



Faculty of Resource Science and Technology

**Possible Impact of Climate Change and Environmental Health on the Geographical
Distribution of Sarawak Frogs**

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Possible Impact of Climate Change and Environmental Health on the Geographical
Distribution of Sarawak Frogs

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DECLARATION

I hereby declare that this thesis titled “Possible Impact of Climate Change and Environmental Health on the Geographical Distribution of Sarawak Frogs” is my original work, conducted in accordance with the regulations of Universiti Malaysia Sarawak (UNIMAS). I confirm that no part of this thesis has been copied from other students’ work or sources without proper citation, and no section has been written by anyone else.

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Signature

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ABSTRACT

Climate change, together with habitat loss, represents a major threat to global biodiversity, with frogs particularly at risk because of their ectothermic nature, reliance on specific microhabitats, and heightened sensitivity to environmental variation. This study investigated the impacts of climate and habitat change on the physiology and distribution of frogs in Sarawak by addressing three related questions: (i) how microhabitat conditions shape body temperatures and thermoregulatory strategies, (ii) how habitat quality and human disturbance influence species diversity and microhabitat use across protected and altered sites, and (iii) how projected temperature increases may shift the future range of *Fejervarya limnocharis*, used here as a model species to anticipate broader distributional responses among Bornean frogs. Field surveys were carried out between November 2022 and May 2023 at five study locations: Bung Jagoi, Matang Wildlife Centre, UNIMAS West Campus, Kampung Telok Melano, and Mulu National Park. There were 261 individuals in all, representing 40 species across six families. Results from Chapter 4 demonstrated the thigmothermic nature of frogs by showing a close correlation between their body temperatures and substrate temperatures. The higher body temperatures of frogs in non-flowing aquatic environments compared to those in streams and terrestrial habitats have significant implications for physiological function and disease susceptibility, especially with relation to *Batrachochytrium dendrobatidis*. Chapter 5 revealed that protected sites like Mulu National Park, Matang Wildlife Centre, and Bung Jagoi supported healthier ecosystems and higher frog diversity due to the availability of intact microhabitats, while disturbed sites like Telok Melano and UNIMAS West Campus showed signs of habitat degradation and lower diversity. These results highlight the critical role of microhabitat variety and community-driven conservation in maintaining amphibian populations. Chapter

6 applied species distribution models (SDMs) for *Fejervarya limnocharis*, showing that its suitable habitat is likely to expand significantly by 2050 under both moderate (SSP2-4.5) and high (SSP5-8.5) climate scenarios. This reflects the high adaptability of this generalist species, yet also highlights potential risks to more sensitive native frog species. Overall, the results indicate that Bornean frogs respond to environmental changes through physiological regulation, alterations in species assemblages, and shifts in distribution, emphasising their susceptibility in a rapidly changing climate. By combining information on thermal ecology, habitat quality, and species distribution predictions, this study delivers comprehensive insights into amphibian vulnerability and adaptability, providing practical guidance for conservation planning, management of protected areas, and climate adaptation strategies in Sarawak.

Keywords: Anurans, body temperature, ecosystem health, habitat degradation, species distribution models (SDMs)

Kemungkinan Kesan Perubahan Iklim dan Kesihatan Persekitaran terhadap Taburan

Geografi Katak Sarawak

ABSTRAK

Perubahan iklim bersama dengan kehilangan habitat merupakan ancaman utama kepada biodiversiti global, dengan katak terutamanya berisiko tinggi disebabkan sifat ektotermik, kebergantungan terhadap mikrohabitat tertentu, dan kepekaan yang tinggi terhadap variasi persekitaran. Kajian ini menyiasat kesan perubahan iklim dan habitat terhadap fisiologi dan taburan katak di Sarawak dengan meengemukakan tiga soalan berkaitan: (i) bagaimana keadaan mikrohabitat membentuk suhu badan dan strategi termoregulasi, (ii) bagaimana kualiti habitat dan gangguan manusia mempengaruhi kepelbagaian spesies dan penggunaan mikrohabitat merentasi tapak yang dilindungi dan yang telah diubah suai, dan (iii) bagaimana unjuran peningkatan suhu mungkin mengalihkan julat masa hadapan Fejervarya limnocharis, yang digunakan sebagai spesies model untuk menjangkakan tindak balas taburan yang lebih luas dalam kalangan katak Borneo. Kajian lapangan telah dijalankan antara bulan November 2022 dan Mei 2023 di lima lokasi kajian: Bung Jagoi, Pusat Hidupan Liar Matang, Kampus Barat UNIMAS, Kampung Telok Melano, dan Taman Negara Mulu. Sebanyak 261 individu telah direkodkan, mewakili 40 spesies daripada enam famili. Keputusan daripada Bab 4 menunjukkan sifat tigmoterma (thigmothermic) katak dengan memaparkan perkaitan rapat antara suhu badan dan suhu substrat. Suhu badan katak yang tinggi dalam persekitaran akuatik tidak mengalir berbanding dengan dalam sungai dan habitat daratan mempunyai implikasi yang ketara terhadap fungsi fisiologi dan kerentanan penyakit, terutamanya yang berkaitan dengan Batrachochytrium dendrobatidis. Bab 5 mendedahkan bahawa kawasan yang dilindungi seperti Taman Negara Mulu, Pusat Hidupan Liar Matang, dan Bung Jagoi menyokong ekosistem yang lebih sihat serta

