aimed to identify these diversity and distribution patterns and to predict habitat suitability for selected *Japonia* species using the Maximum Entropy algorithm based on bioclimatic data. Seventeen species were identified, categorised into widely distributed (*J. barbata*, *J. bauensis*, *J. metcalfei*), short-ranged (*J. dido*, *J. keppeli*, *J. baritense*), and endemic (*J. lambirensis*, *J. hyalina*, *J. sp. 'Mulu'*). Notably, *Japonia barbata* is abundant in the western region, *J. quinquelirata quinquelirata* in the central region, and *J. keppeli* in the eastern region. Key environmental factors influencing habitat suitability varied by species: precipitation during the driest quarter was crucial for *J. barbata* and *J. bauensis*, mean temperature in the driest quarter played a significant role for *J. baritense*, and precipitation during the wettest quarter was a determining factor for *J. dido*. Six bioregions were identified, highlighting species-rich areas. Conservation priority analysis identified Lundu, Bau, Kuching, Asajaya, and Samarahan (west); Tatau, Bintulu, Niah Suai, and Sibuti (east); and Lubok Antu, Song, and Kapit (central) have the high priority conservation value. Recommendations include expanding existing parks and reserves, establishing new protected areas to prevent endemic species loss, particularly *Japonia padawanensis*. This research provides valuable insights into *Japonia* distribution and proposes targeted conservation strategies to safeguard these ecologically significant organisms.

Keywords: Bioregion; conservation; diversity; *Japonia*; species distribution modelling

Taburan Geografi dan Strategi Pemuliharaan Potensi untuk Genus Japonia di Sarawak, Malaysia

ABSTRAK

Kepelbagaian dan taburan taksa invertebrata berbeza mengikut kesesuaian habitat dan pilihan ekologi mereka. Gastropod daratan, contohnya, cenderung simpatrik, alopatrik, endemik, atau mempunyai taburan terhad, menjadikan perubahan ekologi berpotensi mempengaruhi kepelbagaian dan taburan mereka secara signifikan. Kajian ini bertujuan untuk menentukan kepelbagaian dan taburan genus Japonia serta meramalkan kesesuaian habitat spesies di Sarawak, Malaysia. Sebanyak 17 spesies telah dikenalpasti, dikategorikan kepada spesies yang tersebar luas (J. barbata, J. bauensis, J. metcalfei), spesies dengan taburan terhad (J. dido, J. keppeli, J. baritense), dan spesies endemik (J. lambirensis, J. hyalina, J. sp. 'Mulu'). Peta haba menunjukkan kelimpahan genus Japonia di Sarawak, dengan J. barbata paling melimpah di wilayah barat, J. quinquelirata di wilayah tengah, dan J. keppeli di wilayah timur. Penilaian faktor persekitaran menunjukkan faktor yang mempengaruhi setiap spesies: jumlah hujan suku paling kering bagi J. barbata dan J. bauensis, suhu suku paling kering bagi J. baritense, jumlah hujan suku paling basah bagi J. dido, dan musim suhu bagi J. metcalfei. Algoritma Entropi Maksimum digunakan untuk memodelkan kesesuaian habitat berdasarkan data bioklimatik. “Bioregion Infomap” menunjukkan pengelompokan spatial bagi spesies Japonia, menghasilkan enam bioregion utama. Analisis keutamaan pemuliharaan mengenal pasti kawasan keutamaan seperti Lundu, Bau, Kuching, Asajaya, dan Samarahan (wilayah barat); Tatau, Bintulu, Niah Suai (wilayah timur); dan Lubok Antu, Song, serta Kapit (wilayah tengah) sebagai kawasan yang mempunyai nilai keutamaan pemuliharaan yang tinggi. Strategi pemuliharaan mencadangkan perluasan kawasan perlindungan dan penubuhan kawasan baru untuk mengelakkan kepupusan spesies

endemik seperti Japonia padawanensis. Kajian ini menyajikan maklumat komprehensif tentang taburan Japonia di Sarawak serta strategi pemuliharaan berpotensi untuk melindungi spesies penting bagi pemuliharaan.

Kata kunci: *Bioregion; pemuliharaan; kepelbagaian; Japonia; pemodelan taburan spesies*

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LIST OF ABBREVIATIONS

km ²	square kilometers
km	Kilometer
°C	Degree celsius
%	Percent
Mha	Million Hectares
TPAs	Totally Protected Areas
MZU	Museum Zoology UNIMAS
m	meter
mm	millimeters
GIMP	GNU Image Manipulation Program
QGIS	Geographic Information System Software
MYS	Malaysia
DOPA	Digital Observatory of Protected Area
SDM	Species Distribution Modelling
MaxEnt	Maximum Entropy
CAZ2	Core-area Zonation 2
IUCN	International Union for Conservation of Nature
SDGs	Sustainable Development Goals

CHAPTER 1

INTRODUCTION

1.1 Study Background

The tropical forests of Sarawak, have the richest biodiversity of animal and plant life among Old World sites (Primack & Hall, 1992). These forests are home to rare and significant species of flora and fauna such as the Orangutan, the Rhinoceros' Hornbill, the largest flower (i.e., *Rafflesia*), and the tropical durian fruit (Primack & Hall, 1992). The species richness in Sarawak makes it an ideal location for studying the diversity of the species and the factors that contribute to the development and maintenance of biological diversity in tropical forests. Yet, the tropics may have experienced significant biodiversity loss due to extensive anthropogenic activities, such as quarrying and mining, resulting in changes in land use and environmental degradation (Sodhi, 2008; Sen et al., 2012). Primary tropical forests are losing biodiversity at an alarming rate, and this loss of biodiversity has been particularly reported among vertebrates and plants (Brook et al., 2003; Sodhi, 2008; Sen et al., 2012; Eisenhauer & Hines, 2021). However, the loss of invertebrates is not well documented but most of them either demonstrate value or strong potential as bioindicators (Paoletti, 2012). For example, the phylum Mollusca already has a strong tradition in ecological studies (Braby et al., 2011; Altaf et al., 2017; Gheoca et al., 2021). This phylum is useful for assessment of landscape status, forest quality, and environment degradation. (Altaf et al., 2017; Gheoca et al., 2021). So far, a study by Liew et al. (2014) stated that the endemic species, *Plectostoma sciaphilum* in Pahang, Malaysia, has gone extinct due to habitat destruction from quarrying. Another species, *Plectostoma decrespignyi* from Labuan Island, is close to extinction due to habitat loss (Phung et al., 2017).

The phylum Mollusca is the second most diverse animal phylum in the world (Tattersfield et al., 1998). The order Gastropoda as a group of animals of this phylum comprises of organism which are important to the ecosystems. The gastropods are generally involved in litter decomposition (Graveland et al., 1994; Dunk et al., 2004; Sen et al., 2012) as well as a food source for various other animals such as small mammals, birds, reptiles, amphibians, and other invertebrates like carnivorous snails (Lange, 2003; Deepak et al., 2010; Nunes & Santos, 2012; Gheoca et al., 2021). Another major importance of the gastropods is their ability to serve as effective bioindicators (Watters et al., 2005; Nunes & Santos, 2012). For example, gastropods can be used to evaluate the impact of climatic and ecological changes towards short-ranged distributed taxa (Shimek, 1930; Čejka & Hamerlík, 2009). They also constitute a vital element of forest ecosystems as they actively contribute to nutrient recycling (Graveland et al., 1994; Dunk et al., 2004). Therefore, gastropods serve as valuable tools in ecological studies (Gümüş, 2010).

Terrestrial snails prove to be invaluable subjects for research in evolutionary biology (Richards & Davison, 2010), biogeography (Martin & Sommer, 2004; Davison & Chiba, 2008), phylogeography (Harl et al., 2014), biodiversity (Davison, 2002), ecology (Lange, 2003), and conservation biology (Schilthuizen et al., 2005; Régnier et al., 2009). Due to their limited dispersal abilities, land snails tend to exhibit conservative distribution patterns, making them important for the study of historical biogeography (Solem, 1984; Naggs & Raheem, 2005; Wade et al., 2006). Their high diversity and narrow distribution also make land snails excellent indicators of areas of conservation importance and endemism when compared to widely distributed groups like vertebrates (Moritz et al., 2001).

Numerous ecological factors have been studied by researchers that are known to affect the richness of land snail communities, and there is a positive correlation between calcium concentrations and the distribution of land snails (Wärborn, 1969; Wärborn, 1970;

Goodfriend, 1986; Dallinger et al., 2001; Hylander et al., 2005; Horsák, 2006; Juříčková et al., 2008). Additionally, there are studies that show soil moisture also contributes to the dispersal pattern of the land snails (Wäreborn, 1969; Martin & Sommer, 2004). The studies also shows that the land snails have the relation to the habitat alteration caused by climate change (Beltramino et al., 2015; Teles et al., 2022).

Large mammals in Sarawak are well-conserved compared to invertebrates, especially land snails. Moreover, some protected areas in Sarawak were established to conserve specific animal species, but this conservation strategy may not significantly increase the number of species within protected areas. Therefore, well-designed conservation strategies are needed to not only increase the number of species conserved but also to mitigate ecological impacts on endemic species.

1.2 Problem statement

Over the past two decades, numerous studies have emphasised the necessity of global mollusc conservation efforts (Ponder, 1997; Herbert, 1998; Killeen & Seddon, 2004; Budha, 2005; Sólymos & Fehér, 2005; Régnier et al., 2009). Killeen and Seddon (2004) and Kayeye et al. (2014) notably compiled a comprehensive volume on the molluscan biodiversity and conservation, underlining the significance of molluscan ecology and conservation on a worldwide scale. However, there is little information regarding the status and threats faced by land snails in Malaysia, specifically in Sarawak. To date, there are several studies on the relationship between the distribution and abundance of terrestrial land snails in Sarawak (e.g., Marzuki et al., 2021; Lee et al., 2024; Nasir et al., 2024). Several research has examined the environmental factors affecting land snail distribution, but there are no specific studies on the distribution of the genus *Japonia* in Sarawak. In addition, little is known about the diversity of the genus *Japonia* in Sarawak. While a few studies have proposed conservation strategies for the limestone hills in Sarawak (Lee et al., 2024; Nasir et al., 2024), there are no specific

strategies that involve land snails, specifically, the genus *Japonia* to determine the conservation value of an area.

1.3 Research questions

The current study was conducted to answer the following questions:

1. How does the genus *Japonia* distribute in Sarawak?
2. Where are the areas of high conservation values in Sarawak?

1.4 Research objectives

This research study embarks on the following objectives:

1. To determine the diversity and the distribution of the genus *Japonia* in Sarawak.
2. To determine the high conservation priority areas in Sarawak, based on the distribution and abundance of the genus *Japonia*

1.5 Chapter summary

Chapter one provides general information about land snails and addresses the current issues related to the genus *Japonia* in Sarawak. Therefore, this chapter aims to fill this gap by investigating the diversity, distribution, and conservation priorities of *Japonia* in Sarawak. Chapter two presents the literature review for this study, covering topics such as the limestone hills in Sarawak, environmental parameters affecting land snails, the distribution of the genus *Japonia* in Asia, the distribution of *Japonia* in Sarawak, and the conservation strategies for protected areas and wildlife in Sarawak. Chapter three is about the methodology of this study. The study sites were located across limestone and non-limestone hills in various regions of Sarawak. Both active and passive methods were applied. A species distribution map and heatmap of species abundance were generated to address the first objective of the study. Species distribution modelling, conservation prioritisation analysis, and Infomap Bioregions were used to achieve the second objective. Chapter four is about the results of this

study. Chapter five is about the discussion of the result's chapter. Lastly, chapter six is about the conclusion and recommendations of this study.

CHAPTER 2

LITERATURE REVIEW

2.1 The Biodiversity of Limestone in Sarawak

Limestone hills are a hotspot of diverse flora and fauna. A total of 264 limestone outcrops, covering 27,836 hectares of land, have been identified in Sarawak (Liew et al., 2021). The southwest region of Sarawak, from Bau to Serian, contains many of these formations, with approximately 112 outcrops. Additionally, there are 111 outcrops in the Miri Division, 19 in the Limbang Division, 17 in the Bintulu Division, three in the Kapit Division, and two in the Mukah Division.

According to Figure 2.1, the map shows limestone hills in Sarawak (Liew et al., 2021), with a total of 98 limestone outcrops in western Sarawak, 14 limestone outcrops in the central regions (Balingian and Tatau divisions), and approximately 78 outcrops in the eastern part of Sarawak. Many studies have indicated that limestone areas have high abundance and diversity of land snails (Vermeulen, 1991a; 1991b; 1993; 1994; 1996; Marzuki et al., 2021). Limestone outcrops of tropical rainforest are considered as globally significant sites due to their high concentration of biodiversity. These areas harbour more than 50% of living organisms, including endemic plant, for example, there are a total of 18 species of *Begonia* are unique to the limestone hills (Kiew, 2001) and animal species like land snails (Clements et al., 2006; Eguakhide et al., 2023).

Kaliella, and *Diplommatina*. Meanwhile, the land snails at Eastern Lanjak Entimau, a non-limestone area in Sarawak, contributed a total of 43 species with the family Ariophantidae as the most species-rich family (Liew & Huong, 2011).

The level of endemism among land snails is often exceptionally high on limestone outcrops, especially in geographically isolated hill clusters (Foon et al., 2017). The separation of these limestone hills by non-calcareous substrates (Paton, 1961) restricts gene flow between populations, fostering high endemism in certain taxa. This occurs through speciation mechanisms such as allopatric (van Benthem-Jutting, 1958; Tweedie, 1961) and parapatric (Schilthuizen et al., 2002) processes, contributing to the rich diversity of land snail species in these areas. For instance, the isolated limestone outcrops at Bukit Sarang, covering only 0.2km², support at least six site-endemic species (Vermeulen & Junau, 2007). In contrast, the smaller Batu Kudik outcrop (0.006km²) hosts just one endemic species (Lee et al., 2024), whereas the larger Subis limestone outcrop (15km²) harbors over 50 endemic species (Vermeulen & Whitten, 1999). Generally, larger limestone areas tend to sustain a higher number of endemic species due to their greater habitat diversity, which drives higher speciation rates (Losos & Schluter, 2000; Roos et al., 2004; Clements et al., 2008).

In general, the limestone outcrops in Sarawak are vulnerable to degradation due to various human activities. Among these, quarrying for materials like cement, marble, and road surfacing is particularly destructive. The complete disappearance of several hills due to quarrying has resulted in the documented extinction of certain species endemic to those sites (Vermeulen, 1994; Schilthuizen et al., 2005). There are also other disturbances of limestone hills such as logging and agricultural activities and these activities have resulted in the disappearance of certain land snail's species as limestone habitats serve as crucial reservoirs for the local malacofauna (Schilthuizen et al., 2005; Eguakhide et al., 2023).

2.2 Environmental Parameters that Affecting the Diversities and Distribution of Land Snails.

Environmental factors such as biotic, abiotic, food source, and habitat suitability are known to affect the distribution and population size of land snails (Barker & Mayhill, 1999; Horsák et al., 2007; Nunes & Santos, 2012). Studies have shown that the characteristics of the habitat have an important role in the diversity and distribution of land snails.

Physical parameters such as temperature, humidity, calcium levels, and pH are known to affect the distribution of the land snails. The higher levels of humidity in the environment can increase the diversity of land snail species (Nunes & Santos, 2012). According to Cameron (1970) and Nunes and Santos (2012), moisture is essential for land snails to respire, reproduce, and produce the necessary mucus for their movement. The litter depth also can affect the communities of land snails. Several research investigations have recorded the influence of soil qualities, such as pH and moisture, on the abundance, densities, and species richness of the land snails (Graveland et al., 1994; Graveland & van der Wal, 1996; Schilthuizen et al., 2003; Martin & Sommer, 2004; Clements, 2008). The acidity of soils could potentially facilitate speciation by acting as significant obstacles for land snails to disperse away from limestone, particularly among groups that have a strong dependence on calcareous habitats. Additionally, a study by Tattersfield et al. (2001) stated that the snail abundance is positively affected by the soil pH, but not on species richness.

High calcium levels in the soil led to an increase for both individuals and species in the terrestrial snail population (Johannessen & Solhoy, 2001). Schilthuizen et al. (2003) stated that land snails require lots of calcium to produce eggs and shells. The presence of exchangeable calcium ions and pH values in the upper soil and litter layers are thought to significantly impact the diversity and abundance of gastropods (Kappes, 2005; Jordan & Black, 2012). Based on the studies of Wärebörn (1969), shelled organisms can receive the

essential calcium from leaf litter of trees in areas containing ash, lime, maple, and elm trees, which provide calcium in the readily soluble citrate form. Calcium is an important micronutrient of the land snail (Dallinger et al., 2001) as land snails need calcium for the growth of their shells (Wäreborn, 1970). In a previous study of Juříčková et al. (2008), the pattern of land snails depended on different lengths of calcium and moisture gradients and on which of these factors are limiting for many species occurring at studied sites. Wäreborn (1970) and Juříčková et al. (2008) also stated that calcium content is the main controller for the abundance of land snail species. Due to the alkaline soils and high concentration of calcium on limestone hills, this will affect the abundance of land snails' living and decomposition of the empty shells (Schilthuizen & Rutjes, 2001).

Furthermore, climate change was also one of the factors that affect the distribution and abundance of the land snails. The alterations in the climate have resulted in changes to the geographic ranges of various species, phenology as well as the risk of extinction for numerous species (Walther et al., 2002; Anouschka, 2011; Beltramino et al., 2015). In this century, climate change has been identified as a major contributor to potential future extinctions (Thomas et al., 2004; Anouschka, 2011; Beltramino et al., 2015). The distribution of ectothermic species like land snail's ecosystem is primarily affected by climatic factors such as temperature and precipitation, as the impact of climate change can influence the whole ecosystem (Woodward, 1987; Anouschka, 2011). A study by Baur and Baur (1993) mentioned that the higher the temperature, the lower the abundance of the land snails. Besides, the behaviour and activity of land snails and slugs are also influenced by weather conditions (Webley, 1964; Anouschka, 2011). The higher temperatures and increased humidity will lead to increase their activities (Webley, 1964; Crawford-Sidebotham, 1972; Anouschka, 2011). Crawford-Sidebotham (1972) observed that a rise of 2°C in temperature,

along with an elevation in relative humidity from 90% to 100%, resulted in the increased quantity of slugs displaying activity.

A possible response to climate change is species adaptation to their altered surroundings (Davis & Shaw, 2001; Parmesan, 2006; Anouschka, 2011). Thus, it is expected that the climate change has direct influences on the geographical distribution of the species (Parmesan, 2006). Apart from potential alterations in the geographical distribution of the species due to shifts in temperature and precipitation patterns, climate change can also influence both species communities and the structure of habitats. Land snails are not only sensitive to weather conditions, but they also respond sensitively to changes in the configuration of their habitats and interactions with other species. For example, prey and predation interactions with the carabids (Konuma et al., 2011; Němec & Horsák, 2019), dipteran flies (Foote, 2008; Němec & Horsák, 2019), carnivorous gastropods (Barker & Efford, 2004), birds and mammals (Mayer & Shiels, 2009; Rosin et al., 2011), that feed on invertebrate could have a great impact on the population of the land snails (Symondson et al., 1996).

2.3 The Distribution of the Genus *Japonia* in Asia

The land snails of the genus *Japonia* are widely distributed throughout East and Southeastern Asia such as Taiwan, Japan, Indonesia, and Vietnam (Yamazaki, 2022). Nurinsiyah et al. (2019) discovered three *Japonia* species in Gunung Halimun Salak National Park (GHSNP), Java Indonesia, namely, *J. ciliocinctum*, *J. ciliferum*, and *J. grandipilum*. *J. ciliocinctum* emerged as the predominant species in Java (Mujiono & Priawandiputra, 2020) (Table 2.1). However, it is noteworthy that both *J. grandipilum* and *J. convexum* can be found in Gunung Galunggung, Western Java, where the trees have not arisen yet (Heryanto, 2020). Furthermore, a study by Mujiono and Priawandiputra (2020), stated that *J. convexum* tend to face local and global extinction. Moreover, Do et al. (2015) discovered two new distribution

species, namely *Japonia fischri* and *J. scissimargo* in Son La region, Vietnam (Table 2.1). Furthermore, a total of nine species of *Japonia* from Taiwan are described by Yen-Chen et al. (2008) and Hwang (2014a; 2014b). There are *Japonia formosana*, *J. lanyuensis*, *J. boonkioensis* n. sp., *J. changi* n. sp., *J. duplifolia* n. sp., *J. pngsiar* n. sp., *J. junipervallis* n. sp., *J. tadai* n. sp., and *J. heterovena* n. sp. (Table 2.1). In Japan, there are a total of nine species of *Japonia*, namely *J. hispidus*, *J. striatula*, *J. gouldi*, *J. shigetai*, *J. katorii*, *J. inouei*, *J. tokunoshimana*, *J. tokunoshimana okinoerabuensis*, *J. sadoensis* (Table 2.1). Additionally, two *Japonia* species remain unidentified where they distribute in Yonagunijima, Iriomotejima and Ishigakijima Islands.

Table 2.1: The distribution of the genus *Japonia* in Asia

Country	Species	Distribution	References
Indonesia	<i>J. ciliocinctum</i>	Western Java.	Mujiono and Priawandiputra (2020) Nurinsiyah et al. (2019)
	<i>J. ciliferum</i>		Nurinsiyah et al. (2019)
	<i>J. grandipilum</i>		Heryanto (2020) Nurinsiyah et al. (2019)
	<i>J. convexum</i>		Heryanto (2020)
Vietnam	<i>J. fischri</i>	Son La.	Do et al. (2015)
	<i>J. scissimargo</i>		
Taiwan	<i>J. formosana</i>	Southwest Taiwan, approximately along the Alishan Range.	Hwang (2014a; 2014b) Yen-Chen et al. (2008)
	<i>J. lanyuensis</i>	Endemic in Lanyu Island.	Hwang (2014a) Yen-Chen et al. (2008)
	<i>J. boonkioensis</i> n. sp.	Fen-chi-hu in Jia-i County.	Yen-Chen et al. (2008)
	<i>J. changi</i> n. sp.	Liu-gui.	Hwang (2014b)
	<i>J. duplifolia</i> n. sp.	Bi-lu, and Hualiang.	Hwang (2014b)
	<i>J. pngsiar</i> n. sp.	Central Highway, Rong-xing, Ren-ai, and Nantou.	Hwang (2014b)
	<i>J. junipervallis</i> n. sp.	Kuai-gu (Juniper Valley), Mt. Bei-da-wu, Tai-wu, and Pingtung.	Hwang (2014a)
	<i>J. tadai</i> n. sp.	N. Kaohsiung and Nantou.	Hwang (2014a)
	<i>J. heterovena</i> n. sp.	Jin-ze-keng, Guo-xing, and Nantou.	Hwang (2014a)
Japan	<i>J. hispidus</i>	Iejima, Ujigunto Islets, and Kagoshima-ken.	Minato (1982)

		Tomiyama (1984)
<i>J. striatula</i>	Danjo-Guntō and Uji-Guntō Islets.	Minato (1982) Tomiyama (1984)
<i>J. gouldi</i>	In the middle and northern parts of the Ryūkyū Islands.	Minato (1982)
<i>J. shigetai</i>	Tokara Island: Kuchinoshima, Nakanoshima, Tairajima and Akusekijima.	Ichikawa et al. (2014) Minato (1985)
<i>J. katorii</i> n. sp.	Mt. Hōraiji, Aichi-ken; Washizawa-cho, Hamamatu, Shizuoka-ken.	Minato (1985)
<i>J. inouei</i>	Kii Peninsular.	Minato (1975) Minato (1985) Hayase et al. (2015)
<i>J. tokunoshimana</i>	Amami-oshima and Tokunoshimana.	Minato (1985)
<i>J. tokunoshimana okinoerabuensis</i>	Okinoerabujima.	Minato (1985)
<i>J. sadoensis</i>	Honshu (West of Kanto), Shikoku and Northern Kyushu.	Minato (1985)
<i>Japonia</i> sp. 1	Yonagunijima islands.	Yamazaki (2022)
<i>Japonia</i> sp. 2	Iriomotejima and Ishigakijima islands.	Yamazaki (2022)

2.4 The Distribution of the Genus *Japonia* (Family Cyclophoridae) in Sarawak

Japonia is one of the genera classified under the Cyclophoridae family (Gray, 1847). There are a total of seven species are discovered in Sarawak (Figure 2.2). Recently, there are a total of five *Japonia* species that have been discovered by Marzuki et al. (2021) around limestone hills in Bau, Sarawak. Five species are *Japonia barbata*, *J. bauensis*, *J. metcalfei*, *J. mundyana*, and *J. rabongensis*. Furthermore, there are two *Japonia* species, namely *Japonia hyalina* and *J. ditropis* from Bukit Sarang (Vermeulen & Junau, 2007). All these species are listed as endemic to Borneo (Table 2.2).

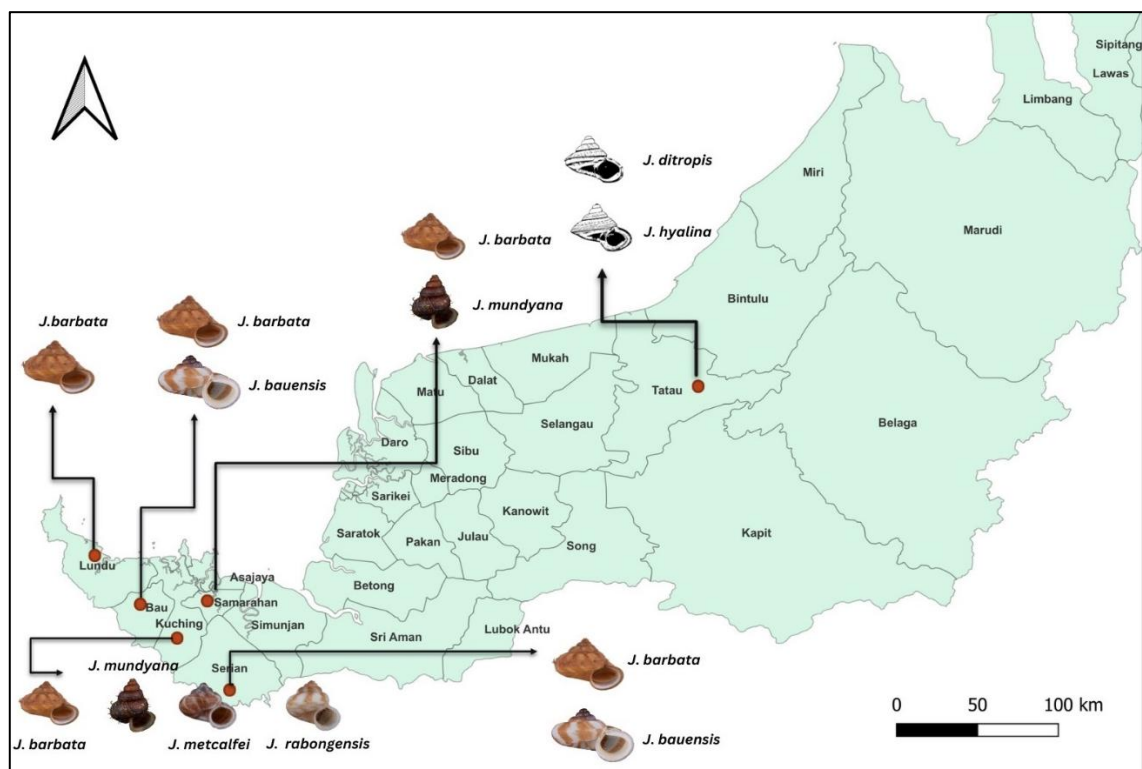


Figure 2.2: The distribution of the genus *Japonia* in Sarawak based on Marzuki et al. (2021) and Vermeulen and Junau (2007)

Table 2.2: The distribution of the genus *Japonia* which is endemic to Sarawak

Species	Distribution	References
<i>J. barbata</i>	Kuching, Samarahan, Serian, Sibu, and Mukah Divisions.	Marzuki et al. (2021)
<i>J. bauensis</i>	Bau and Serian-Padawan.	Marzuki et al. (2021)
<i>J. metcalfei</i>	Kuching Division.	Marzuki et al. (2021)
<i>J. rabongensis</i>	Kuching Division.	Marzuki et al. (2021)
<i>J. mundyana</i>	Kuching Division.	Marzuki et al. (2021)
<i>J. ditropis</i>	Tatau River Basin, Bukit Sarang.	Vermeulen and Junau (2007)
<i>J. hyalina</i>	Tatau River Basin, Bukit Sarang.	Vermeulen and Junau (2007)

2.5 The Diagnostic Features of the Genus *Japonia*

The differences in morphological characteristics within populations of a species can be attributed to either genetic variations or environmental factors, as evidenced by observations made in snails (Kemp & Bertness, 1984; Proćków et al., 2018). It is believed that the variation is linked to organisms adapting to particular environmental conditions (Kemp & Bertness, 1984; Price et al., 2003). There are some parameters that can affect the variations of the shells due to light availability (Giokas et al., 2014), forestation (Proćków et al., 2018), isothermality (Proćków et al., 2017), and precipitation of the driest month and warmest quarter play a significant role in determining habitat preferences (Kemp & Bertness, 1984). Moreover, the morphology of the land snails has been associated with various factors, including soil composition (Gould, 1969; Gould, 1971; Goodfriend, 1986), predators (Cook & Pettitt, 1979; Goodfriend, 1986), and climatic conditions (Goodfriend, 1986; Lazaridou-Dimitriadou et al., 1994; Proćków et al., 2017).

The morphological characteristics for example, some of the land snails have periostracal hairs on the body whorls, like species from the genus *Trochulus* (Pfenninger et al., 2005), and small marine snails from the genus *Trichotropis* (Proćków et al., 2018; Bullis et al., 2019). In addition, hairs also have been observed in freshwater snail species under the

family Viviparidae (Allgaier, 2011; Neubauer et al., 2019) and from marine taxa (Iyengar et al., 2008; Neubauer et al., 2019). The hairy characteristics of land snails can be observed in moist microhabitats, such as fallen leaves, vegetation with broad-leaved, moist meadows, or wet scree (Suvorov, 1999; Pfenninger et al., 2005). The presence of hydrophobic hairs can help them move in a damp environment by reducing the surface tension stated by Suvorov (1999) and Pfenninger et al. (2005). A statement by Pfenninger et al. (2005) and Proćków et al. (2018) said that the hairs of the genus *Trochulus* will be drop off on their own because this also related to a change in habitat, especially, the presence of hairs is restricted to moist habitats, primarily woodland environments. Their hair durability also related to the environments, for example, the species *Trochulus sericeus* are preferred to stay in moist and low temperature of microhabitats which have more hairs covered on the shell, while the species *Trochulus hispidus* are preferred dry and open areas which mostly hairless.

Land snails are normally active during high periods of ambient humidity, especially when leaves are coated with a layer of water caused by rain and their hairy shells require a notably greater force to overcome adhesion, making them more difficult to dislodge from wet leaves (Pfenninger et al., 2005; Proćków et al., 2018; Bullis et al., 2019; Neubauer et al., 2019). The stronger the adhesion, the chance of dropping or falling off from the leaves will decrease. Hairs on shells could provide a selective advantage by enhancing their adhesion to the water film and moving on the leaves for feeding, thereby aiding in foraging activities and locomotion (Pfenninger et al., 2005). Moreover, the periostracal hairs of the shells act as a prevention from predators by storing the water to mitigate the movement (Pfenninger et al., 2005; Dourson et al., 2013; Neubauer et al., 2019). Dourson et al. (2013) stated that the hairy characteristics of some land snails could also aid in regulating temperature. It also helps to camouflage themselves from predators like insects such as shell-boring beetle larvae (Baalbergen et al., 2014), birds, and salamanders (Dourson et al., 2013).

Furthermore, the hairs of the marine snail, *Trichotropis cancellata* proved that it is against crabs and sea stars as well as epibionts (Iyengar et al., 2008; Neubauer et al., 2019). The periostracal hairs of snails can minimize the time and energy consumption when they are feeding on the leaves of the angiosperms (Neubauer et al., 2019). Even if the snails are dropping off on the forest floors, the hair of the snails can reduce the impact of damage to the shell. Another advantage of having hairs on the shells that is the land snails can transport the seeds and pollen of the flowers from one to another through its body (Neubauer et al., 2019). An additional statement mentioned by Neubauer et al. (2019), the bristly hairs of land snails can act as a shield to protect those harmful compounds and pathogens of fungal from the soil and forest litter. The snails with thicker hair can serve as an insulating and thermoregulatory strategy in the hot and humid environment of a tropical forest, as mentioned by Dourson et al. (2013) and Neubauer et al. (2019).

2.6 Conservation Strategies of Organisms of Importance in Sarawak

Sarawak is comprising about approximately 17% of Borneo, the world's third-largest island, spans 746,337km² and harbours one of the most diverse collections of flora and fauna in the Sundaland region. Sundaland is recognised for its high density of endemic species but faces significant threats from rapid deforestation and habitat degradation (Myers et al., 2000; Mohd-Azlan & Lawes, 2011). A substantial portion of Sarawak's wildlife is endemic to Borneo, including approximately 19% of its mammals (5% of 98 bat species, 5 primate species, 3 carnivore species, 21 rodent species, and two large mammals), 20% of snakes, and 6% of birds (Mohd-Azlan & Lawes, 2011). However, limited information exists regarding the diversity and conservation status of land snails in Sarawak.

Borneo's forests are vanishing at an alarming rate, with deforestation occurring at 0.25Mha per year and over 18Mha lost since 1973 (Gaveau et al., 2016; Gaveau et al., 2019;

Alamgir et al., 2000). This ongoing deforestation has placed more than 600 vertebrate and plant species in the region at a risk of extinction (Alamgir et al., 2000). The primary drivers of forest loss include agricultural expansion, industrial logging, oil palm plantations, illegal hunting, and infrastructure development, such as roads and hydroelectric dams (Gaveau et al., 2016; Alamgir et al., 2000). In Malaysian Borneo, Sarawak has lost 80% of its primary forests over the last four decades. Despite this, infrastructure expansion, particularly roads and hydroelectric dams continues to be a priority for economic growth as shown in Figure 2.3.

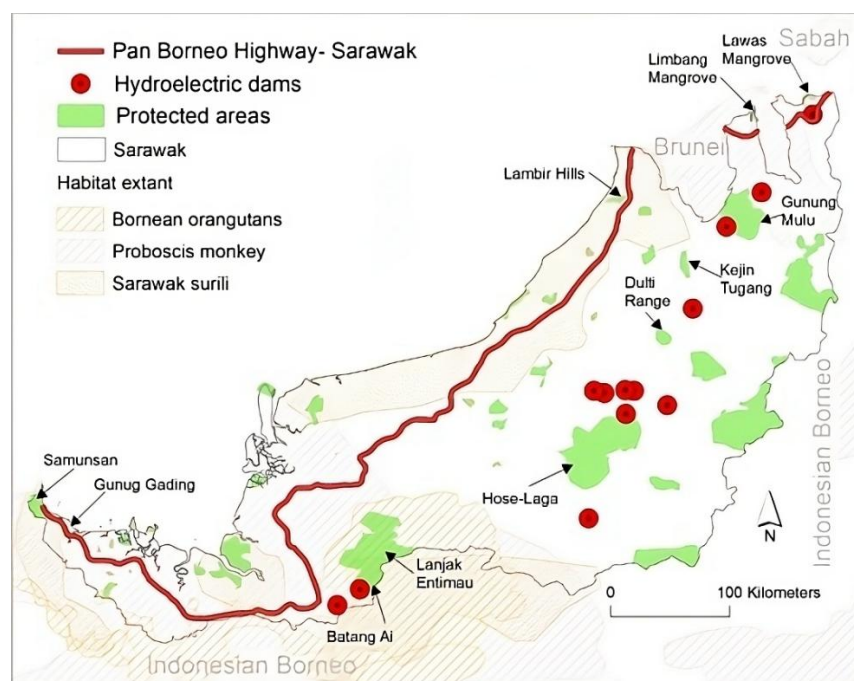


Figure 2.3: The Pan-Borneo Highway and hydroelectric dams in Sarawak are encroaching into protected areas. This map is adapted by Alamgir et al. (2020)

Sarawak has designated a total of 67 Totally Protected Areas (TPAs), of which 12 have been geographically expanded, while 55 remain unchanged. Several of these protected areas were established using the umbrella species concept to conserve specific animal and plant communities. For example, Batang Ai National Park was created to protect orangutans, while Gunung Gading National Park was designated for the conservation of *Rafflesia* species (Mohd-Azlan & Lawes, 2011). However, these strategies may fall short in addressing the

current land use pressures in Sarawak and may not significantly increase the number of species conserved within protected areas (Mohd-Azlan & Lawes, 2011). While conservation planning for land snails in Malaysia has utilised biogeographical patterns of endemic land snails to improve the protection of limestone karsts (Clements et al., 2008), and a few studies have proposed conservation strategies for the limestone hills in Sarawak (Lee et al., 2024; Nasir et al., 2024), no research has been conducted to develop specific strategies involving land snails, particularly in evaluating the conservation value of an area in Sarawak.