kepelbagaian katak yang lebih tinggi disebabkan ketersediaan mikrohabitat yang utuh, manakala tapak-tapak terganggu seperti Telok Melano dan Kampus Barat UNIMAS menunjukkan tanda-tanda kesusutan habitat dan kepelbagaian yang lebih rendah. Keputusan ini menekankan peranan kritikal kepelbagaian mikrohabitat dan pemuliharaan yang didorong oleh komuniti dalam mengekalkan populasi amfibia. Bab 6 menggunakan model taburan spesies (SDMs) untuk *Fejervarya limnocharis*, menunjukkan bahawa habitat sesuai untuk spesies ini berkemungkinan besar akan meluas dengan ketara menjelang tahun 2050 di bawah kedua-dua senario iklim sederhana (SSP2-4.5) dan tinggi (SSP5-8.5). Ini mencerminkan kebolehsuaian yang tinggi bagi spesies generalis ini, namun turut menyerlahkan potensi risiko kepada spesies katak asli yang lebih sensitif. Secara keseluruhan, dapatan kajian menunjukkan bahawa katak Borneo bertindak balas terhadap perubahan persekitaran melalui regulasi fisiologi, perubahan dalam himpunan spesies, dan anjakan dalam taburan, menekankan kerentanan dalam iklim yang berubah dengan pantas. Dengan menggabungkan maklumat mengenai ekologi terma, kualiti habitat, dan ramalan taburan spesies, kajian ini menyampaikan pandangan komprehensif tentang kerentanan dan kebolehsuaian amfibia, menyediakan panduan praktikal untuk perancangan pemuliharaan, pengurusan kawasan perlindungan, dan strategi adaptasi iklim di Sarawak.

Kata kunci: Anuran, suhu badan, kesihatan ekosistem, kesusutan habitat, model taburan spesies (SDMs)

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LIST OF ABBREVIATIONS

UNIMAS	Universiti Malaysia Sarawak
SDM	Species Distribution Models
m	Metre
km	Kilometre
IUCN	International Union for Conservation of Nature
NE	Not Evaluated
DD	Data Deficient
LC	Least Concern
NT	Near Threatened
VU	Vulnerable
EN	Endangered
CR	Critically Endangered
km ²	Square kilometre
DNA	Deoxyribonucleic Acid
WWF	World Wide Fund for Nature
LKWS	Lower Kinabatangan Wildlife Sanctuary
Bd	<i>Batrachochytrium dendrobatidis</i>
ENM	Ecological Niche Model
MAS	Malaysian Airline System
PITAS	Pusat Islam Tun Abg Salahuddin
N	North

E	East
HQ	Headquarters
GPS	Global Positioning System
SVL	Snout-vent length
TL	Tibia length
W	Weight
IBM	International Business Machines Corporation Statistical
SPSS	Package for Social Sciences
AEHI	Anuran Ecosystem Health Indicator
MaxEnt	Maximum Entropy
GIS	Geographic Informations System
T_b	Body temperature
T_s	Substrate temperature
T_a	Ambient temperature
RH	Humidity
SC	Stratum Corneum
VES	Visual Encounter Survey
AES	Acoustic Encounter Survey
NMDS	Non-metric Multidimensional Scale
FCD	Final Coordinate Dimension
ENV	Environmental Variable
SSP	Shared Socioeconomic Pathways
GCM	Global Climate Model
CMIP	Climate Model Intercomparison Project

°C	Degree Celsius
mm	Millimetre
AUC	Area Under Curve
ROC	Receiver Operating Curve

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Over the next several years, research indicate that climate change may overshadow habitat degradation as the leading worldwide biodiversity risk (Leadley, 2010; Palita, 2016; Muluneh, 2021). This is supported by Bellard et al. (2012) and Muluneh (2021), who argue that global climate change is recognized as the primary factor for species extinction, contributing to significant shifts in species distribution, with species relocating to higher altitudes at a typical pace of 11.0m decennially, to higher latitudes of 16.9km decennially, altering the composition of ecological communities worldwide. Anthropogenic activities, such as open burning and deforestations, have significantly increased atmospheric concentrations of greenhouse gases, producing a warming effect that has surged by 45 percent from 1990 to 2019 (Stocker et al., 2013; Mwanake et al., 2023).

Amphibians, the most imperilled group of vertebrates, are facing a global decline, with climate change becoming a profound threat since the IUCN's first Global Amphibian Assessment in 2004 (Jacobo, 2023). According to the International Union for Conservation of Nature (IUCN), there are a total of 27 species categorised as NE (Not Evaluated). 15 are classified as DD (Data Deficient), 54 as LC (Least Concern), 40 as NT (Near Threatened), 30 as VU (Vulnerable), nine as EN (Endangered), and three as CR (Critically Endangered) (Das et al., 2014). When evaluating all vulnerable amphibians, the highest risks are habitat reduction and deterioration, particularly due to agricultural development, impacting 77% of the species. Logging and crop harvesting affects 53%, while infrastructural development

affects 40%. Climate change and disease also causes substantial risks, affecting 29% in the species (Luedtke et al., 2023).

The ongoing climate change towards warmer and drier regimes jeopardises the physiological functions of amphibian populations, causing range shift distribution, altered reproductive phenology, disrupted ecology interactions, and extinctions (Llusia et al., 2013; Duan et al., 2016). Climate change, through directional selection and rapid migration, threatens species persistence by constricting genetic diversity and habitat corridors (Bellard et al., 2012; McIntyre et al., 2014). This decline in connectivity diminishes dispersal, gene flow, and population viability, ultimately increasing the risk of local extinctions (Hoffman & Sgrò, 2011; Wasserman et al., 2012; Guan et al., 2021).

Rising water temperatures will likely alter stream currents, lake levels, pond hydroperiods, and soil moisture, which will then hinder reproductive success and larval amphibian survival (Lawler et al., 2010; Pottier et al., 2022). For example, frogs from the genus *Pseudophryne* deposit their eggs in burrows, where exposure to soil and rain stimulates hatching and supplies still water for metamorphosis processes (Bradford & Seymour, 1988; Eads et al., 2012). Deb et al. (2016) had proposed that rising temperatures and increasing variability in precipitation, including prolonged droughts and intense rainfall, are disrupting wetland ecosystems and may lead to population fluctuations or local extinctions of frog species.

1.2 Problem Statement

Amphibians are among the most climate-sensitive animals, with their well-being depends greatly on the environment, especially temperature, humidity, and the availability of suitable habitats. Frogs are highly vulnerable to climate change due to their thin,

permeable skin and their need to absorb heat and moisture from their surroundings (Duan et al., 2016; Montori & Amat, 2023). In places like Borneo, particularly in Sarawak, the effects of climate change are overlapping with ongoing habitat loss caused by deforestation, land development, and fragmentation (Enriquez-Urzelai et al., 2019). As natural habitats become smaller and become increasingly disconnected, many frog species face greater difficulty in surviving, adapting, or relocate to more suitable environments (Larsen & Ramløv, 2013; Konapala et al., 2020).

Sarawak is known for its high diversity of frog species, yet there is still a lack of local research on how environmental changes are affecting their body temperature regulation, habitat preferences, and long-term survival. While species like *Megophrys nasuta* have shown clear microhabitat dependence (Mohamad Paisal, 2016), and studies from other regions has shown that microhabitats can offer some protection from heat stress (Scheffers et al., 2014). However, little has been done to connect these physiological and habitat patterns with predictions of how frog distributions might change under future climate conditions in Sarawak.

To help address this gap, this study examines frog body temperatures, ecosystem health and microhabitat preferences across five key study sites in Sarawak (i.e., Bung Jagoi, Matang Wildlife Centre, UNIMAS West Campus, Kampung Telok Melano, and Mulu National Park), and then modelling the current and future range of *Fejervarya limnocharis*. This research offers insights into how frogs might respond to environmental change and to provide useful information for local conservation planning and land management.

1.3 Research Questions

This study focuses on exploring the following questions:

- i. How do microhabitat characteristics of frogs of Sarawak influence body temperatures, and what factors contributed to variations in thermoregulation?
- ii. How do temperature change, in combination with habitat loss and fragmentation, impact the health of frogs and influence microhabitat preferences across localities in Sarawak?
- iii. How would rising temperature over the next 26 years affect the geographic distribution of *Fejervarya limnocharis* in Sarawak, and how could this model predict future distribution patterns for other Bornean frog species?

1.4 Objectives

This study aimed to provide insights into how climate and habitat changes affected frog physiology and distribution, thus improving awareness of their susceptibility and resilience in the face of environmental change over time in Sarawak. Three main research objectives were developed:

- i. To analyse body temperatures of Bornean frogs in Sarawak: Bung Jagoi, Matang Wildlife Centre, UNIMAS West Campus, Kampung Telok Melano, and Mulu National Park;
- ii. To examine the anuran ecosystem health and microhabitat preferences in five different study locations; and
- iii. To project the map of distribution of *Fejervarya limnocharis* (Asian Grass Frog) in Sarawak.

1.5 Hypotheses

To address the research questions and objectives, and guided by existing ecological knowledge of anuran thermal biology and habitat use in tropical regions, the following hypotheses were formulated:

- i. There is a significant positive relationship between body temperatures of Bornean frogs and environmental factors such as substrate temperature, ambient temperature, and humidity, and these relationships vary according to microhabitat type across the five study locations.
- ii. Frogs in protected areas will show higher species diversity and healthier ecosystem indicators compared to those in disturbed or fragmented habitats, and microhabitat preferences will differ depending on environmental quality.
- iii. The future geographic distribution of *Fejervarya limnocharis* will expand under projected climate change scenarios due to its ecological adaptability, particularly in areas with suitable temperature and precipitation conditions.

1.6 Research Chart

Figure 1.1 illustrates the overall flow of the present research. The study begins by establishing the main research problem in Chapter 1, followed by a review of relevant literatures in Chapter 2 to identify knowledge gaps. Based on this, the research questions are formulated (Chapter 1). The methodological framework is then outlined, detailing the study sites, data collection techniques, and analytical approaches (Chapter 3). Data collected from fieldwork and environmental databases are analysed and interpreted across three core chapters: frog body temperature and thermoregulation (Chapter 4), ecosystem health and microhabitat preferences (Chapter 5), and species distribution modelling under

climate scenarios (Chapter 6). Finally, in Chapter 7, the overall findings are synthesised, discussed in relation to the research objectives, and concluded with key recommendations for conservation and future research.