To address these challenges, a comprehensive study of organisms of conservation importance is crucial. Such research can inform better conservation planning and support effective strategies to safeguard Sarawak's unique biodiversity amid ongoing environmental pressures.

CHAPTER 3

MATERIALS AND METHODS

3.1 Study Sites

This study was conducted across limestone and non-limestone hills in various locations in Sarawak including division of Lundu, Bau, Padawan, Serian, Kuching, Simunjan, Siburan, Miri, Mulu, and Kapit in Sarawak. The live specimens of species *Japonia* were collected in a total of 24 localities (Figure 3.1). Additional some specimens were collected and examined from Museum Zoology UNIMAS (MZU) and the private collection.

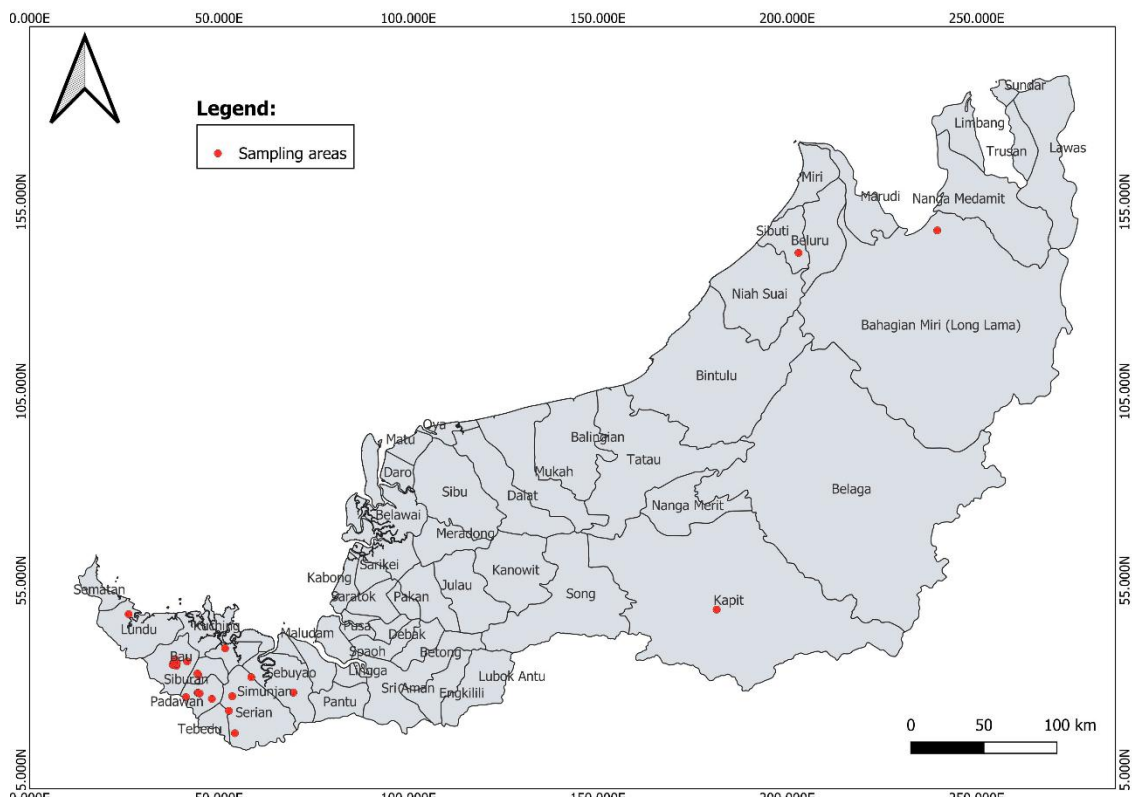


Figure 3.1: Map of Sarawak showing the study sites located in the divisions of Lundu, Bau, Kuching, Siburan, Padawan, Simunjan, Serian, Kapit, and Miri. The red dots indicate where live specimens were found in the sampling areas

3.2 Sampling Method and Data Collection

Fieldwork was conducted during the daytime, with each sampling site comprised of multiple plots of 20m × 20m (5 to 6 plots- depending on the size of the sampling areas). For the active method, direct searching of living snails took place in four types of microhabitats such as limestone walls, leaf litter, plant debris, and wood logs. Each of the survey taking a duration of at least one hour. All collected living specimens were stored in a sample vial containing 70% ethanol and the empty shells were stored in a plastic bag or plastic container. For the passive method, approximately five litres of loose topsoil were collected. Later, the floatation method was carried out to extract the snails and empty shells. Finally, the snails were sorted based on their shell morphology prior to the identification process in the Museum Zoology UNIMAS.

3.3 Species Identification

The identification of each *Japonia* species were based on Marzuki et al. (2021) and Vermeulen and Liew (2022). Each representative of the *Japonia* species were photographed with a digital camera equipped with a 100mm macro lens with 20× magnification. For the setup and photoshoot, Capture One 15.0.0 was used for stack imaging. After that, the stacked images were uploaded to Helicon 8.2.0 to create a composite image of the representative shell. The final images were scaled and cropped by using Adobe Photoshop 24.1 before importing into GIMP 2.10.32 to remove the image background, image sharpening, and arranging the images onto a plate.

3.4 Data Analysis

3.4.1 Species Distribution Map

All collected data during the samplings were used to determine the diversity and distribution of the genus *Japonia* in Sarawak. The location of the sampling plots, longitude and latitude were recorded using Garmin GPS Map 76s. The total number of the species from each of the plots, the number of individuals of the species and their microhabitat were recorded.

The species distribution maps were generated using QGIS 3.26.1 software. The global map layer was obtained by using a plug-in inside the software called Quick Map Services. The layers for the borders for the map of Malaysia were formed by importing the MYS_adm2.shp shape file downloaded through DIVA-GIS, <https://www.diva-gis.org/gdata>. The distribution data of the *Japonia* samples were imported into QGIS 3.26.1 and their geographical coordinates were plotted onto the map. Gazetted protected areas of Sarawak were obtained from the Sarawak Forestry website (<https://sarawakforestry.com/national-parks-nature-reserves/>) and the Digital Observatory of Protected Area (DOPA) Explorer website (<https://dopa-explorer.jrc.ec.europa.eu/>). Each of the total areas covered was manually marked on the map using QGIS Desktop 3.26.1.

The distribution of the genus *Japonia* is categorised into three different patterns, (i) wide-ranged - species that are known to be distributed in more than one locality and distributed in an area of more than 20km radius, (ii) short-ranged - species that are known to be distributed in more than one locality and distributed in the area within 20km radius, and (iii) endemic - species that are known to occur at only one locality (Figure 3.5). The selection criteria of the distribution pattern could be further tested when there are more distribution data available in the future, especially data from the central regions of Sarawak. This

selection is used to proceed with species distribution modelling and conservation prioritisation analysis.

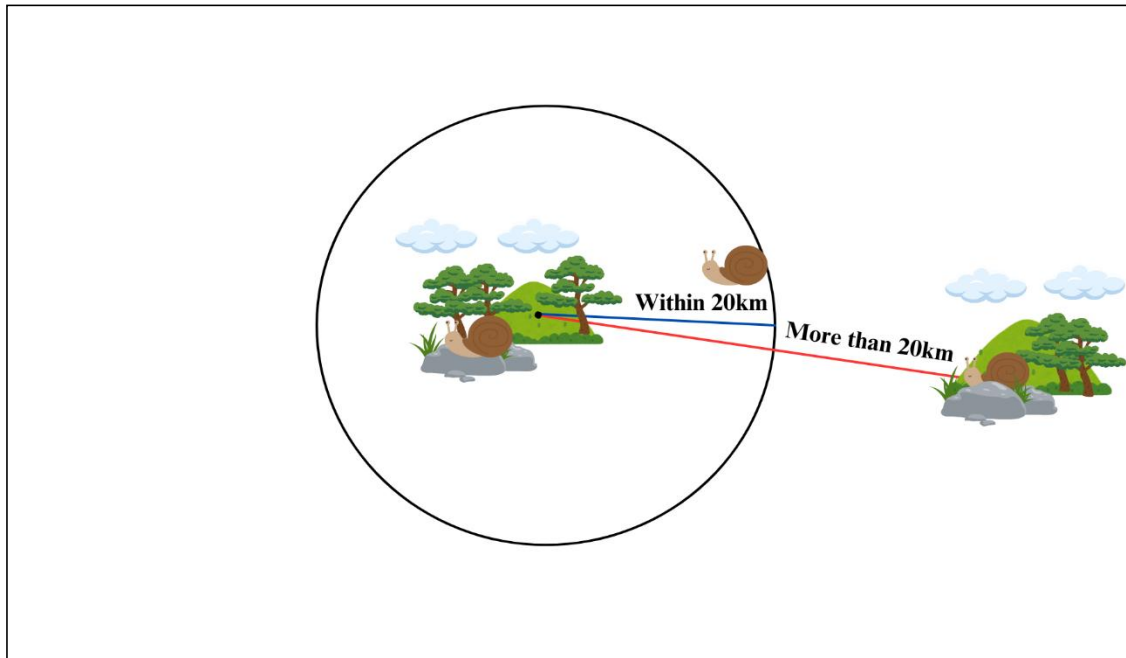


Figure 3.2: The distribution patterns of the genus *Japonia* are classified into three categories: (i) Red line indicates species distributed in more than one locality with a range exceeding 20km radius, (ii) blue line species distributed within a 20km radius, and (iii) black dot indicates species confined to a single locality

3.4.2 The Heatmap of The Species Abundance

The total number of localities and individuals of the genus *Japonia* were used to generate the heatmap of the species abundance. The data were arranged into a matrix for easier manipulation and visualisation. The colour of the abundance was arranged from darker (brown) to lighter (white) colours. The darker colour shows the species that have the highest abundance, while the lighter colour shows the species that have the lowest abundance. Then, the heatmap was generated to determine the abundance of each *Japonia* species in different localities using the “ggplot2” package in RStudio.

3.4.3 Species Distribution Modelling

Species distribution modelling (SDM) results were generated in RStudio. Species with more than 10 unique coordinates are the selected *Japonia* species that were used as presence data for modelling. These include *Japonia barbata*, *J. bauensis*, *J. metcalfei*, *J. mundyana*, *J. rabongensis*, *J. dido*, *J. keppeli* and *J. baritense*. A total of 19 bioclimatic variables' raster were downloaded from the WorldClim project (<http://worldclim.org>) which has collected globally standardised climate coverages at extremely high resolution as the current environmental data. Nineteen bioclimatic variables (Table 3.1) with a spatial resolution of 2.5 minutes all of which were imported from the WorldClim database. WorldClim, a widely utilised dataset, offers bioclimatic indicators at elevated spatial resolutions. This level of precision proves valuable for various ecological and environmental applications, such as modelling species distribution. The 2.5-minute spatial resolution of WorldClim's bioclimatic variable is well-suited for utilisation in MaxEnt due to its ability to offer intricate details regarding climate variables at a high level of spatial resolution (Kaky et al., 2020; Noce et al., 2020; Smith et al., 2022).

A spatial resolution of 2.5 minutes implies that the climate data is presented in grid cells measuring 2.5 arc-minutes, corresponding to roughly 4.6 kilometers at the equator. Several R packages were used such as the "dismo" package (Hijmans et al., 2012) for the utilisation of Maximum Entropy (MaxEnt), the "raster" package (Hijmans & Etten, 2012) to read raster files such as bioclimatic data raster files, the "dplyr" package to pre-process and manipulate data, "sp" package and "sf" package for processing data into coordinates. The presence data were pre-processed first before training the species distribution model to remove any errors such as duplicates and missing longitude and latitude data to avoid overfitting the model. The absence data were then generated to improve the performance of the model. The presence and absence data were then combined to become the presence-

absence data. Then, 80% of the presence-absence was used as training data and 20% was used as test data. The training data were used to train the MaxEnt species distribution model. MaxEnt was applied to generate the species distribution modelling as it is commonly used in ecological modelling studies (Elith et al., 2006; Hijmans & Graham, 2006; Wisz et al., 2008; Hof, 2011). Then, the test data were used to generate the performance of the trained model.

Table 3.1: The 19 bioclimatic variables used in species distribution modelling

Environmental Variables	Description
BIO1	Annual Mean Temperature
BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO3	Iso-thermality (BIO2/BIO7) ($\times 100$)
BIO4	Temperature Seasonality (standard deviation $\times 100$)
BIO5	Max Temperature of Warmest Month
BIO6	Min Temperature of Coldest Month
BIO7	Temperature Annual Range (BIO5-BIO6)
BIO8	Mean Temperature of Wettest Quarter
BIO9	Mean Temperature of Driest Quarter
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	Annual Precipitation
BIO13	Precipitation of Wettest Month
BIO14	Precipitation of Driest Month
BIO15	Precipitation Seasonality (Coefficient of Variation)
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	Precipitation of Warmest Quarter
BIO19	Precipitation of Coldest Quarter

3.4.4 Conservation Prioritisation Analysis

Conservation prioritisation analysis was conducted in Zonation 5.0 software to determine priority areas for conserving the selected *Japonia* species. The analysis utilised large grids of spatial data as input files and established a correlation between species distribution modelling data and spatial conservation prioritisation (Moilanen et al., 2005). Additionally, it generates a hierarchical prioritisation of the landscape based on the occurrence levels of biodiversity features (such as species and land cover types) within grid cells (pixels on a map). Zonation employs a raster for each biodiversity feature, where each cell contains a value representing the occurrence level of that feature. The aggregation of conservation value loss across features in a cell depends on the cell-removal rule. This iterative priority ranking process starts with the entire landscape and systematically removes cells, minimising conservation value loss until no cells remain. The least valuable cells (e.g., those with few common species) are removed first, while the most critical cells for biodiversity (e.g., those with high species richness and occurrence) are preserved until the end. This ranking process facilitates easy identification and visualisation through a prioritised rank map, where different colours indicate varying rank values (Lehtomäki & Moilanen, 2013).

The Core-area Zonation 2 (CAZ2) removal rule was selected to establish the priority ranking. This method prioritises areas based on “the most important occurrence of a feature in the cell”, allowing it to highlight regions with a high occurrence of a single rare or highly weighted feature a high priority (Minin et al., 2014; Ovando et al., 2019). The Human Footprint V2.0 raster was downloaded from the Wildlife Conservation Society, <https://wchumanfootprint.org/data-access>. Then, the species distribution modelling output of the selected *Japonia* species, the totally protected areas in Sarawak, and the human footprint data were pre-processed and exported as raster files in RStudio. In the analysis, the species

distribution modelling output raster for the selected *Japonia* species are the biodiversity features and are positively weighted. Different weights were assigned to each feature according to the species analysed: short-ranged distributed species were assigned as a weight of two, while the widely distributed species were assigned a weight of one. Additionally, existing totally protected areas are used as hierarchical masks. Moreover, the human footprint data was used as a negative variable, penalizing pixels with high human influence following Nori et al. (2016).

Lastly, a performance curve was generated to quantify the proportion of occurrences retained for each biodiversity feature (Minin et al., 2014; Moilanen et al., 2014) at each selected top fraction of the landscape designated for conservation. This is the assessment of the representativeness of the existing protected areas network and the top priority areas of the available territory.

3.4.5 Infomap Bioregion

The Infomap Bioregions is an interactive web application that inputs the species distribution data and generates bioregions map. To generate the Infomap Bioregions, the overall coordinates of the genus *Japonia* were recorded in Microsoft Office Excel in a .csv file and then exported to the web to input the data. In cases of limited data, individual cells can be grouped into distinct regions. Infomap Bioregions adjusts the grid size automatically according to the amount and spatial distribution of the input data to prevent over-specification based on the available data (Edler et al., 2017). The adaptive resolution was set according to the cell size and cell capacity. With these criteria, Infomap Bioregion can identify high-resolution bioregions in areas with ample data and low-resolution bioregions in areas with sparse data, and therefore can effectively prevent both overfitting and underfitting across all bioregions. The maximum and minimum cell size and capacity configuration will

be an estimate of the sampling areas visited. The cell size ranged between $1/128^\circ$ and $1/8$

- , while the cell capacity ranged between 1 to 50.

CHAPTER 4

RESULTS

4.1 Species Distribution of The Genus *Japonia* in Sarawak.

The distribution of the genus *Japonia* is generally widespread in Sarawak including both protected and non-protected areas (Figure 4.1). *Japonia barbata* (Figure 4.2A), *J. bauensis* (Figure 4.2B), *J. mundyana* (Figure 4.2C), *J. metcalfei* (Figure 4.2D), and *J. rabongensis* (Figure 4.2E) are widely distributed in western Sarawak where they are distributed in the Lundu, Bau, Samarahan, Kuching, Serian, Simunjan, and Daro Divisions.

Short-ranged distributed species include *Japonia dido* (Figure 4.3A), *J. keppeli* (Figure 4.3B), *J. quinquelirata quinquelirata* (Figure 4.3C), *J. baritense* (Figure 4.3D), and *J. sp. 'Niah 2'* (Figure 4.3E). For *Japonia dido* and *J. keppeli*, these two species are distributed in Niah National Park, Miri Division, meanwhile *J. baritense* and *J. sp. 'Niah 2'* are distributed in Miri and Marudi Divisions, which are in the eastern part of Sarawak. *Japonia quinquelirata quinquelirata* is distributed in Song and Kapit Divisions which is in the central part of Sarawak.

Japonia lambirensis (Figure 4.4A), *J. quadricincta* (Figure 4.4B), *J. padawanensis* (Figure 4.4C), *J. hyalina*, *J. ditropis*, *J. sp. 'Lambir'* (Figure 4.4D), *J. sp. 'Mulu'* (Figure 4.4E), *J. sp. 'Niah 1'* (Figure 4.4F), and *J. sp. 'Katibas'* (Figure 4.4G) are identified as endemic species. *Japonia lambirensis* and *J. sp. 'Lambir'* are found only in Lambir Hills National Park, located in the Miri and Marudi Divisions. Interestingly, *Japonia sp. 'Mulu'* is exclusively found in Mulu National Park, Marudi Division. *Japonia sp. 'Niah 1'* is only distributed in Niah National Park, Miri Division. *Japonia sp. 'Katibas'* is found only in Lubok Bedil Ulu Katibas, Song Division. *Japonia quadricincta* is restricted to Mulu National Park, Marudi

Division. *Japonia padawanensis* is found only in Gua Sireh, Serian Division. *Japonia hyalina* and *J. ditropis* only distributed in Bukit Sarang, Tatau Division.