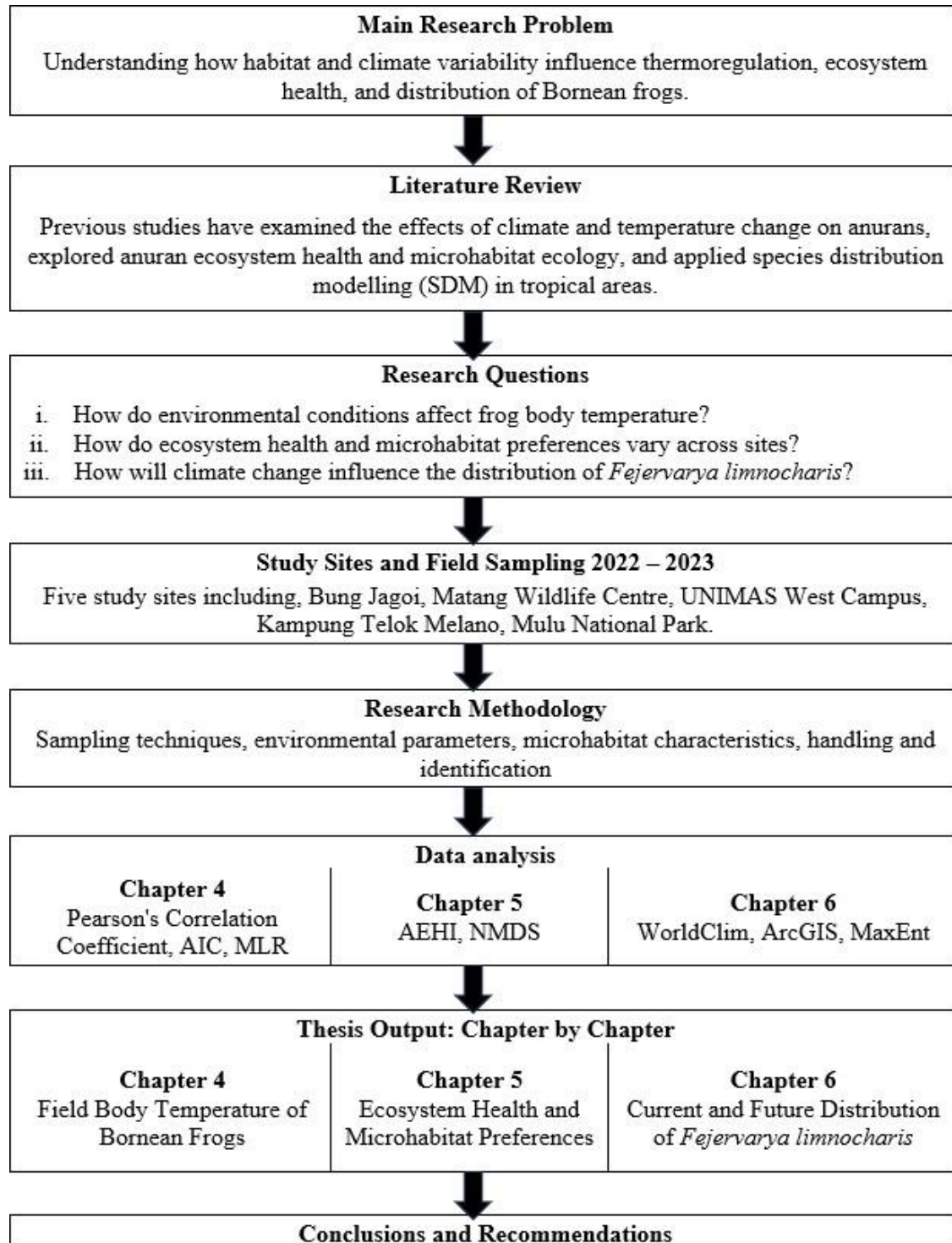


Figure 1.1: Flow chart of the research

CHAPTER 2

LITERATURE REVIEW

2.1 Bornean Frogs

Borneo, the third-largest island worldwide, covers an expanse of 743,330km², with only Greenland and New Guinea being larger. Positioned on the equator, Borneo stretches 1,336 kilometres from the northeast to southwest with the utmost width of 960 kilometres (The Editors of Encyclopedia Britannica, 2024). Borneo, a biodiversity hotspot in Southeast Asian, is renowned for its exceptional herpetofaunal diversity, particularly its anuran fauna, with some species found both on the island and in surrounding regions. Systematic inventory studies in Sabah and Sarawak, conducted since the late 1850s, have highlighted Borneo's significant amphibian diversity (Asad et al., 2015; Inger et al., 2017; Huaimei et al., 2019). Borneo's unique geography, extensive size, and geological history have led to its diverse anuran species. New species are still discovered each year, even in extensively studied regions, often through detailed reviews and advanced DNA analysis (Chan et al., 2020; Sheridan et al., 2023).

Borneo's various ecosystems, shaped by climate, elevation, and habitat, supports various anuran populations. Within Sarawak, the distribution of diverse anuran species is directly related to our distinct ecoregions, which are defined by forest types, moisture levels, and geological history. Figure 2.1 shows these patterns by overlaying WWF ecoregions definitions alongside mapped anuran species richness in Sarawak.