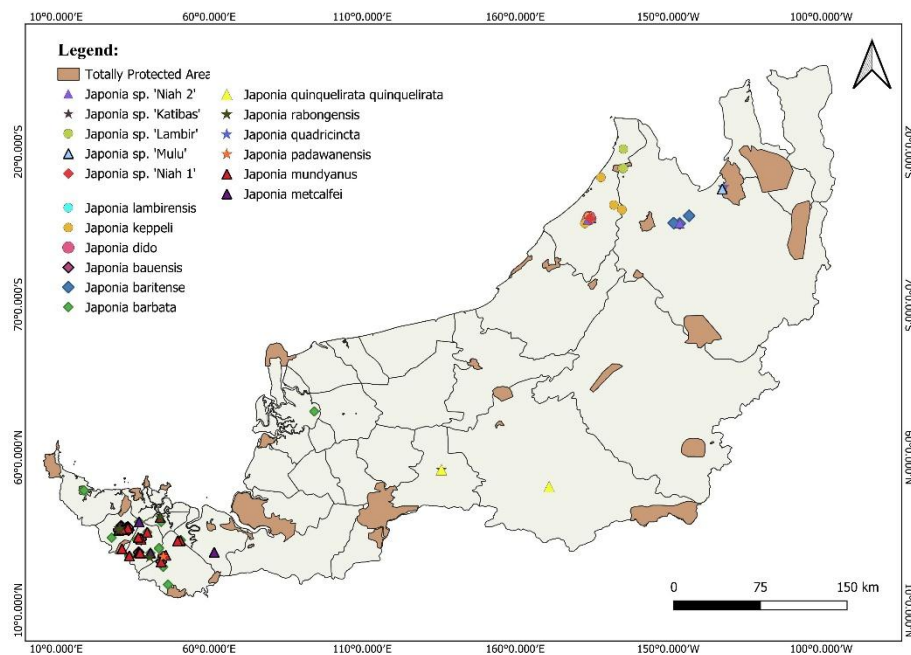


Figure 4.1: Species distribution map of the genus *Japonia* in Borneo, Sarawak. The totally protected areas are represented in brown colour

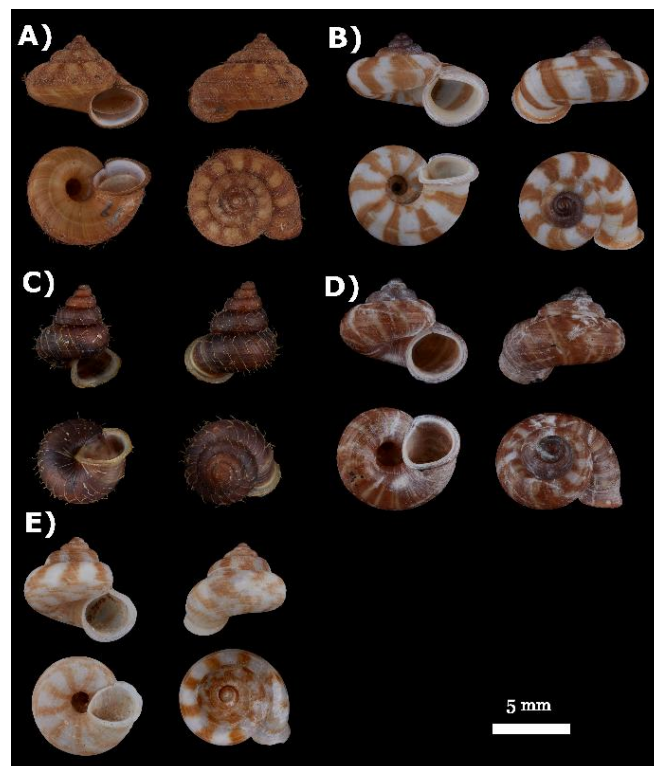


Figure 4.2: Widely distributed species of *Japonia*. (A) *Japonia barbata* (B) *Japonia bauensis* (C) *Japonia mundyana* (D) *Japonia metcalfei* (E) *Japonia rabongensis*

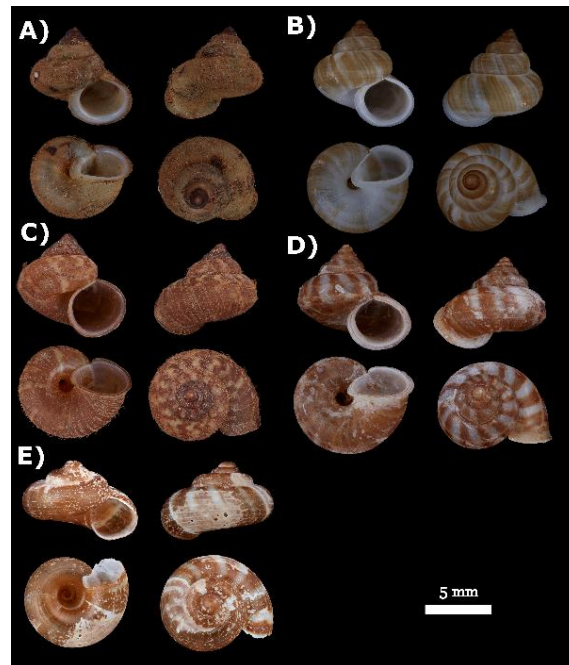


Figure 4.3 Short-ranged distributed species of *Japonia*. (A) *Japonia dido* (B) *Japonia keppeli* (C) *Japonia quinquelirata quinquelirata* (D) *Japonia baritense* (E) *Japonia* sp. 'Niah 2'

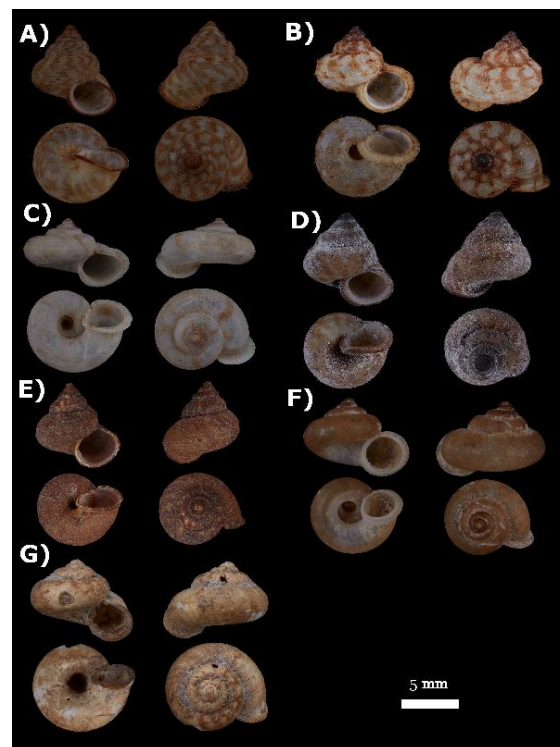


Figure 4.4 Endemic species of *Japonia*. (A) *Japonia lambirensis* (B) *Japonia quadricincta* (C) *Japonia padawanensis* (D) *Japonia* sp. 'Lambir' (E) *Japonia* sp. 'Mulu' (F) *Japonia* sp. 'Niah 1' (G) *Japonia* sp. 'Katibas'

4.2 The Heatmap of The Abundance of Genus *Japonia* in Sarawak

The score range is indicated by the colour intensity, where light colours indicate low abundance and dark colours indicate high abundance. Based on Figure 4.2, the score ranges between 30 to 40 which in brown colour represents the species that have the highest abundance, while the score ranges between 0 to 10, which represents the species that have the lowest abundance. *Japonia barbata* has the highest abundance in western Sarawak, with a total of 218 individuals recorded across 24 localities. In particular, *J. barbata* has the most abundance in Fairy Caves Nature Reserve. For *J. quinquelirata quinquelirata* is the most abundant in the central of Sarawak, with a total of 7 individuals recorded across 2 localities. Meanwhile, *J. keppeli* has the highest abundance in eastern Sarawak, with 36 individuals recorded across 3 localities. *Japonia keppeli* in Niah National Park has the highest record number of individuals. Moreover, *J. lambirensis*, *J. sp. 'Katibas'*, and *J. sp. 'Mulu'* have the lowest abundance compared to the other species.

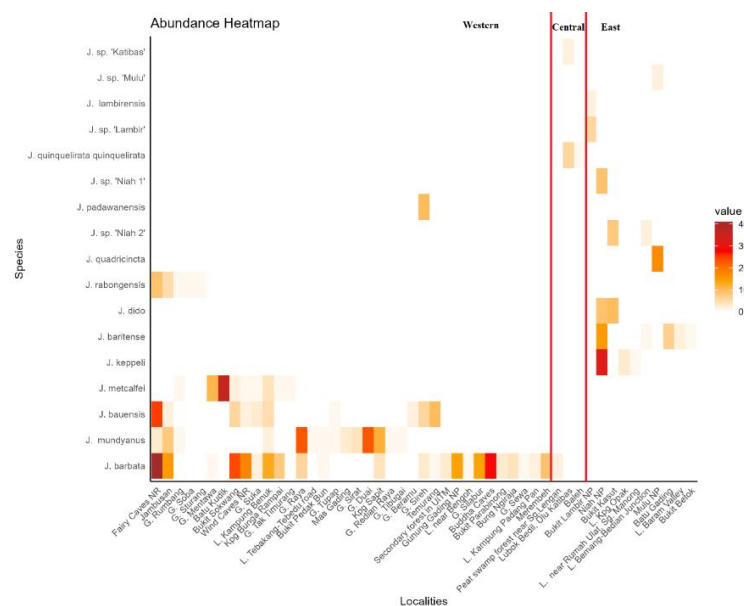


Figure 4.5: The heatmap of the abundance of the genus *Japonia* in Sarawak. The score range is based on the number of individuals of the *Japonia* species found at the localities: 31 to 40 indicates high abundance (red-brown), 11 to 29 indicates moderate abundance (light orange to orange), and 0 to 10 indicates low abundance (white to light orange)

4.3 Species Distribution Modelling

The Area Under the Curve (AUC) score ranges between 0.9 to 1.0, representing excellent model performance of the MaxEnt modelling. A range between 0.8 to 0.9 indicates good performance, 0.7 to 0.8 signifies fair performance, 0.6 to 0.7 suggests poor performance, and 0.5 to 0.6 implies similarity to a randomly selected predictive distribution (Kaky et al., 2020). Only selected species of the genus *Japonia* were utilised for species distribution modelling. *Japonia barbata*, *J. bauensis*, *J. metcalfei*, *J. mundyana*, and *J. rabongensis* are predicted to be distributed in the western part of Sarawak while *J. dido*, *J. keppeli* and *J. baritense*, are projected to be occur in Northeastern region of Sarawak.

Based on the AUC scores of the generated MaxEnt models for the training data (Table 4.1), the highest AUC is achieved by the models for *J. dido* with the scores of 1.000. *Japonia keppeli* and *J. rabongensis* (0.999), followed by *J. mundyana* (0.996), *J. baritense* (0.995), *J. barbata* and *J. bauensis* (0.993). *J. metcalfei* follows AUC of 0.983. This show that the model of the genus *Japonia* in MaxEnt is performed relatively well, and it is good to be utilised for inferences and predictions.

The MaxEnt modelling generated outputs of predicted current suitability maps for the genus *Japonia* of Sarawak, the green areas ranged from 0.6 to 0.8 and above indicating that the habitat is expected to be high in probability for the *Japonia* species to occur. A yellow to red coloured area with a plausibility of occurrences ranging from 0.2 to 0.6 is predicted to have a low probability for the *Japonia* species to occur. In grey-coloured areas which range below 0.2, few or no possible observations of the genus.

From the Table 4.1, the analysis of the highest variable contributions has shown that for *J. barbata* and *J. bauensis*, “BIO17”, precipitation of driest quarter, *J. baritense*, “BIO9”, mean temperature of driest quarter, *J. dido*, “BIO16”, precipitation of wettest quarter, *J. keppeli*, “BIO18”, precipitation of warmest quarter, *J. metcalfei* and *J. rabongensis*, “BIO4”, temperature seasonality, and *J. mundyana*, “BIO15”, precipitation seasonality.

Table 4.1: The variable contributions and the AUC scores of the selected *Japonia* species

Species	Variable contribution	AUC
<i>Japonia dido</i>	BIO16	1.000
<i>Japonia keppeli</i>	BIO18	0.999
<i>Japonia rabongensis</i>	BIO4	0.999
<i>Japonia mundyana</i>	BIO15	0.996
<i>Japonia baritense</i>	BIO9	0.995
<i>Japonia barbata</i>	BIO17	0.993
<i>Japonia bauensis</i>	BIO17	0.993
<i>Japonia metcalfei</i>	BIO4	0.983

Thus, *J. barbata* (Figure 4.3A), *J. bauensis* (Figure 4.3B), *J. metcalfei* (Figure 4.3C), *J. mundyana* (Figure 4.3D), and *J. rabongensis* (Figure 4.3E) are likely to be distributed in the western region. In contrast, *J. baritense* (Figure 4.3F) is predicted to occur in the eastern region (Marudi Division), while *J. dido* (Figure 4.3G) and *J. keppeli* (Figure 4.3H) are predicted to be found in the northeastern region, spanning from Miri to Limbang.

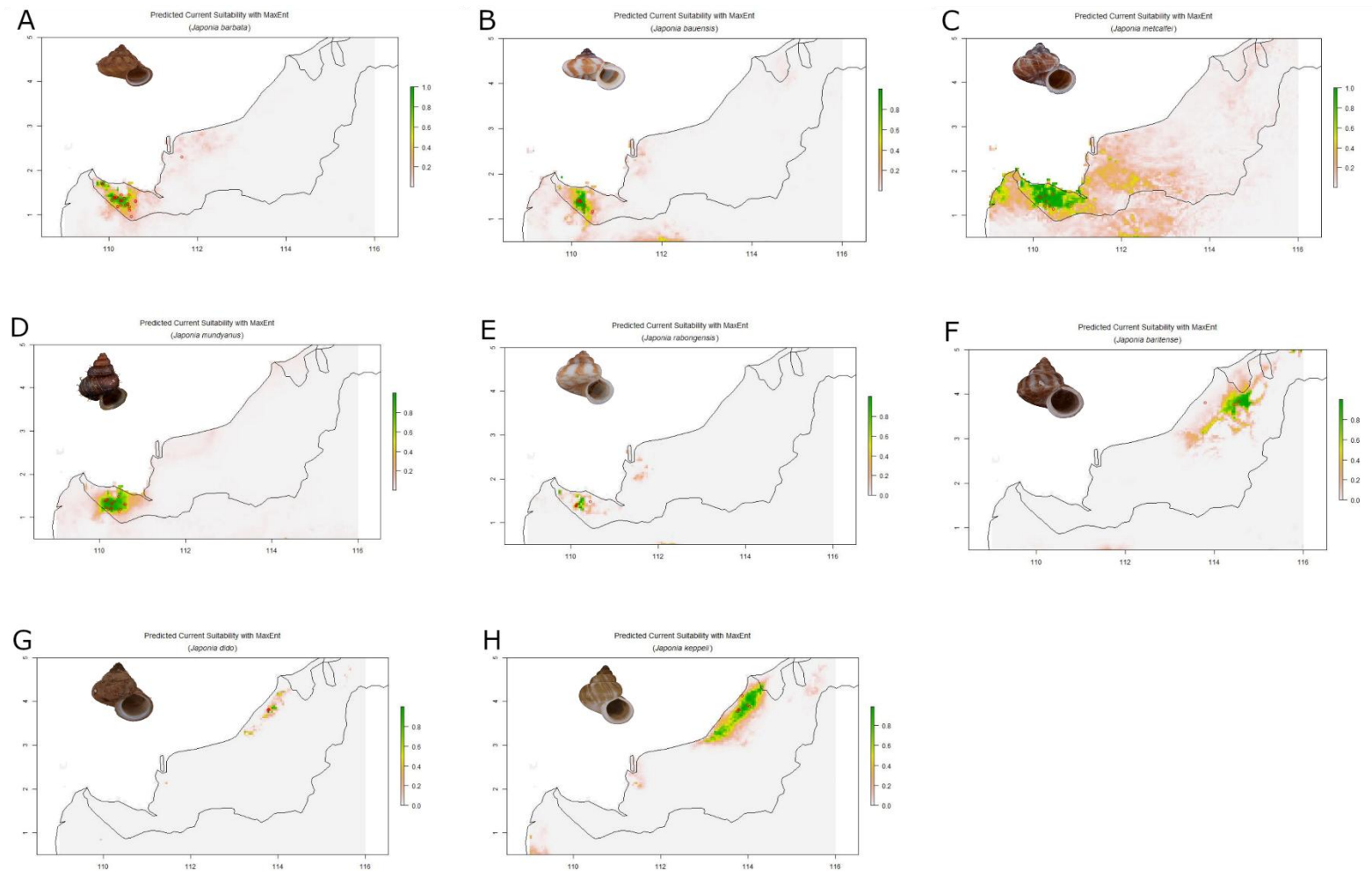


Figure 4.6: Predicted current suitability for each of the species of the genus *Japonia* in Sarawak, which shows the possible distribution of (A) *Japonia barbata*, (B) *Japonia bauensis*, (C) *Japonia metcalfei*, (D) *Japonia mundyana*, (E) *Japonia rabongensis*, (F) *Japonia baritense*, (G) *Japonia dido*, and (H) *Japonia keppeli*. The colour ranges from high suitable (green), low suitability (yellow to orange), and least favourable

(grey)

4.4 Conservation Prioritisation of The Selected Genus *Japonia* in Sarawak

From Figure 4.4, the high conservation priorities, which are indicated by red and brown colours, are around western Sarawak, including the Lundu, Bau, Kuching, Asajaya, Samarahan, Siburan, Padawan, Tebedu, and Serian Divisions. In central Sarawak, the highest conservation priorities are specifically in the Lubok Antu, Song, and Kapit Divisions. In the eastern part of Sarawak, the areas with the highest conservation are the Tatau, Bintulu, Niah Suai, Sibuti, Miri, and Marudi Divisions.

A positive mean performance curve (blue solid line), negative mean performance curve (yellow solid line), and the performance curve of each of the selected *Japonia* species (black solid line) provides a clearer summary of feature coverage across various priority ranks (Figures 4.5A to 4.5I). Based on the performance curve of the selected *Japonia* species, the top 3% priority rank (red solid line) are the protected areas, while those below are outside and nearby of protected areas (Figures 4.5A to 4.5I). The species with the highest performance curve (maximum curve) is *J. dido* (Figure 4.5B), followed by *J. rabongensis* (Figure 4.5C), *J. keppeli* (Figure 4.5D), *J. barbata* (Figure 4.5E), *J. mundyana* (Figure 4.5F), and *J. bauensis* (Figure 4.5G). *Japonia dido* and *J. barbata* have the highest performance curve in the top 3% of the priority rank. According to the performance curve of *J. bauensis* and *J. mundyana* drops in the top 20% and 30% of the priority rank. *Japonia baritense*, minimum curve (Figure 4.5H) has the lowest performance curve followed by *J. metcalfei* (Figure 4.5I) as the second lowest.

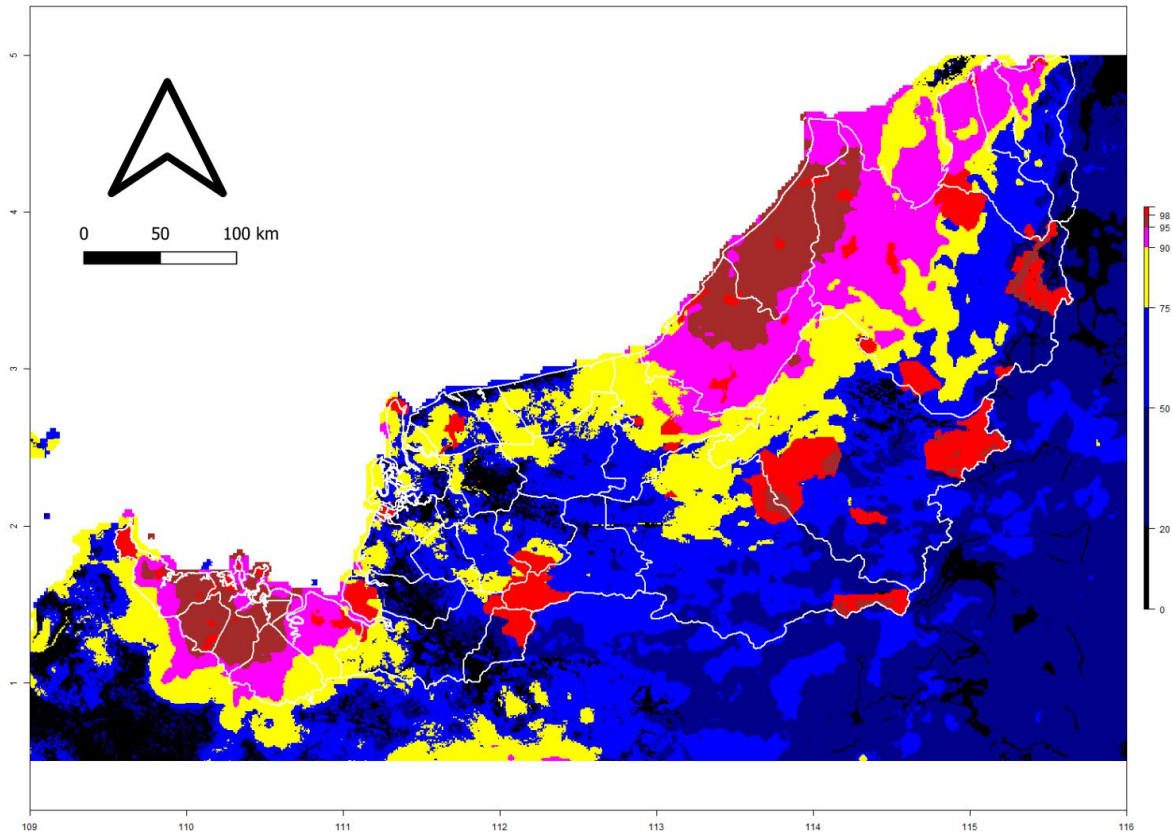


Figure 4.7: Map with the results layered with land uses analyses (human footprint), protected areas in Sarawak, and species distributions modelling of the selected genus *Japonia* in Sarawak. The colours range from high priority (red) to low priority (black)

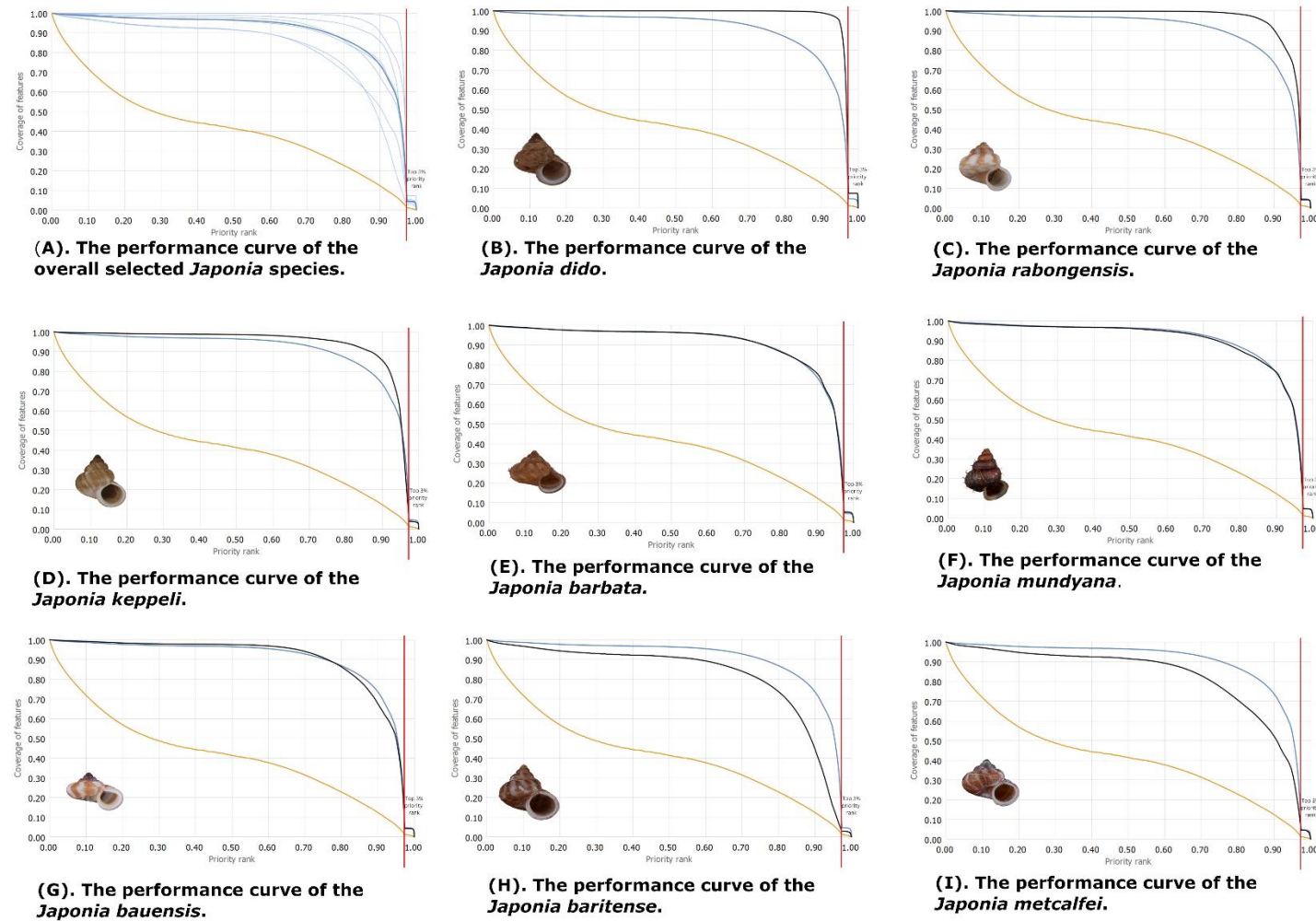


Figure 4.8: The performance curve for each of the selected *Japonia* species. The blue solid line indicates the positive mean of the performance curve, the yellow solid line indicates the negative mean of performance curve, the black solid line indicates the performance curve of each of the selected *Japonia* species

4.5 The Infomap Bioregion of The Genus *Japonia*, Sarawak

A total of six bioregions were identified for the genus *Japonia*, as illustrated in Figure 4.6. Table 4.2 highlights that bioregion 1 is the bioregion has the most abundant with only common species. Bioregions 1, 2, and 6 are the most species-rich bioregion, as each region having five species.

Bioregion 1 is the largest bioregion, which includes species *J. barbata* as the most common species. We also identified smaller bioregions, such as bioregions 2, 3, 4, 5, and 6, where endemic species are common in the western, central, and eastern parts of Sarawak. Specifically, bioregion 2 includes the endemic species of *J. sp. 'Niah 1'*; bioregion 3 features *J. sp. 'Katibas'* as an endemic species; bioregion 4 has *J. lambirensis* and *J. sp. 'Lambir'*; bioregion 5 includes *J. quadricincta* and *J. sp. 'Mulu'*; bioregion 6 includes *J. padawanensis*. Generally, each bioregion is generated based on the ecological similarity and species distribution pattern.

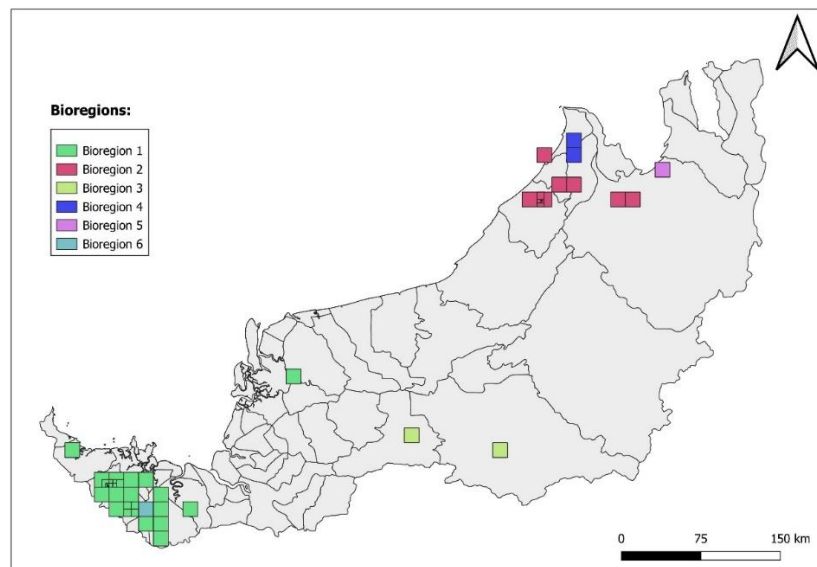


Figure 4.9: Bioregion map showing a total of six bioregions of the *Japonia* species generated with Infomap Bioregions

Table 4.2: The Infomap Bioregion table of the genus *Japonia*

Bioregions	Rank in Bioregion	Common species count	Common species name	Indicative species name
1	1	312	<i>J. barbata</i>	<i>J. rabongensis</i>
	2	95	<i>J. bauensis</i>	<i>J. metcalfei</i>
	3	82	<i>J. mundyana</i>	<i>J. mundyana</i>
	4	53	<i>J. metcalfei</i>	<i>J. metcalfei</i>
	5	17	<i>J. rabongensis</i>	<i>J. barbata</i>
	6	6	<i>J. metcalfei</i>	<i>J. bauensis</i>
2	1	87	<i>J. keppeli</i>	<i>J. baritense</i>
	2	26	<i>J. baritense</i>	<i>J. dido</i>
	3	19	<i>J. dido</i>	<i>J. sp. 'Niah 2'</i>
	4	10	<i>J. sp. 'Niah 2'</i>	<i>J. sp. 'Niah 1'</i>
	5	9	<i>J. sp. 'Niah 1'</i>	<i>J. keppeli</i>
3	1	5	<i>J. quinquelirata quinquelirata</i>	<i>J. quinquelirata quinquelirata</i>
	2	2	<i>J. sp. 'Katibas'</i>	<i>J. sp. 'Katibas'</i>
	3	2	<i>J. quinquelirata quinquelirata</i>	<i>J. quinquelirata quinquelirata</i>
4	1	5	<i>J. sp. 'Lambir'</i>	<i>J. sp. 'Lambir'</i>
	2	2	<i>J. lambirensis</i>	<i>J. lambirensis</i>
	3	1	<i>J. sp. 'Lambir'</i>	<i>J. sp. 'Lambir'</i>
5	1	17	<i>J. quadricincta</i>	<i>J. quadricincta</i>
	2	2	<i>J. sp. 'Mulu'</i>	<i>J. sp. 'Mulu'</i>
6	1	10	<i>J. padawanensis</i>	<i>J. padawanensis</i>
	2	9	<i>J. barbata</i>	<i>J. bauensis</i>
	3	9	<i>J. bauensis</i>	<i>J. barbata</i>
	4	2	<i>J. mundyana</i>	<i>J. mundyana</i>
	5	1	<i>J. metcalfei</i>	<i>J. metcalfei</i>

CHAPTER 5

DISCUSSION

5.1 The Species Abundance and Distribution of The Genus *Japonia*

Limestone areas of Borneo are well-known for their rich and varied biodiversity, featuring endemic species that are unique to particular locations or regions (Vermeulen & Whitten, 1999). The high diversity of the land snails in limestone regions results from the numerous ecological niches afforded by complex terrains such as fissured cliffs and extensive caves, along with varying climatic conditions (Clements et al., 2006). *Japonia barbata*, *J. mundyana*, *J. bauensis*, *J. metcalfei*, and *J. rabongensis* have the highest abundance and are widely distributed in the western part of Sarawak. These findings indicate that the widely distributed species are well adapted to their microhabitat environments, facilitating their establishment and dispersion (Albuquerque et al., 2008). Limestone hills in Borneo are known for their high diversity of land snails, and several studies have examined this diversity (Vermeulen, 1991a; 1991b; 1993; 1994; 1996; Marzuki et al., 2021). A recent study by Marzuki et al. (2021) identified a total of 122 species of land snails of which 47 species are endemic species to the Bau limestone clusters in the south of Sarawak.

The limestone ecosystem, characterised as high calcium carbonate deposits, serves as a habitat for numerous calcium-dependent organisms, especially land snails. It is well established that land snails require high calcium carbonate for reproduction and the growth of their shells (Wärebörn, 1970; Graveland et al., 1994). For example, the land snail of the genus *Opisthostoma* (family Diplommatinidae) is typically abundant in limestone areas and absent from non-

limestone areas (Schilthuizen et al., 2003). Similarly, the current study has shown that *J. bauensis* is found only in limestone areas.

Japonia keppeli, *J. dido*, *J. baritense*, *J. quinquelirata quinquelirata*, and *J. sp.* ‘Niah 2’ are categorised as short-ranged distributed species and usually found in high density. Short-ranged distributed are typically habitat specialists with low reproductive rates and have limited dispersal capabilities (Harvey, 2002; Mason et al., 2018; Gretgrix et al., 2023). These traits make short-ranged distributed species highly vulnerable to disturbances and climate change (Harvey et al., 2011), which is why they are often listed by the IUCN as one of the most at-risk groups due to climate change (Gretgrix et al., 2023).

Japonia quadricincta, *J. lambirensis*, *J. padawanensis*, *J. hyalina*, *J. ditropis*, *J. sp.* ‘Mulu’, *J. sp.* ‘Katibas’, *J. sp.* ‘Lambir’, and *J. sp.* ‘Niah 1’, are categorised as endemic species. Endemic species, being highly adapted to their specific environments, are more vulnerable to initial changes in their habitats compared to other species (Chiba, 2009). Parkyn and Newell (2013) stated that endemic species have highly specialised habitat requirements to survive. For example, a recent study by Lee et al. (2024) found that *Plectostoma wallacei kudikense* is endemic at Batu Kudik. A separate study by Khalik et al. (2018) indicated that *Georissa anyiensis* is endemic at Bukit Sarang, and *Georissa silaburensis* is endemic at Gunung Silabur. Previous research by Roos et al. (2004) and Clements et al. (2008) have shown that larger limestone areas typically harbour more endemic species due to their greater habitat diversity, which promotes higher rates of speciation (Losos & Schluter, 2000; Clement et al., 2008). For example, Gunung Mulu National Park, with an area of 80km², hosts 97 species of land snails, including 33 endemic species, while Niah National Park, with an area of 9km², hosts 108 species, including 38 endemic species (Vermeulen, 2003). Vermeulen and Whitten (1999) stated that limestone outcrops can

support two to five times more species than a comparable non-limestone area, and that the number of land snail's species and shells found in limestone habitats is 10 to 1000 times higher. Also, this may be explained by the larger areas of both these national parks are in the totally protected areas. Numerous studies have documented the influence of soil characteristics, such as pH and moisture, on the abundance, density, and species richness of land snails (Graveland et al., 1994; Graveland & van der Wal, 1996; Schilthuizen et al., 2003; Martin & Sommer, 2004). However, none have shown the potential effects of soil type on land snail endemism. For example, podzolic soils which are typically acidic (Andriesse, 1968), may promote speciation by creating significant barriers to the dispersal of land snails away from limestones, particularly among species that require calcareous environments (Clements et al., 2008).

Japonia quinquelirata quinquelirata found in Song and Kapit divisions are distributed in the non-limestone areas which in the central part of Sarawak and the abundance is low. There is a notable lack of survey coverage in non-limestone regions, especially in the interior areas of the second and third divisions, which are in Song and Kapit districts. This disparity is due to several factors, particularly the common belief that land snails are typically rare and less diverse in these environments (Schilthuizen & Rutjes, 2001). Milne (1937) mentioned that tropical rainforest soils are frequently heavily leached, while Richards (1996) noted that at higher elevations, many tropical mountain soils resemble the leached and wet temperate soils (Tattersfield, 2001). These two conditions are known to cause less abundance of land snails. Wärebörn (1969) also stated that land snails can obtain vital calcium from tree leaf litter, which provides calcium in a readily soluble citrate form. However, there are species which are widely distributed in both limestone and non-limestone areas. For example, *Cyclophorus perdis borneensis* can be found in primary

forests on various soils, on limestone bedrock, and in secondary vegetation (Vermeulen, 1999).