Ecoregions and Anuran Species Richness across Sarawak

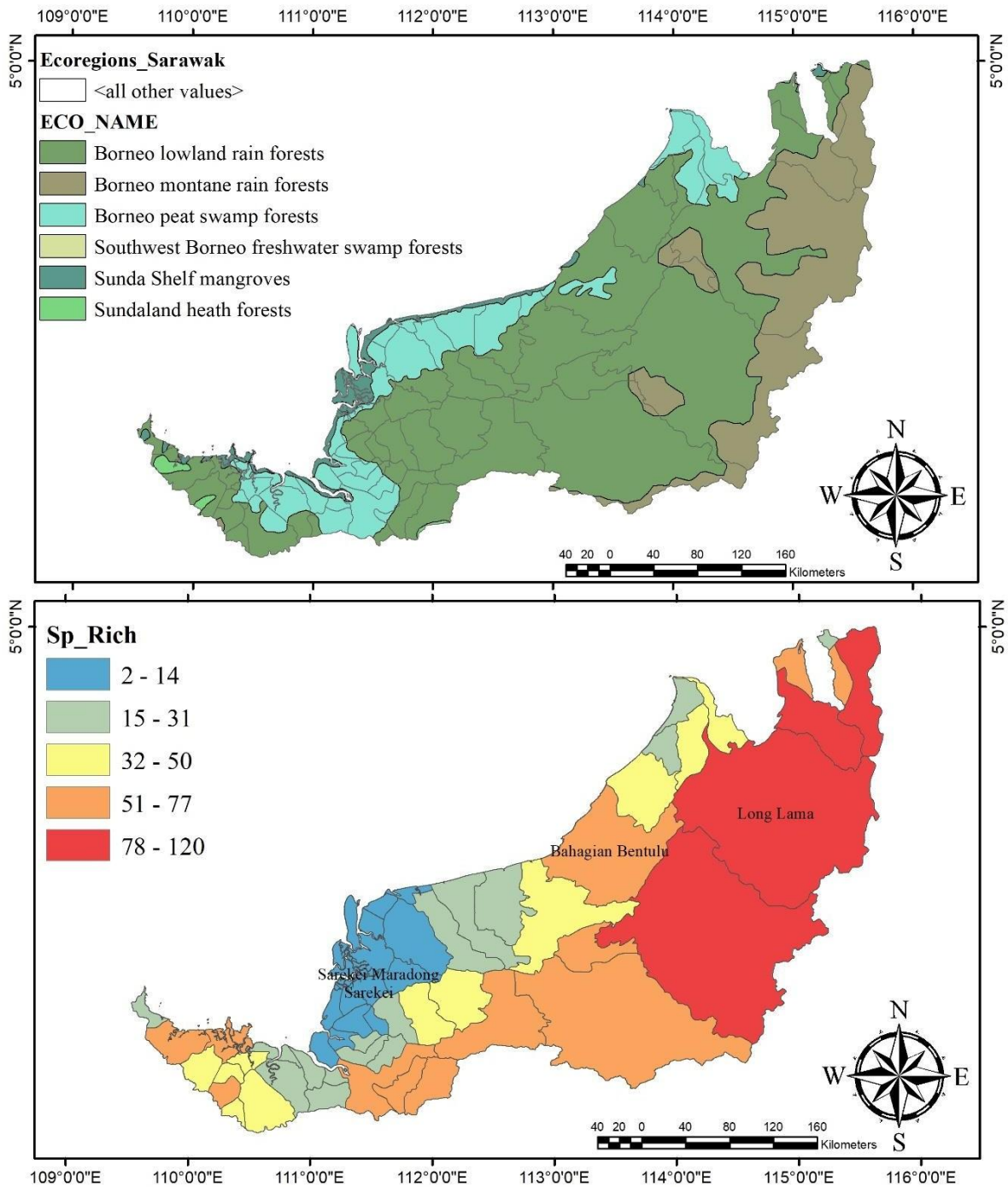


Figure 2.1: Ecoregions of Sarawak and spatial distribution of anuran species richness, based on IUCN data. Warmer colours indicating areas with higher number of frog species.
Generated by ArcMap version 10.8.2

Early European visits, notably the British– (in the northern and western Borneo) and the Dutch (in the southern regions of the island), known for their exploration and study of natural history, initiated studies of Borneo's anuran species (Das, 2003). As of 2023, Borneo hosts around 195 anuran species from eight different families (such as Bombinatoridae, Bufonidae, Ceratobatrachidae, Dicroglossidae, Megophryidae, Microhylidae, Ranidae, and Rhacophoridae), with approximately 140 being endemic to the island, and nearly half of the assessed species, totalling 83, are deemed at risk (IUCN, 2022; Salim et al., 2023). These data demonstrate the immense variety and high degree of endemism of Bornean anurans, with approximately 28% (55 species) not previously identified. The population of 13 species (30.2%) is declining, 26 species (60.5%) is constant, and 4 species (9.3%) is unassessed (IUCN, 2024). Figure 2.2 illustrates representative examples of Bornean frog species recorded during fieldwork, highlighting the diversity observed across various habitats.

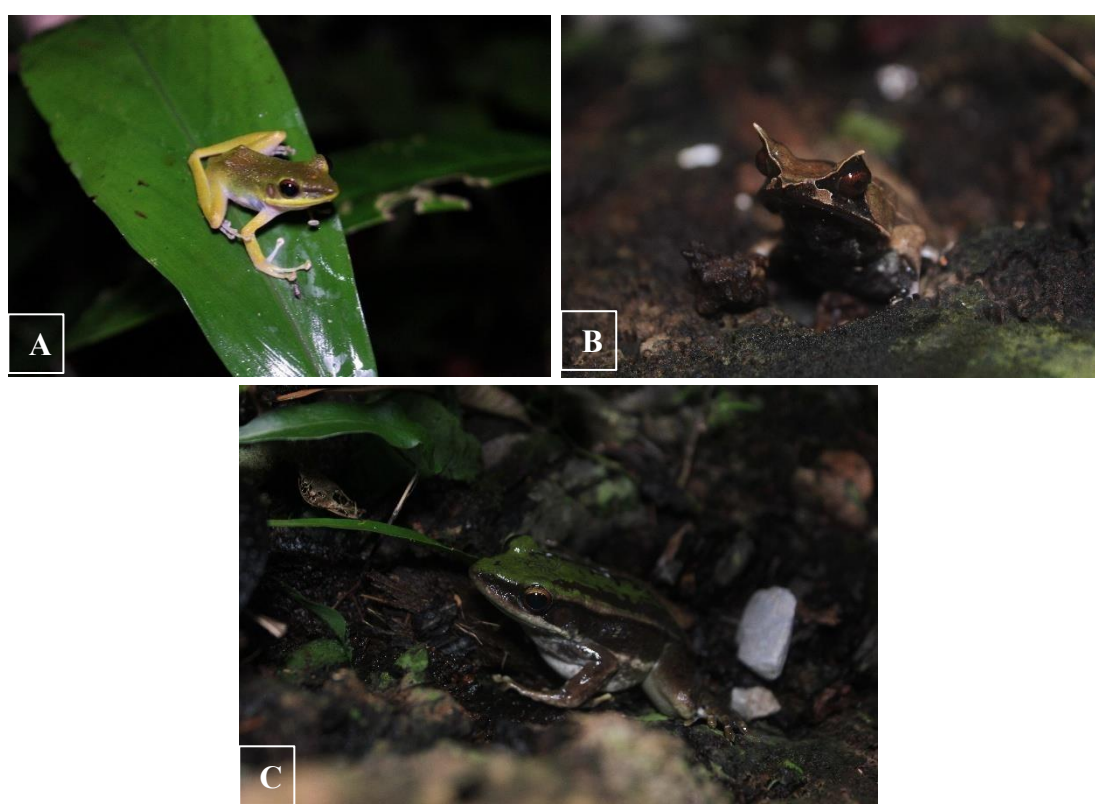


Figure 2.2: Selected frog species recorded during fieldwork in Sarawak: (A) *Chalcorana raniceps*, (B) *Megophrys nasuta*, and (C) *Hylarana erythraea*

2.1.1 Anurans as Bioindicators

Anurans serve as important indicators of tropical biodiversity and environmental conditions due to their vulnerability to environmental changes and dependence on clean water and forest cover, making them particularly effective in indicating pollution and habitat deterioration (Das et al., 2014; Rohman et al., 2020; Estes-Zumpf et al., 2022). Anuran skin is crucial for overall frog health, supporting physiological functions such as water absorption, heat transfer, ion transport, respiration, as well as defence mechanism like camouflage and predator deterring. Additionally, the skin plays a crucial role in sexual behaviour and motion, highlighting its critical importance in maintaining overall well-being and protection against pathogens (Larsen & Ramløv, 2013; Varga et al., 2019; Akat et al., 2022). The thin, permeable skin and superficial vasculature of anurans make them effective bioindicators, as their skin allows easy absorption of environmental substances such as heavy metals and pesticides, leading to deformities, disease, and death. Due to this high permeability, anurans can absorb harmful chemicals from both air and water, making them particularly sensitive to pollution (Thanomsangad et al., 2020; Zaghloul et al., 2020; Guezgouz et al., 2021). This permeability is crucial for their physiological homeostasis, including fluid and electrolyte balance (Varga et al., 2019).

Anurans, with their sensitivity to environmental quality and close correlation to water quality, availability, and rainfall patterns, make them ideal indicators for detecting environmental disturbances and assessing the impacts of climate change, thereby helping to prevent ecological collapse (Rohman et al., 2020). Due to their highly specialised usage of either lotic (flowing water) or lentic (non-flowing water) microhabitats, aquatic anuran at larval stages are particularly sensitive to even little environmental changes (Sinai et al., 2022; Ujszegi et al., 2022). Continued anuran decline would make it difficult to identify harmful

contaminants before the ecosystem is irreparably damaged or even collapses. This increases the pace of ecosystem breakdowns and extinctions and makes environmental preservation considerably more difficult (West, 2018; Luedtke et al., 2023).

An example is a study done by Aguilar-León (2020) on the impacts of habitat destruction and palm oil cultivation on anuran species in the Lower Kinabatangan Wildlife Sanctuary (LKWS). According to the findings, secondary forests offer better preservation value for anurans relative to oil palm plantations and other non-forest ecosystems, supporting a greater number of anuran species, including a higher proportion of endemics. In contrast, oil palm plantations exhibit lower species diversity, reduced endemism, and primarily support anurans adaptability. This study confirms that oil palm plantations significantly harm regional biodiversity by causing habitat loss, fragmentation, and reliance on agrochemicals, leading to species decline and extinction. Additionally, oil palm farms adversely affect amphibian diversity even in adjacent forest areas, indicating that fragmented forest areas must be sufficiently large and wide to mitigate edge effects and preserve biodiversity over the long term (Lucey et al., 2014; Scriven et al., 2018).

2.1.2 Declination in Anuran Population

Habitat alteration, including anthropization, remains the leading cause of local anuran declines and is a primary cause of global biodiversity loss. Habitat depletion and degradation persist as the predominant factors in deteriorating species status, affecting 32% of species from 1980 to 2004 and 37% from 2004 to 2022 (Venter et al., 2016; Luedtke et al., 2023). However, enigmatic declines in anuran populations in undisturbed habitats suggests that factors other than direct human impact may be contributing to the problem. Global anuran declines that vary by different geographical locations and even amongst

populations of the same species are the result of interacting cofactors, rather than a single cause. Habitat degradation, introduced species, climate change, overexploitation, pathogens, and environmental contaminants are the ultimate causes of anuran decreases (Hayes et al., 2010; May, 2010; Luedtke et al., 2023). Figure 2.3 shows the various stressors that contribute to the decline and extinction of anuran populations worldwide.

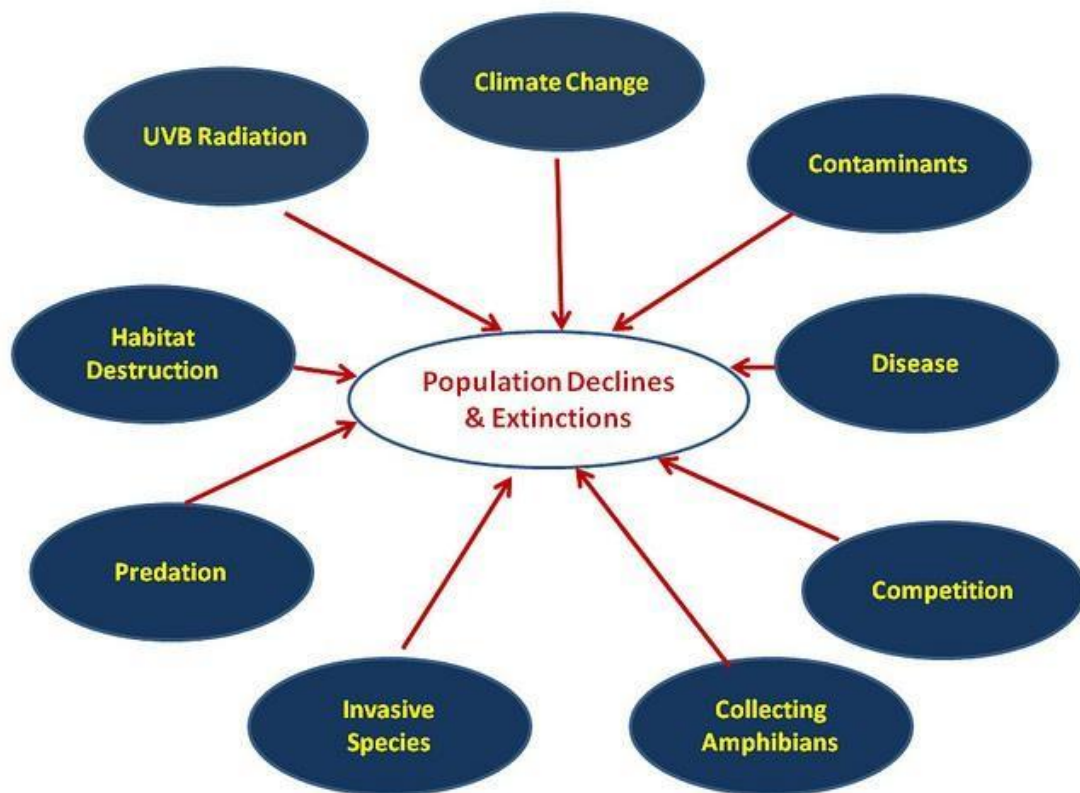


Figure 2.3: Multiple stressors affecting anurans. Adapted from “The complexity of anuran population declines: Understanding the role of cofactors in driving anuran losses,” by A. R. Blaustein et al. (2011), *Annals of the New York Academy of Sciences*, 1223, p. 108-119. Copyright 2011 by Annals of the New York Academy of Sciences

Anthropogenic climate alteration due to elevated greenhouse gases, is accelerating extinction events, and making anurans more vulnerable to diseases as their habitats experience rapid and extreme temperature shifts, surpassing their ability to adapt compared to historical environmental changes. (Urban, 2015; Bosch et al., 2018; Menéndez-Guerrero et al., 2020). The amphibian chytrid pathogen, *Batrachochytrium dendrobatidis* (Bd), which

has caused extensive declines and species loss in anuran populations since emerging in the late 20th century, was previously believed to have originated in Africa but is now recognized to have developed from East Asia (Anonymous, 2021; O’hanlon et al., 2018). Chytridiomycosis, which affects anuran skin and causes cardiac collapse, thrives in temperatures ranging from 17°-25°C and is particularly effective in warmer climates. Although it reproduces asexually and has limited adaptation, the chytrid fungus spreads widely and drives species to extinction (Bachtlin, 2020).