This species is widespread in Borneo, West Malaysia, and Singapore.

5.2 Conservation Strategies of Genus *Japonia* in Sarawak

Through the predicted current suitability maps and the most variable contribution, the genus *Japonia* is expected to expand its distribution further from the currently known localities. *Japonia barbata* and *J. bauensis* are highly likely to occur if the precipitation conditions during the three continuous driest months of the year (BIO17) are suitable. *Japonia baritense* has a high probability of occurrence in regions characterised by high mean temperatures during the driest quarter (BIO9), suggesting its adaptation to environments with pronounced dry conditions and elevated temperatures. For *Japonia metcalfei* and *J. rabongensis*, they have high probability of occurrence in regions with high and low temperature seasonality (BIO4), indicating they are well-suited to environments with significant temperature variations throughout the year.

Japonia mundyana has a high probability of occurrence in regions with high and low precipitation seasonality (BIO15), indicating it thrives in environments with significant variation in monthly rainfall throughout the year. *Japonia dido* is highly prone to inhabiting regions with significant precipitation during the wettest quarter (BIO16). *Japonia keppeli* has a high probability of occurrence in regions characterised by significant precipitation during the warmest quarter (BIO18), indicating its adaptation to environments with ample rainfall during the hottest months of the year. Studies have shown that dry environments may restrict the movement of the land snails (Prior, 1985; Luchtel & Deyrup-Olsen, 2001; Moreno-Rueda, 2009). Continuous exposure to dry environment creates persistence and adaptation against dehydration. Such adaptation is achieved by effectively utilising microhabitats where the dehydration risk is reduced (Cook, 2001; Moreno-Rueda, 2009). For instance, the land snail *Sphincterochila prophetarum* seeks shelter under stones when moisture is at its lowest (Moreno-Rueda, 2009). Another example, *Cepaea nemoralis* climbs the vegetation in order to escape the heat from the

ground (Jaremovic & Rollo, 1979). Ultimately, land snails have shown the ability to mitigate unfavourable ecological condition.

Based on the conservation prioritisation analysis, only a small percentage of the average distribution ranges of the selected *Japonia* species is safeguarded within existing protected areas. This further indicates that the current protected area system is insufficient for their protection. The increasing intensity of human footprints such as infrastructure expansion projects, deforestation, and other anthropogenic activities in Sarawak are causing the loss and degradation of natural habitats and the species within them (Myers et al., 2000; Mohd-Azlan & Lawes, 2011; Alamgir et al., 2020). For this reason, areas with high human footprints shows high conservation priorities when compared to areas with low human footprints.

The conservation prioritisation analysis revealed several areas within the western of Sarawak (Lundu, Bau, Kuching, Asajaya, Samarahan, Siburan, Padawan, Tebedu, and Serian Divisions), eastern of Sarawak (Tatau, Bintulu, Niah Suai, Sibuti, Miri, and Marudi Divisions) and central of Sarawak (Lubok Antu, Song, and Kapit Divisions) are categorised as high conservation priorities due to high human activities. The coverage levels of *J. bauensis* and *J. mundyana* show a slight drop below the positive mean curve in the top 20% and 30% of the priority ranks, primarily because of their distribution coverages are within the high priority ranked areas outside of the protected areas and near to the human footprints. As for *Japonia metcalfei* and *J. baritense*, these two species have the lowest coverage levels which indicate low conservation effectiveness. This is similar to *J. bauensis* and *J. mundyana*.

For *Japonia dido*, *J. rabongensis*, *J. keppeli*, and *J. barbata*, their coverage levels are above the positive mean curves which indicate that these species are well protected as they are distributed in areas of less human footprints. For *Japonia dido* and *J. barbata*, they have the

highest coverage across the priority ranks above the top 3% due to their distribution which is mainly in protected areas.

Although the analysis shows high conservation priority areas in the western and eastern parts of Sarawak, recent highway and hydroelectric dam projects are likely to affect the habitats of flora and fauna (Alamgir et al., 2020). These infrastructure expansions threaten 32 protected areas, including crucial habitats for threatened species such as the proboscis monkey (*Nasalis larvatus*), Sarawak surili (*Presbytis chrysomelas*), Bornean orangutans (*Pongo pygmaeus*), and tufted ground squirrel (*Rheithrosciurus macrotis*).

Besides, the endemic *Japonia* species with their limited dispersal capabilities and high sensitivity to environmental changes, are particularly vulnerable to human activities around these hills, where the highway and hydroelectric dam projects threatens, (i) the habitat of *J. quinquelirata quinquelirata* at the Kapit Division (ii) the diversity of the land snails in Lanjak Entimau Wildlife Sanctuary (Liew & Huong, 2011), (iii) endemic species such as *J. sp.* ‘Mulu’ and *J. quadricincta* at Marudi Division, Mulu National Park and (iv) the habitat of *J. padawanensis* at Serian Division. Additionally, the expansion of the highway along Lambir Hills National Park will impact the environment, subsequently, affecting *J. sp.* ‘Lambir’ and *J. lambirensis*, as Lambir Hills National Park is a non-limestone area with potentially several endemic land snails may be affected by this development combined with human activities.

The conservation prioritisation analysis suggests prioritising conservation in high priority ranked areas. Expanding protected areas or establishing new protected areas are conservation strategies that are deemed to be effective based on the conservation prioritisation analysis. The caveat to this is that not all high-priority ranked areas are significant for conservation. Therefore, the understanding on the bioregions and selecting the region with high priorities for effective

conservation is very important. In many scientific disciplines, including conservation biology, focusing on bioregions rather than individual species is more effective. Protecting bioregions with high biodiversity or uniqueness can help safeguard numerous species from extinction (Edler et al., 2017). Based on the Infomap Bioregion analysis of the overall *Japonia* species in Sarawak, it is recommended to expand the areas of selected National Parks and Nature Reserves in western Sarawak and the eastern part of Sarawak (Figure 5.1). These areas include Bungo Range National Park, Dered Krian National Park, Fairy Cave National Park, Gunung Gading National Park, Wind Cave Nature Reserve, Semenggoh Nature Reserve, Niah National Park, Lambir Hills National Park, Kejin Tugang Nature Reserve, and Mulu National Park. Additionally, the establishment of new protected areas in western Sarawak can safeguard *J. padawanensis*, an endemic species of the genus *Japonia* from extinction.

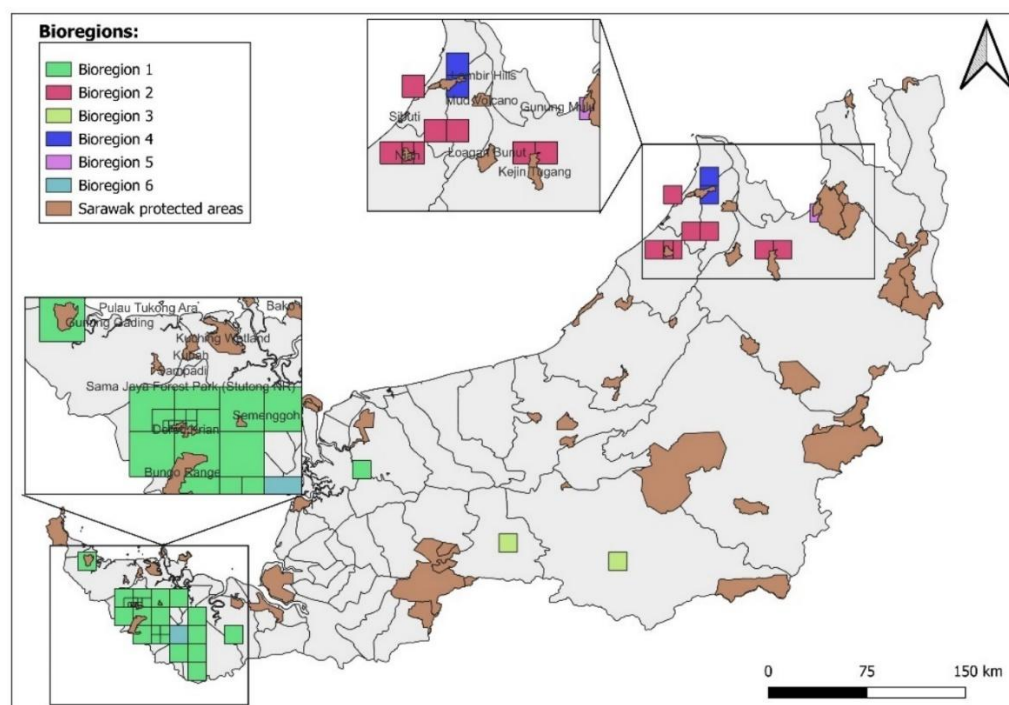


Figure 5.1: Bioregion map construction based on the distribution and abundance of the genus *Japonia* in Sarawak layered with the totally protected areas in Sarawak

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

The diversity and the distribution of the genus *Japonia* in Sarawak is well documented in this study. In this research, a total of 17 species were identified throughout the Sarawak and some of them are yet to be confirmed. Additionally, the high abundance and wide distribution of several species, such as *J. barbata*, *J. mundyana*, *J. bauensis*, *J. metcalfei*, and *J. rabongensis*, were determined in the western part of Sarawak. These species' ability to thrive in various microhabitats indicates their high adaptability to different environmental conditions. In contrast, endemic species such as *J. padawanensis* only endemic in western Sarawak, *J. hyalina* and *J. ditropis* are endemic in central Sarawak, *J. lambirensis*, *J. quadricinta*, *J. sp. 'Lambir'*, *J. sp. 'Mulu'*, *J. sp. 'Niah 1'*, and *J. sp. 'Katibas'* are primarily distributed in the eastern part of Sarawak, which may emphasise the unique ecological niches provided by these regions.

The study also demonstrated the critical role of limestone outcrops in sustaining high biodiversity, particularly for calcium-dependent organisms like the land snails. The presence of numerous endemic species in the limestone areas underscores the importance of these habitats for conservation activities. Species distribution modelling was employed to forecast possible extension habitats of the genus *Japonia* in Sarawak. In addition, conservation prioritisation analysis and Infomap Bioregion have provided valuable data for future conservation planning and identifying priority areas that require protection to preserve the unique biodiversity of Sarawak's limestone ecosystems. Therefore, the findings serve as a foundation for future studies

and conservation initiatives aimed at preserving the unique and diverse land snails' fauna of Sarawak as well as other organisms.

6.2 Recommendations

Preservation and conservation of the limestone areas in Sarawak should be the utmost priority as limestone outcrops potentially contain higher numbers of endemic organisms such as land snails and orchids. The limestone areas in Sarawak that the government does not conserve particularly those limestone hills within communities that are commonly used for leisure activities like hiking, should be protected and conserved. Community-based ecotourism required additional guidelines for maintaining sustainable activities and development. This strategy is necessary to protect the endemic species and to prevent the extensive human activities at high conservation prioritisation areas that do not fall under the protected areas. This strategy could provide communities with the necessary resources to enhance their standard of living, protect their natural and cultural heritage, and provide various opportunities in socioeconomic. This approach fosters societal progress and environmental health through sustainable economic growth.

Besides, assessments of the environmental impact of planned activities, including impacts on biodiversity, vegetation, ecology, water, and air, should be rigorously conducted prior to undertaking any development. This is important in the effort to maintain sustainable development. Conducting these assessments not only aims to mitigate negative impacts but also seeks to enhance positive contributions to the natural environment and human well-being.

Therefore, this study highlights the important of conservation activities towards achieving the Sustainable Development Goals (SDGs). It emphasises how empowered communities can enhance and lead ecotourism destinations by conserving heritage, culture, and biodiversity. The

suggested of conservation activities to achieve the Sustainable Development Goals (SDGs) are as follows:

- **Goal 4 (quality education):** In Sarawak, the Sarawak Forestry Corporation (SFC) manages the National Parks in partnership with the Sarawak Tourism Board (STB) to enhance understanding of tropical ecosystems, wildlife, and biodiversity through adoption initiatives, conservation programmes, educational activities, eco-tours, and wildlife encounters. Besides, the educational activities could span at various levels, from primary schools to higher education institutions, where students engage in interactive sessions, field trips, in-depth studies, and research opportunities. These activities can enhance the understanding of tropical ecosystems, wildlife, and biodiversity, while also promoting awareness about the importance of sustainable conservation solutions for the natural environment.
- **Goal 11 (sustainable cities and communities):** Community-based ecotourism initiatives in Sarawak foster sustainable urban and community development. The local authorities could come out with conservation plans and share the information to the communities. This initiative not only safeguard the environment but also create economic opportunities, enhance living standards, protect cultural and natural heritages, as well as supporting the development of sustainable cities and communities.
- **Goal 15 (life on land):** Protection of high biodiversity area in Sarawak is important in the effort to prevent habitat loss of various conservation important organisms including the endemic species.

REFERENCES

- Alamgir, M., Campbell, M. J., Sloan, S., Engert, J., Word, J., & Laurance, W. F. (2020). Emerging challenges for sustainable development and forest conservation in Sarawak, Borneo. *PLoS ONE*, 15(3), e0229614. <https://doi.org/10.1371/journal.pone.0229614>
- Albuquerque, F. S., Peso-Aguiar, M. C., & Assunção-Albuquerque, M. J. T. (2008). Distribution, feeding behaviour and control strategies of the exotic land snail *Achatina fulica* (Gastropoda: Pulmonata) in the northeast of Brazil. *Brazilian Journal of Biology*, 64(4), 837-842.
- Andriesse, J. P. (1968). A study of the environment and characteristics of tropical podzols in Sarawak (East Malaysia). *Geoderma*, 2, 201–227. [https://doi.org/10.1016/0016-7061\(69\)90038-X](https://doi.org/10.1016/0016-7061(69)90038-X)
- Altaf, J., Qureshi, N. A., & Siddiqui, M. J. I. (2017). Terrestrial snails as bioindicators of environmental degradation. *Journal of Biodiversity and Environmental Sciences*, 10(1), 253-264.
- Allgaier, C. (2011). A hairy business - periostracal hair formation in two species of helicoid snails (Gastropoda, Stylommatophora, Helicoidea). *Journal of Morphology*, 272(9), 1131-43.
- Anouschka, R. H. (2011). European terrestrial gastropods distribution. How may climate change affect their diversity and current distribution. *Gastropods: Diversity, habitat and genetics* (pp. 165-182). Hauppauge, NY: Nova Science Publishers.
- Baalbergen, E., Helwerda, R., Schelfhorst, R., Cajas, R. F. C., van Moorsel, C. H. M., Kundrata, R., Welter-Schultes, F. W., Giokas, S., & Schilthuizen, M. (2014). Predator-prey

- interactions between shell-boring beetles larvae and rock-dwelling land snails. *PLoS ONE*, 9(6), e100366. <https://doi.org/10.1371/journal.pone.0100366>
- Barker, G. M., & Mayhill, P. C. (1999). Patterns of diversity and habitat relationships in terrestrial mollusc communities of the Pukeamaru ecological district, northeastern New Zealand. *Journal of Biogeography*, 26(2), 215-238.
- Barker, G. M., & Efford, M. G. (2004). Predatory gastropods as natural enemies of terrestrial gastropods and other invertebrates. In: G.M. Barker (Ed.), *Natural enemies of terrestrial molluscs* (pp. 279–403). Wallingford, UK: Cabi Publishing.
- Baur, B., & Baur, A. (1993). Climatic warming due to thermal radiation from an urban area as possible cause for the local extinction of a land snail. *Journal of Applied Ecology*, 30(2), 333-340. <https://doi.org/10.2307/2404635>
- Bentham-Jutting van, W. S. S. (1958). Non-marine Mollusca of the island of Misool. *Nova Guinea, ns*, 9, 293-338.
- Braby, M. F., Willan, R. C., Woinarski, J. C. Z., & Kessner, V. (2011). Land snails associated with limestone outcrops in northern Australia – a potential bioindicator group. *Northern Territory Naturalist*, 23, 2-17.
- Beltramino, A. A., Vogler, R. E., Gutiérrez Gregoric, D. E., & Rumi, A. (2015). Impact of climate change on the distribution of a giant land snail from South America: predicting future trends for setting conservation priorities on native malacofauna. *Climatic Change*, 131(4), 621-633. <https://doi.org/10.1007/s10584-015-1405-3>
- Brook, B. W., Sodhi, N. S., & Ng, P. K. L. (2003). Catastrophic extinctions follow deforestation in Singapore. *Nature*, 424, 420-423. <https://doi.org/10.1038/nature01795>

- Budha, P. B. (2005). Nepalese malacology trails behind “catch up”. *Himalayan Journal of Sciences*, 3(5), 9-10.
- Bullis, D. A., Herhold, H. W., Czekanski-Moir, J. E., Grimaldi, D. A., & Rundell, R. J. (2019). Diverse new tropical land snail species from mid-Cretaceous Burmese amber (Mollusca: Gastropoda: Cyclophoroidea, Assimineidae), *Cretaceous Research*, 107, 104267. <https://doi.org/10.1016/j.cretres.2019.104267>
- Cameron, R. A. D. (1970). The survival, weight-loss and behaviour of three species of land snail in conditions of low humidity. *Journal of Zoology*, 160(2), 143-157. <https://doi.org/10.1111/j.1469-7998.1970.tb02900.x>
- Clements, R., Sodhi, N. S., Schilthuizen, M. & Ng, P. K. L. (2006). Limestone karsts of Southeast Asia: imperiled arks of biodiversity. *BioScience*, 56(9), 733-742. [https://doi.org/10.1641/0006-3568\(2006\)56\[733:LKOSAI\]2.0.CO;2](https://doi.org/10.1641/0006-3568(2006)56[733:LKOSAI]2.0.CO;2)
- Clements, R., Ng, P. K. L., Lu, X. X., Ambu, S., Schilthuizen, M., & Bradshaw, C. J. A. (2008). Using biogeographical patterns of endemic land snails to improve conservation planning for limestone karsts. *Biological Conservation*, 141(11), 2751-2764. <https://doi.org/10.1016/j.biocon.2008.08.011>
- Cook, L. M., Pettitt, C.W.A. (1979). Shell form in *Discula polymorpha*. *Journal of Molluscan Studies*, 45(1), 45–51. <https://doi.org/10.1093/oxfordjournals.mollus.a065483>
- Crawford-Sidebotham, T. J. (1972). The influence of weather upon the activity of slugs. *Oecologia*, 9, 141-154.
- Čejka, T. & Hamerlík, L. (2009). Land snails as indicators of soil humidity in Danubian woodland (SW Slovakia). *Polish Journal of Ecology*, 57, 741-747.

- Chiba, S., Okochi, I., Ohbayashi, T., Miura, D., Mori, H., Kimura, K., & Wada, S. (2009). Effects of habitat history and extinction selectivity on species-richness patterns of an island land snail fauna. *Journal of Biogeography*, 36, 1913-1922. <https://doi.org/10.1111/j.1365-2699.2009.02115.x>
- Cook, A. (2001). Behavioural ecology: On doing the right thing, in the right place at the right time. In G. M. Barker (Ed.), *The biology of terrestrial molluscs* (pp. 447–487). Wallingford, UK: CAB International.
- Dallinger, R., Berger, B., Triebkorn-Kohler, R., & Kohler, H. (2001). Soil biology and ecotoxicology. In G. M. Barker (Ed.), *The biology of terrestrial molluscs* (pp. 489–525). Wallingford, UK: CAB International.
- Davison, A. (2002). Land snails as a model to understand the role of history and selection in the origins of biodiversity. *Population Ecology*, 44(3), 0129-0136. <https://doi.org/10.1007/s101440200016>
- Davison, A., & Chiba, S. (2008). Contrasting response to Pleistocene climate change by ground-living and arboreal *Mandarina* snails from the oceanic Hahajima archipelago. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, 363, 3391–3400. <https://doi.org/10.1098/rstb.2008.0113>
- Davis, M. B., & Shaw, R. G. (2001). Range shifts and adaptive responses to quaternary climate change. *Science*, 292, 673. <https://doi.org/10.1126/science.292.5517.673>
- Do, D. S., Nguyen, T. H. T., & Do, V. N. (2015). A checklist and classification of terrestrial prosobranch snails from Son La, north-western Vietnam. *Ruthenica*, 25(4), 117-132.

- Deepak, V., Vsudevan, K., & Pandav, B. (2010). Preliminary observation on the diet of the cane turtle (*Vijayachelys silvatica*). *Hamdaryad*, 34, 166–168.
- Dourson, D. C., Langdon, K., & Dourson, J. (2013). *Land Snails of the Great Smoky Mountains National Park and Southern Appalachians, Tennessee & North Carolina*. Goatslug Publications.
- Dunk, J. R., Zielinski, W. J., & Preisler, H. K. (2004). Predicting the occurrence of rare mollusks in northern California forests. *Ecological Applications*, 14(3), 713-729.
<https://doi.org/10.1890/02-5322>
- Eisenhauer, N., & Hines, J. (2021). Invertebrate biodiversity and conservation. *Current Biology*, 31, R1141–R1224.
- Eguakhide, E. G., Osiele, V. O., & Anani, O. A. (2023). Diversity and species richness of land snails inhabiting an impacted macrozone-Mfamosing limestone hill in SubSaharan Region. *Global Ecology and Conservation*, 47, e02660.
<https://doi.org/10.1016/j.gecco.2023.e02660>
- Elith, J., Graham, C., Anderson, R., Dudík, M., Ferrier, S., Guisan, A., Hijmans, R., Huettmann, F., Leathwick, J., & Lehmann, A. (2006). Novel methods improve prediction of species' distributions from occurrence data. *Ecography*, 29, 129-151.
- Edler, D., Guedes, T., Zizka, A., Rosvall, M., & Antonelli, A. (2017). Infomap bioregions: Interactive mapping of biogeographical regions from species distributions. *Software for Systematics and Evolution*, 66(2), 197-204. <https://doi.org/10.1093/sysbio/syw087>

- Foote, B. A. (2008). Biology and immature stages of snail-killing flies belonging to the genus *Tetanocera* (Diptera: Sciomyzidae). IV. Life histories of predators of land snails and slugs. *Annals of Carnegie Museum*, 77(2), 301-312. <https://doi.org/10.2992/0097-4463-77.2.301>
- Foon, J. K., Clements, G. R., & Liew, T. S. (2017). Diversity and biogeography of land snails (*Mollusca, Gastropoda*) in the limestone hills of Perak, Peninsular Malaysia. *ZooKeys*, 682, 1-94. <https://doi.org/10.3897/zookeys.682.12999>
- Gaveau, D. L. A., Sheil, D., Husnayaen, Salim, M. A., Arjasakusuma, S., Ancrenaz, M., Pacheco, P., & Meijaard, E. (2016). Rapid conversions and avoided deforestation: examining four decades of industrial plantation expansion in Borneo. *Scientific Reports*, 6(32017). <https://doi.org/10.1038/srep32017>
- Gaveau, D. L. A., Locatelli, B., Salim, M. A., Yaen, H., Pacheco, P., & Sheil, D. (2019). Rise and fall of forest loss and industrial plantations in Borneo (2000–2017). *Conservation Letters*, 12, e12622. <https://doi.org/10.1111/conl.12622>
- Giokas, S., Páll-Gergely, B., & Mettouris, O. (2014). Nonrandom variation of morphological traits across environmental gradients in a land snail. *Evolutionary Ecology*, 28(2), 323-340.
- Gheoca, V., Benedek, A. M., & Schneider, E. (2021). Exploring land snails' response to habitat characteristics and their potential as bioindicators of riparian forest quality. *Ecological Indicators*, 132, 108289. <https://doi.org/10.1016/j.ecolind.2021.108289>
- Gretgrix, L. J., Decker, O., Green, P. T., Köhler, F., Moussalli, A., & Murphy, N. P. (2023). Genetic diversity of a short-ranged endemic terrestrial snail. *Ecology and Evolution*, 13, e10785. <https://doi.org/10.1002/ece3.10785>

- Goodfriend, G. A. (1986). Variation in land-snail shell form and size and its causes: A review. *Systematic Biology*, 35(2), 204-223. <https://doi.org/10.1093/sysbio/35.2.204>
- Graveland, J., van der Wal, R., & van Balen, J. (1994). Poor reproduction in forest passerines from decline of snail abundance on acidified soils. *Nature*, 368, 446–448. <https://doi.org/10.1038/368446a0>
- Graveland, J., & van der Wal, R. (1996). Decline in snail abundance due to soil acidification causes eggshell defects in forest passerines. *Oecologia*, 105, 351–360.
- Gümüş, B. A. (2010). The land snails of Kâhta, Adiyaman, Turkey (Mollusca: Gastropoda: Pulmonata). *Munis Entomology & Zoology*, 5(1), 286-289.
- Gould, S. J. (1969). An evolutionary microcosm: Pleistocene and recent history of the land snail *P. (Poecilozonites)* in Bermuda. *Bull. Museum of Comparative Zoology*, 138, 407–531.
- Gould, S. J. (1971). Environmental control of form in land snails. A case of unusual precision. *Nautilus (Philadelphia)*, 84, 86–93.
- Harl, J., Páll-Gergely, V., Kirchner, S., Sattman, H., Duda, M., Kruckenauser, L., & Haring, E. (2014). Phylogeography of the land snail genus *Orcula* (Orculidae, Stylommatophora) with emphasis on the Eastern Alpine taxa: speciation, hybridization and morphological variation. *BMC Evolutionary Biology*, 14, 223. <https://doi.org/10.1186/s12862-014-0223-y>
- Harvey, M. S. (2002). Short-range endemism amongst the Australian fauna: Some examples from non-marine environments. *Invertebrate Systematics*, 16(4), 555–570. doi: 10.1071/IS02009
- Harvey, M. S., Rix, M. G., Framenau, V. W., Hamilton, Z. R., Johnson, M. S., Teale, R. J., Humphreys, G., & Humphreys, W. F. (2011). Protecting the innocent: Studying short-

- range endemic taxa enhances conservation outcomes. *Invertebrate Systematics*, 25(1), 1–10. <https://doi.org/10.1071/IS11011>
- Hayase, Y., Kimura, S., & Kawabe, K. (2015). A new record of *Japonia inouei* (Gastropoda: Cyclophoridae) from Mie Prefecture, central Honshu, Japan. *Venus*, 73, 79–83.
- Heryanto, H. (2020). Land snails on two different sides of Mt. Galunggung. *BIO Web of Conferences*, 19, 00007. <https://doi.org/10.1051/bioconf/20201900007>
- Herbert, D. G. (1998). Molluscan conservation in South Africa: diversity, issues and priorities. *Journal of Conchology*, 2, 61-76.
- Horsák, M. (2006). Mollusc community patterns and species response curves along a mineral richness gradient: a case study in fens. *Journal of Biogeography*, 33(1), 98-107. <https://doi.org/10.1111/j.1365-2699.2005.01359.x>
- Horsák, M., Hájek, M., Tichý, L., & Juříčková, L. (2007). Plant indicator values as a tool for land mollusc autecology assessment. *Acta Oecologica*, 32(2), 161-171. <https://doi.org/10.1016/j.actao.2007.03.011>
- Hwang, C. (2014a). Three new species of the genus *Japonia* Gould, 1895 (Gastropoda: Cyclophoridae) from Taiwan. *Bulletin of Malacology*, 38, 1-12.
- Hwang, C. (2014b). Taxonomic revision of the operculated snails genus *Japonia* Gould, 1859 (Gastropoda: Cyclophoridae) from Taiwan. *Bulletin of Malacology*, 38, 13-30.
- Hylander, K., Nilsson, C., Jonsson, B. G., & Göthner, T. (2005). Differences in habitat quality explain nestedness in a land snail meta-community. *Oikos*, 108(2), 351-361. <https://doi.org/10.1111/j.0030-1299.2005.13400.x>

- Hijmans, R., & Graham, C. (2006). The ability of climate envelope models to predict the effect of climate change on species distributions. *Global Change Biology*, 12, 2272-2281.
- Hijmans, R. J., Phillips, S., Leathwick, J., & Elith, J. (2012). *An R Package for Species Distribution Modelling*. Retrieved from <http://cran.r-project.org/web/packages/dismo/index.html> [Accessed June 4, 2013].
- Hijmans, R. J., & Etten, J. V. (2012). *Raster: Geographic analysis and modeling with raster data. R package version 2.0-12*. Retrieved from <http://CRAN.R-project.org/package=raster>
- Hof, A. R. (2011). European terrestrial gastropod distribution: How may climate change affect their diversity and current distribution. In *Gastropods: Diversity, habitat and genetics* (pp. 165–182). Hauppauge, NY: Nova Science Publishers Inc.
- Iyengar, E. V., Sitvarin, M. I., & Cataldo, M. (2008). Function of the flexible periostracal hairs in *Trichotropis cancellata* (Mollusca, Gastropoda). *Invertebrate Biology*, 127(3), 299-313. <https://doi.org/10.1111/j.1744-7410.2008.00141.x>
- Ichikawa, S., Nakashima, T., Katanoda, Y., & Tomiyama, K. (2014). The biogeographical studies of land snail fauna in Tokara Islands, Japan. *Bulletin of the Biogeographical Society of Japan*, 69, 25-40.
- Jaremovic, R., & Rollo, C. D. (1979). Tree climbing by the snail *Cepaea nemoralis* (L.): A possible method for regulating temperature and hydration. *Canadian Journal of Zoology*, 57, 1010-1014. <https://doi.org/10.1139/z79-128>
- Johannessen, L. E., & Solhoy, T. (2001). Effect of experimentally increased calcium levels in the litter on terrestrial snail populations. *Pedobiologia*, 45(3), 234-242. <https://doi.org/10.1078/0031-4056-00082>

- Jordan, S. F., & Black, S. H. (2012). *Effects of forest land management on terrestrial mollusks: A literature review*. The Xerces Society for Invertebrate Conservation, Portland, Oregon, USA.
- Juříčková, L., Horsák, M., Cameron, R., Hylander, K., Míková, A., Hlaváč, J. C., & Rohovec, J. (2008). Land snail distribution patterns within a site: The role of different calcium sources. *European Journal of Soil Biology*, 44(2), 172-179.
<https://doi.org/10.1016/j.ejsobi.2007.07.001>
- Kaky, E., Nolan, V., Alatawi A., & Gilbert F. (2020). A comparison between Ensemble and MaxEnt species distribution modelling approaches for conservation: A case study with Egyptian medical plants. *Ecological Informations*, 60, 101150.
<https://doi.org/10.1016/j.ecoinf.2020.101150>
- Kappes, H. (2005). Influence of coarse woody debris on the gastropod community of managed calcareous beech forest in western Europe. *Journal of Molluscan Studies*, 71(2), 85-91.
<https://doi.org/10.1093/mollus/eyi011>
- Killeen, I. J., & Seddon, M. B. (2004). Molluscan biodiversity and conservation. *Journal of Conchology Special Publication*, 3, 172.
- Kayeye, J. L. B., Kabale, B. N., Cishibanji, P. B., Mashimango, J. J. B., & Bajope, J. P. B. (2014). A preliminary survey and distribution of land snails of Katana region, Southern Kivu, democratic republic of Congo. *International Journal of Innovation and Scientific Research*, 9(2), 212-224.

- Kemp, P., & Bertness, M. D. (1984). Snail shape and growth rates: Evidence for plastic shell allometry in *Littorina littorea*. *Proceedings of the National Academy of Sciences*, 81(3), 811–813. <https://doi.org/10.1073/pnas.81.3.811>
- Kiew, R. (2001). The limestone Begonias of Sabah, Borneo – Flagship species for conservation. *Gardens' Bulletin Singapore*, 53, 241-286.
- Khalik, M. Z., Hendriks, K., Vermeulen, J. J., & Schilthuizen, M. (2018). A molecular and conchological dissection of the “scaly” *Georissa* of Malaysian Borneo (Gastropoda, Neritimorpha, Hydrocenidae). *ZooKeys*, 773, 1-55. <https://doi.org/10.3897/zookeys.773.24878>
- Konuma, J., Nagata, N., & Sota, T. (2011). Factors determining the direction of ecological specialization in snail-feeding carabid beetles. *Evolution*, 65(2), 408-418. <https://doi.org/10.1111/j.1558-5646.2010.01150.x>
- Lazaridou-Dimitriadou, M., Karakousis, Y., & Staikou, A. (1994). Geographical variation in shell morphology and isoenzymes of *Helix aspersa* Müller, 1774 (Gastropoda, Pulmonata), the edible land snail, from Greece and Cyprus. *Heredity*, 72, 23–35. <https://doi.org/10.1038/hdy.1994.3>
- Lange, C. N. (2003). Environmental factors influencing land snail diversity patterns in Arabuko Sokoke forest, Kenya. *African Journal of Ecology*, 41, 352-355. <https://doi.org/10.1111/j.1365-2028.2003.00482.x>
- Lee, J. Y., Nasir, N. S., Marzuki, M. E., Vermeulen, J. J., & Khalik, M. Z. (2024). The land snail fauna of Batu Kudik, isolated limestone outcrop near Simunjan, Sarawak, Malaysian

- Borneo (Mollusca, Gastropoda). *Biodiversity Data Journal*, 12, e115556.
<https://doi.org/10.3897/BDJ.12.e115556>
- Liew, T. S., Vermeulen, J. J., Marzuki, M. E., & Schilthuizen, M. (2014). A cybertaxonomic revision of the micro-landsnail genus *Plectostoma* Adam (Mollusca, Caenogastropoda, Diplommatinidae), from Peninsular Malaysia, Sumatra and Indochina. *ZooKeys*, 393, 1-107.
- Liew, T. S., Foon, J. K., & Clements, G. R. (2021). Conservation of limestone ecosystems, Part VI: Detailed information of limestone outcrops of Sarawak. *Institute for Tropical Biology and Conservation, Universiti Malaysia Sabah, Kota Kinabalu*, 572 pp.
<https://doi.org/10.6084/m9.figshare.14907885.v5>
- Liew, T. S., & Huong, J. T. (2011). The land snail fauna of Eastern Lanjak Entimau (Mollusca: Gastropoda). *ResearchGate*.
- Losos, J. N., & Schluter, D. (2000). Analysis of an evolutionary species-area relationship. *Nature*, 408, 847-850. <https://doi.org/10.1038/35048558>
- Luchtel, D. L., & Deyrup-Olsen, I. (2001). Body wall: Form and function. In G. M. Barker (Ed.), *The biology of terrestrial molluscs* (pp. 147–178). Wallingford, UK: CAB International.
- Lehtomäki, J., & Moilanen, A. (2013). Methods and workflow for spatial conservation prioritization using Zonation. *Environmental Modelling & Software*, 47, 128-137.
<https://doi.org/10.1016/j.envsoft.2013.05.001>
- Mason, L. D., Bateman, P. W., & Wardell-Johnson, G. W. (2018). The pitfalls of short-range endemism: high vulnerability to ecological and landscape traps. *PeerJ*, 6, e4715.
<https://doi.org/10.7717/peerj.4715>

- Martin, K., & Sommmmer, M. (2004). Relationships between land snail assemblage patterns and soil properties in temperate-humid forest ecosystems. *Journal of Biogeography*, 31(4), 531-545. <https://doi.org/10.1046/j.1365-2699.2003.01005.x>
- Moritz, C., Richardson, K. S., Ferrier, S., Monteith, G. B., Stanistic, J., Williams, S. E., & Whiffin, T. (2001). Biogeographical concordance and efficiency of taxon indicators for establishing conservation priority in a tropical rainforest biota. *Proceeding of The Royal Society B*, 268, 1875–1881. <https://doi.org/10.1098/rspb.2001.1713>
- Moilanen, A., Franco, A. M. A., Early, R. I., Fox, R., Wintle, B., & Thomas, C. D. (2005). Prioritizing multiple-use landscapes for conservation: Methods for large multi-species planning problems. *Proceedings of the Royal Society*, 272, 1885-1891. <https://doi.org/10.1098/rspb.2005.3164>
- Marzuki, M. E., Liew, T., & Mohd-Azlan, J. (2021). Land snails and slugs of Bau limestone hills, Sarawak (Malaysia, Borneo), with the descriptions of 13 new species. *ZooKeys*, 1035, 1-113. <https://doi.org/10.3897/zookeys.1035.60843>
- Mayer, W. M., & Shiels, A. B. (2009). Black rat (*Rattus rattus*) predation on nonindigenous snails in Hawai’I: Complex management implications. *Pacific Science*, 63(3), 339-347. <https://doi.org/10.2984/049.063.0304>
- Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, 403, 853–858.
- Minato, H. (1975). *Japonia inouei* Kuroda & Habe, 1961 (Gastropoda, Cyclophoridae) with its historical notes, morphology and distribution. *Nankiseibutu*, 17, 40–41.