The thermal mismatch theory explains that fluctuations in temperature and season can weaken the immune systems of anurans, increasing their vulnerability to parasites like the chytrid fungus, which thrives in cooler temperatures and causes disease outbreaks that are less severe in warmer conditions. (Chytridiomycosis, n.d.; Cohen et al., 2017; Sonn et al., 2019). Heat waves caused by climate change have rendered once-suitable environments unsuitable, drying up ponds and causing significant larval mortality, while severe temperatures increase physiological stress, interrupt breeding seasons, and reduce breeding success across a wide range of species (Richards-Zawacki, 2010; Ujszegi et al., 2022). As a result, when their external environment changes in temperature, anurans struggle to maintain optimal body temperatures. Many parasites, such as chytrid fungus, have a greater temperature range than their host, making anuran species that need to relocate to a more favourable environment far more susceptible to infections (Bradley et al., 2019; Cohen et al., 2018). Human-caused climate change is altering natural habitats, making it difficult for anuran species to adapt to their new environment.

Bornean frogs are key players to stability of tropical ecosystems. They serve as vital food for higher trophic levels and aid in controlling bug populations as both predators and prey (Hocking & Babbitt, 2014). They are useful models for understanding environmental

change in Southeast Asian rainforests and effective bioindicators due to their variable reproductive strategies, microhabitat specialisation, and high endemism, particularly in montane and lowland forests (Zainudin et al., 2017). Despite their ecological significance, little is known about the physiological reactions of Bornean frogs in Sarawak to the rapid changes in environment, including increased temperatures, changed precipitation patterns, and habitat fragmentation. Effective risk assessment and conservation planning are hampered by this knowledge gap. Thus, this study intends to close these gaps by examining how body temperature regulation, ecosystem health, and predicted distribution patterns of anurans across major Sarawak sites impacted by anthropogenic pressures and climate change.

To further illustrate the conservation status and distribution patterns of anurans, a summary table (**Table 2.1**) presents selected frog species with their conservation status and distribution across Sarawak and Borneo. These categories include Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), and Least Concern (LC). These examples offer insight into the diversity and vulnerability of anurans in the region, which is crucial for informing targeted conservation strategies.

Table 2.1: Selected anuran species distributed across Sarawak and Borneo with IUCN Red List Status (2025)

Family	Species Name	Distribution	IUCN 2025
Bufonidae	<i>Ansonia latidisca</i>	Borneo	EN
	<i>Ansonia spinulifer</i>	Borneo	LC
	<i>Pelophryne rhopophilia</i>	Borneo	VU
	<i>Ansonia vidua</i>	Sarawak	CR
	<i>Ingerophrynus quadriporcatus</i>	Borneo	LC
	<i>Pelophryne murudensis</i>	Sarawak	CR
	<i>Pelophryne saravacensis</i>	Sarawak	NT
	<i>Ansonia torrentis</i>	Sarawak	NT
Ceratobatrachidae	<i>Alcalus baluensis</i>	Borneo	LC
	<i>Alcalus sariba</i>	Sarawak	EN
Dicroglossidae	<i>Limnonectes kenepaiensis</i>	Borneo	VU
	<i>Limnonectes ibanorum</i>	Borneo	LC
	<i>Limnonectes ingeri</i>	Borneo	LC
	<i>Limnonectes cintalubang</i>	Sarawak	EN
	<i>Occidozyga baluensis</i>	Borneo	LC
Megophryidae	<i>Leptobrachium abbotti</i>	Borneo	LC
	<i>Megophrys nasuta</i>	Borneo	LC
	<i>Leptobrachella serasanae</i>	Sarawak	NT
	<i>Leptobrachium kantonishikawai</i>	Sarawak	CR
	<i>Leptobrachella brevicrus</i>	Sarawak	NT
Microhylidae	<i>Microhyla borneensis</i>	Borneo	LC
	<i>Glyphoglossus capsus</i>	Borneo	NT
	<i>Kalophrynus meizon</i>	Borneo	LC
	<i>Kalophrynus nubicola</i>	Sarawak	NT
Ranidae	<i>Staurois guttatus</i>	Borneo	LC
	<i>Chalcorana raniceps</i>	Borneo	LC
	<i>Staurois parvus</i>	Borneo	VU
	<i>Meristogenys jerboa</i>	Sarawak	VU
	<i>Meristogenys penrissenensis</i>	Borneo	EN
Rhacophoridae	<i>Polypedates ottilophus</i>	Borneo	LC
	<i>Philautus kerangae</i>	Sarawak	VU
	<i>Philautus juliandringi</i>	Sarawak	NT
	<i>Rhacophorus borneensis</i>	Borneo	LC
	<i>Philautus acutus</i>	Sarawak	LC
	<i>Leptomantis gadingensis</i>	Sarawak	NT
	<i>Philautus ingeri</i>	Borneo	VU

2.2 Effects of Climate and Temperature Change on Anurans

Temperature changes can have a substantial impact on anurans due to their ectothermic nature, as they are unable to control their temperatures internally like birds and mammals. Ectotherms depend on external thermal sources to adjust their body temperature, with their surrounding temperature having a direct effect on their body temperature (Sanabria & Quiroga, 2019; Guevara-Molina et al., 2020). Ectothermic animals are particularly vulnerable to temperature fluctuations due to their absence of metabolic, physiological, and anatomical capabilities needed to regulate a constant body temperature, making them reliant on external temperatures and capable of maintaining optimal function limited to a specific threshold (Mokhatla et al., 2019; Ujszegi et al., 2022). The wet skin of anurans, which accelerates both evaporative water loss and heat dissipation, makes them especially susceptible to dehydration, significantly impacting their behaviour and physiology (Sanabria & Quiroga, 2019). As a result, they are sensitive to temperature variations and are impacted by daily fluctuates in habitat temperatures (Paajimans et al., 2013; Lima et al., 2020).