- Minato, H. (1982). Land shell fauna of Ujigunto and Kusakakigunto Islets, the southwestern Kyushu, Japan, with the descriptions of a new genus and six new species. *Japanese Journal of Malacology*, 41(2), 124-140.
- Minato, H. (1985). Two new *Japonia* (Prosobranchia: Cyclophoridae) from Japan. *Venus*, 44(2), 81-86. https://doi.org/10.18941/venusjjm.44.2_81
- Minin, E. D., Veach, V., Lehtomäki, J., Pouzols, F. M., & Moilanen, A. (2014). *A quick introduction to Zonation*. Helsingin yliopisto, Helsinki.
- Milne, G. (1937). Essays in Applied Pedology: I.—Soil Type and Soil Management in Relation to Plantation Agriculture in East Usambara. *The East African Agricultural Journal*, 3(1), 7–20. <https://doi.org/10.1080/03670074.1937.11663717>
- Mohd-Azlan, J., & Lawes, M. J. (2011). The efficacy of protected areas and future challenges for wildlife conservation in Sarawak. In *Ecosystem Protection and Community Livelihoods* (Chapter 15).
- Mujiono, N., & Priawandiputra, W. (2020). Land snail from limestone karst in Java: An update with notes on their distribution. *IOP Conference Series: Earth and Environmental Science*, 457, 012002. <https://doi.org/10.1088/1755-1315/457/1/012002>
- Moilanen, A., Meller, L., Leppänen, J., Pouzols, M. F., Arponen, A., & Kujala, H. (2014). *Spatial conservation planning methods and software ZONATION version 3.1 user manual*. Biodiversity Conservation Informatics Group, Department of Biosciences, University of Helsinki, Helsinki, Finland.

- Moreno-Rueda, G., Ruiz-Ruiz, A., Collantes-Martín, E., & Arrébola, J. R. (2009). Relative importance of humidity and temperature on microhabitat use by land snails in arid versus humid environments. *Arid Environments and Wind Erosion*, 331-343.
- Naggs, F., & Raheem, D. (2005). Sri Lankan snail diversity: faunal origins and future prospects. *Records of the Western Australia Museum*, 68, 11–29.
- Nasir, N. S., Lee, J. Y., Marzuki, M. E., Vermeulen, J. J., Mohd-Azlan, J., & Khalik, M. Z. (2024). Checklist of land snail species of Gua Rumbang, Sarawak, Malaysian Borneo (Mollusca, Gastropoda), with a description of a new species, *Diplommatina rumbangensis* sp. nov. *ZooKeys*, 1198, 295-340. <https://doi.org/10.3897/zookeys.1198.116265>
- Nunes, G. K. M., & Santos, S. B. (2012). Environmental factors affecting the distribution of land snails in the Atlantic Rain Forest of Ilha Grande, Angra dos Reis, RJ, Brazil. *Braz. J. Biol.*, 72(1), 79-86.
- Neubauer, T. A., Xing, L., & Jochum, A. (2019). Land snail with periostracal hairs preserved in Burmese Amber. *iScience*, 1-8. <https://doi.org/10.1016/j.isci.2019.09.034>
- Němec, T., & Horsák, M. (2019). Specific damage recognised on land snail shells as a tool for studying predation intensity: Differences related to habitat and predator types. *Contributions to Zoology*, 88, 277-296. <https://doi.org/10.1163/18759866-20191402>
- Nurinsiyah, A. S., Faizah, I., Prasetio, Y., Setiadi, T., Marwoto, M. R., & Hausdorf, B. (2019). Diversity and ecology of land snails in Gunung Halimun Salak National Park (GHSNP) in Java, Indonesia. *Zoo Indonesia*, 28(1), 46-58.

- Noce, S., Caporaso, L., & Santini, M. (2020). A new global dataset of bioclimatic indicators. *Scientific Data*, 7, 398. <https://doi.org/10.1038/s41597-020-00726-5>
- Nori, J., Torres, R., Lescano, J. N., Cordier, J. M., Periago, M. E., & Baldo, D. (2016). Protected areas and spatial conservation priorities for endemic vertebrates of the Gran Chaco, one of the most threatened ecoregions of the world. *Diversity and Distributions*, 22(12), 1212-1219. <https://doi.org/10.1111/ddi.12497>
- Ovando, X. M. C., Miranda, M. J., Loyola, R., & Cuezco, M. G. (2019). Identifying priority areas for invertebrate conservation using land snails as models. *Journal for Nature Conservation*, 50, 125707.
- Paton, J. R. (1961). A brief account of the geology of the limestone hills of Malaya. *Bulletin of the Raffles Museum*, 26, 66-75.
- Primack, R. B., & Hall, P. (1992). Biodiversity and forest change in Malaysian Borneo. *American Institute of Biological Sciences*, 42(11), 829-837.
- Ponder, W. F. (1997). Conservation status, threats and habitat requirements of Australian terrestrial and freshwater Mollusca. *Memoirs of Museum of Victoria*, 56(2), 421-430. <https://doi.org/10.24199/j.mmv.1997.56.33>
- Phung, C. C., Yu, F. T. Y., & Thor-Seng, L. (2017). A checklist of land snails from the west coast islands of Sabah, Borneo (*Mollusca, Gastropoda*). *ZooKeys*, 673, 49-104. <https://doi.org/10.3897/zookeys.673.12422>
- Paoletti, M. G. (2012). *Invertebrate biodiversity as bioindicators of sustainable landscapes: Practical use of invertebrates to assess sustainable land use* (1st ed.). Padova: Elsevier.

- Parmesan, C. (2006). Ecological and evolutionary responses to recent climate change. *Annual Review of Ecology, Evolution, and Systematics*, 37, 637-669. <https://doi.org/10.1146/annurev.ecolsys.37.091305.110100>
- Pfenninger, M., Hrabáková, M., Steinke, D., & Depraz, A. (2005). Why do snails have hairs? A Bayesian inference of character evolution. *BMC Evolutionary Biology*, 5, 59. <https://doi.org/10.1186/1471-2148-5-59>
- Price, T. D., Qvarnström, A., & Irwin, D. E. (2003). The role of phenotypic plasticity in driving genetic evolution. *Proceedings of The Royal Society B Biological Sciences*, 270, 1433–1440. <https://doi.org/10.1098/rspb.2003.2372>
- Proćków, M., Proćków, J., Błazej, P., & Mackiewicz, P. (2018). The influence of habitat preferences on shell morphology in ecophenotypes of *Trochulus hispidus* complex. *Science of The Total Environment*, 630, 1036-1043. <https://doi.org/10.1016/j.scitotenv.2018.02.311>
- Proćków, M., Kuźnik-Kowalska, E., & Mackiewicz, P. (2017). The influence of climate on shell variation in *Trochulus striolatus* (C.Pfeiffer, 1828) (Gastropoda: Hygromiidae) and its implications for subspecies taxonomy. *Annales Zoologici*, 67(2), 199-220. <https://doi.org/10.3161/00034541ANZ2017.67.2.002>
- Parkyn, J., & Newell, D. A. (2013). Australian land snails: A review of ecological research and conservation approaches. *Molluscan Research*, 33(2), 116-129. <https://doi.org/10.1080/13235818.2013.782793>
- Prior, D. J. (1985). Water-regulatory behaviour in terrestrial gastropods. *Biological Reviews*, 60, 403-424. <https://doi.org/10.1111/j.1469-185X.1985.tb00423.x>

- Richards, P. M., & Davison, A. (2010). Adaptive radiations: Competition rules for Galápagos gastropods. *Current Biology*, 20(1), R28–R30. <https://doi.org/10.1016/j.cub.2009.11.019>
- Régnier, C., Fontaine, B., & Bouchet, P. (2009). Not knowing, not recording, not listing: Numerous unnoticed mollusk extinctions. *Conservation Biology*, 23(5), 1214–1221. <https://doi.org/10.1111/j.1523-1739.2009.01245.x>
- Rosin, Z. M., Olborska, P., Surmacki, A., & Tryjanowski, P. (2011). Differences in predatory pressure on terrestrial birds and mammals. *Journal of Biosciences*, 36, 691–699. doi: 10.1007/s12038-011-9077-2
- Roos, M. C., Keßler, P. J. A., Gradstein, S. R., & Baas, P. (2004). Species diversity and endemism of five major Malesian islands: diversity-area relationships. *Journal of Biogeography*, 31(12), 1893–1908. <https://doi.org/10.1007/s12038-011-9077-2>
- Richards, P. W. (1996). The tropical rain forest. *Scientific American*, 229, 6, 58–68.
- Schilthuizen, M., Thor-Seng, Liew., Elhahan, B. B., & Lackman-Ancrenaz, I. (2005). Effects of karst forest degradation on pulmonate and prosobranch land snail communities in Sabah, Malaysian Borneo. *Conservation Biology*, 19, 949–954. <https://doi.org/10.1111/j.1523-1739.2005.00209.x>
- Sen, S., Ravikanth, G., & Aravind, N. A. (2012). Land snails (Mollusca: Gastropoda) of India: Status, threats and conservation strategies. *Journal of Threatened Taxa*, 4(11), 3029–3037.
- Shimek, B. (1930). Land snails as indicators of ecological conditions. *Ecology*, 11(4), 673–686. <https://doi.org/10.2307/1932328>

- Solem, A. (1984). A world model for land snail diversity and abundance. In A. Solem & A. C. V. Bruggen (Eds.), *World-Wide Snails: Biogeographical Studies on Non-Marine Mollusca* (pp. 6–22). Backhuys Publisher.
- Sólymos, P., & Fehér, Z. (2005). Conservation prioritization based on distribution of land snails in Hungary. *Conservation Biology*, 19(4), 1084-1094. <https://doi.org/10.1111/j.1523-1739.2005.00193.x>
- Sodhi, N. S. (2008). Tropical biodiversity loss and people – A brief review. *Basic and Applied Ecology*, 9(2), 93–99. <https://doi.org/10.1016/j.baae.2007.11.001>
- Schilthuizen, M., & Rutjes, H. A. (2001). Land snail diversity in a square kilometre of tropical rainforest in Sabah, Malaysian Borneo. *Journal of Molluscan Studies*, 67(4), 417-423. <https://doi.org/10.1093/mollus/67.4.417>
- Schilthuizen, M., Teräväinen, M. I. F., Tawith, N. F. K., Ibrahim, H., Chea, S. M., Chuan, C. P., Daim, L. J., Jubaidi, A., Madjapuni, M. J., Sabeki, M., & Mokhtar, A. (2002). Microsnails at micro-scales in Borneo: Distributions of prosobranchia versus pulmonata. *Journal of Molluscan Studies*, 68(3), 255-258. <https://doi.org/10.1093/mollus/68.3.255>
- Schilthuizen, M., Hsieh-Nee, C., & Tracy, E. K. (2003). Abundance and diversity of land-snails (Mollusca:Gastropoda) on limestone hills in Borneo. *The Raffles Bulletin of Zoology*, 51(1), 35-42.
- Smith, M. L., Wallace, J., Tank, D. C., Sullivan, J., & Carstens, B. C. (2022). The role of multiple Pleistocene refugia in promoting diversification in the Pacific Northwest. *Molecular Ecology*, 31(16), 4402-4416. <https://doi.org/10.1111/mec.16595>

- Symondson, W. O. C., Glen, D. M., Wiltshire, C. W., Langdon, C. J., & Liddell, J. E. (1996). Effects of cultivation techniques and methods of straw disposal on predation by *Pterostichus melanarius* (Coleoptera: Carabidae) upon slugs (Gastropoda: Pulmonata) in an arable field. *Journal of Applied Ecology*, 33, 741-753.
- Suvorov, A. (1999). Some mechanisms of adaptation to the wet microhabitats in higher geophila (Mollusca, Pulmonata). *Zhurnal Obshchei Biologii*, 60(2), 177-188.
- Tattersfield, P., Seddon, M. B., Meena, C., & Kasigwa, P. (1998). Ecology and conservation of the land-snails of the Eastern arc mountains. *Journal of East African Natural History*, 87(1), 119-138. [https://doi.org/10.2982/0012-8317\(1998\)87\[119:EACOTL\]2.0.CO;2](https://doi.org/10.2982/0012-8317(1998)87[119:EACOTL]2.0.CO;2)
- Tattersfield, P., Warui, C. M., Seddon, M. B., & Kiringe, J. W. (2001). Land-snail faunas of afro-montane forests of Mount Kenya, Kenya: ecology, diversity and distribution patterns. *Journal of Biogeography*, 28(7), 843-861. <https://doi.org/10.1046/j.1365-2699.2001.00606.x>
- Teles, W. S., de Paiva Silva, D., Vilela, B., Lima-Junior, D. P., Pires-Oliveira, J. C., & Miranda, M. S. (2022). How will the distributions of native and invasive species be affected by climate change? Insights from giant South American land snails. *Diversity*, 14(6), 467. <https://doi.org/10.3390/d14060467>
- Thomas, C. D., Cameron, A., Green, R. E., Bakkenes, M., Beaumont, L. J., Collingham, Y. C., Erasmus, B. F. N., de Siqueira, M. F., Grainger, A., Hannah, L., Hughes, L., Huntley, B., van Jaarsveld, A. S., Midgley, G. F., Miles, L., Oetega-Huerta, M. A., Peterson, A. T., Phillips, O. L., & Williams, S. E. (2004). Extinction risk from climate change. *Nature*, 427, 145-148. <https://doi.org/10.1038/nature02121>

- Tomiyama, K. (1984). Land snail fauna of Mukō-jima, Uji-guntō, Northern Ryūkyū Islands, Japan, with descriptions of a new subgenus, a new species and a new subspecies. *Japanese Journal of Malacology*, 43(3), 199-210.
- Tweedie, M. W. F. (1961). On certain Mollusca of the Malayan limestone hills. *Bulletin of the Raffles Museum*, 26, 49-65.
- Vermeulen, J. J. (1991a). Notes on the nonmarine molluscs of the island of Borneo 2. The genus *Opisthostoma* (Gastropoda Prosobranchia: Diplommatinidae). *Basteria*, 55, 139-163.
- Vermeulen, J. J. (1991b). Notes on the non-marine molluscs of the island of Borneo 3. The genus *Platycochlium* (Gastropoda Pulmonata, Streptaxidae). *Basteria*, 55, 165-171.
- Vermeulen, J. J. (1993). Notes on the non-marine mollusks of the island of Borneo 5. The genus *Diplommatina* (Gastropoda Prosobranchia: Diplommatinidae). *Basteria*, 57, 3-69.
- Vermeulen, J. J. (1994). Notes on the nonmarine molluscs of the island of Borneo 6. The genus *Opisthostoma* (Gastropoda Prosobranchia: Diplommatinidae), part 2. *Basteria*, 58, 73-191.
- Vermeulen, J. J. (1996). Notes on the non-marine molluscs of the island of Borneo 8. The genus *Arina* additions to the genera *Diplommatina* and *Opisthostoma*. *Basteria*, 60, 87-138.
- Vermeulen, J. J. (2003). *The terrestrial mollusc fauna of Batu Niah N.P. and Gunung Mulu N.P., Sarawak*. Internal report for the SWMPI-project of DANIDA, Singapore, 21 pp.
- Vermeulen, J., & Whitten, T. (1999). *Biodiversity and cultural property in the management of limestone resources: Lessons from East Asia*. The World Bank.
- Vermeulen, J. J., & Junau, D. J. (2007). Bukit Sarang (Sarawak, Malaysia), an isolated limestone hill with an extraordinary snail fauna. *Basteria*, 71, 209-220.

- Vermeulen, J. J., & Liew, T. S. (2022). *Land snails and slugs of Sabah and Labuan (Malaysia)*. Institute for Tropical Biology and Conservation, Universiti Malaysia Sabah, Kota Kinabalu, Malaysia. Pp iii–x, 1–432. <https://doi.org/10.6084/m9.figshare.17156255>
- Walther, G., Post, G., Convey, P., Menzel, A., Parmesan, C., Beebee, T. J. V., Fromentin, J., Hoegh-Guldberg, O., & Bairlein, F. (2002). Ecological responses to recent climate change. *Nature*, 416(6879), 389-395. <https://doi.org/10.1038/416389a>
- Wade, C. M., Mordan, P. B., & Naggs, F. (2006). Evolutionary relationships among the Pulmonate land snails and slugs (Pulmonata, Stylommatophora). *Biological Journal of the Linnean Society*, 87(4), 593-610. <https://doi.org/10.1111/j.1095-8312.2006.00596.x>
- Wäreborn, I. (1969). Land molluscs and their environments in an oligotrophic area in southern Sweden. *Oikos*, 20(2), 461-479. <https://doi.org/10.2307/3543209>
- Wäreborn, I. (1970). Environmental factors influencing the distribution of land molluscs of an oligotrophic area in southern Sweden. *Oikos*, 21(2), 285-291. <https://doi.org/10.2307/3543685>
- Watters, G. T., Menker, T., & O'Dee, S. H. (2005). A comparison of terrestrial snail faunas between strip-mined land and relatively undisturbed land in Ohio, USA - an evaluation of recovery potential and changing faunal assemblages. *Conservation Biology*, 126(2), 166-174. <https://doi.org/10.1016/j.biocon.2005.05.005>
- Webley, D. (1964). Slug activity in relation to weather. *Annals of Applied Biology*, 53(3), 407-414. <https://doi.org/10.1111/j.1744-7348.1964.tb07254.x>
- Woodward, F. I., & Williams, B. G. (1987). Climate and plant distribution at global and local scales. *Vegetatio*, 69, 189-197. <https://doi.org/10.1007/BF00038700>

- Wisz, M., Hijmans, R., Li, J., Peterson, A., Graham, C., & Guisan, A. (2008). Effects of sample size on the performance of species distribution models. *Diversity and Distributions-a Journal of Biological Invasions and Biodiversity*, 14, 763–773.
- Yamazaki, D. (2022). First record of *Japonia tokunoshimana tokunoshimana* Pilsbry & Y. Hirase, 1904 (Mollusca: Gastropoda: Cyclophoridae) from Kikaijima Island, Japan. *Fauna Ryukyuana*, 65, 75-81.
- Yen-Chen, L., Kuang-Yang, L., & Wen-Lung, W. (2008). Molecular evidence for a polyphyletic genus *Japonia* (Architaenioglossa: Cyclophoridae) and with the description of a new genus and two new species. *Zootaxa*, 1792, 22-38.