Brattstrom (1963) provided one of the earliest and most comprehensive reviews of amphibian thermal biology, documenting over 6,500 body temperature readings from 99 species. His study demonstrated that amphibians do not passively conform to ambient environmental temperatures. Instead, many species use behavioural thermoregulation strategies, such as seeking shaded or moist microhabitats and adjusting their activity periods, to maintain body temperatures within tolerable limits. He also emphasized that relying solely on macroclimatic data can be misleading, as amphibians often inhabit microclimates that differ significantly from regional conditions. Additionally, Brattstrom highlighted that critical thermal maximum values, which are used to determine physiological tolerance thresholds, vary among species, underscoring the importance of considering both species-

specific traits and habitat context in thermal ecology studies. These foundational insights continue to shape modern research on amphibian responses to environmental stressors, including climate change.

Building on Brattstrom's findings, more recent research has shown the unprecedented rate of current temperature increases is rapidly expanding risk areas across tropical zones with high diversity, potentially impacting numerous species, and challenging their thermal traits, such as physiological tolerance and behavioural adjustments, to maintain homeostasis (Feijó et al., 2023; DuBose et al., 2024). Temperature conditions, as the key element driving geographic size changes in both between species and individuals, cause body size to increase with colder temperatures or at higher latitudes due to selective pressure from ambient temperature (Guo et al., 2019). A study by Sheridan et al. (2022) found that there is a crossover link between body temperature and precipitation influences on Bornean frogs' body sizes. This study supports the temperature-size rule, which states that the rate of development (i.e., time the individual takes to reach maturity) increases with temperature, while the growth rate (i.e., the increase in size over time) is less temperature-dependent. In other words, frogs that live in warmer climates mature more quickly but are smaller at first reproduction. However, other possible factors for size variations, such as competition, predation, or habitat fragmentation, are not considered in this study. The overall effects of reductions in body size are expected to include population declines, as size and reproductive production for many species are correlated, increased temperature stress, and ensuing increases in death (Roff, 2002; Buckley, 2021; Peralta-Maraver & Rezende, 2021).

Environmental variables significantly influence anuran activity patterns, including reproduction, mobility, and scavenging. Reproductive activity, which varies daily and seasonally due to factors like habitat quality, the abundance of females, and the presence of

males at nesting sites, is also shaped by environmental cues that signal favorable conditions for reproduction, dispersal, and foraging (Both & Grant, 2012; Bardier et al., 2014; Ceron et al., 2020). Climate change directly impacts anurans' calling behaviour, as shifts in temperature and precipitation patterns force these ectothermic animals to adjust their vocalizations to attract mates and reproduce effectively. Various environmental influences, such as precipitation, temperature, humidity, atmospheric pressure, and light density, influence calling and chorusing behaviour, depending on the interplay between these factors and the species-specific ecological features. (Ospina et al., 2013; Akmentins et al., 2014; Ximenez & Tozetti, 2015; Anaïs et al., 2020). Behavioural changes can reduce the amount and efficacy of reproductive events in anuran species, resulting in a drop in population size and genetic diversity.

Study conducted by Asad et al. (2020) focuses on the perceptibility and habitat interactions of stream amphibians in the Deramakot Forest Reserve, central Sabah, Borneo, found that climatological parameters that influences anuran detectability – moon phase, temperature, humidity, and rainfall – can be associated with calling, reproductive behaviour, and phenological signals. Some species, for example, may be more active or vocal at specific phases of the moon or times of the day, whilst others may be more active or vocal under specific weather conditions. As a result, changes in these parameters due to climate change may have an impact on anurans' calling activities. However, the research was limited to stream anurans, and the findings may not be relevant to other types of anurans. This study did not address the impacts of anthropogenic disturbances beyond logging, such as hunting or pollution, on anuran detectability and habitat relationships. With acoustic pollution increasingly threatening natural communities globally, understanding how anthropogenic vibrations affect animal communication and reproduction could be crucial for informing

future conservation strategies. (Ernst & Rödel, 2005; McGrogan et al., 2013; Caorsi et al., 2019).

2.3 Anuran Ecosystem and Ecology

2.3.1 Habitat Types and Diversity

An anuran ecosystem encompasses the habitat where amphibians interact with their environment and other species, while anuran ecology focuses on studying how these species use their habitat and microhabitats, including how they exploit resources in similar ways and structures (Blanco-Torres et al., 2021). This ecosystem often comprises wetlands, ponds, streams, woodlands, and grasslands, which can vary greatly based on the location, climate, vegetation, and the individual species of anurans present and their ecological requirements (Jiang et al., 2022). The extent of forest habitat in a landscape is an important determinant in determining the ecological variety and compositional arrangement of frog assemblages since loss of forested habitat can result in a targeted loss of ecological functions and traits (Almeida-Gomes et al., 2019). This is because the environment plays a crucial role to the survival and reproduction of anurans, as they possess needs for food sources, breeding areas, and shelter (Jiang et al., 2022).

Microhabitats often serve as crucial resources that are shared among taxonomically related or ecologically comparable species, significantly influencing the distribution of anurans. By analysing how these amphibians use specific microhabitats, such as water bodies for breeding and tadpole development, it becomes easier to identify which species are associated with microhabitats. (Provete et al., 2014; Figueiredo et al., 2019; Nugraha *et al.*, 2021). Understanding these relationships provides valuable insights for conservation management. In Borneo, ecosystems like dipterocarp forests, peat swamps, montane forests,

and mangroves are crucial for the survival of anuran species, offering essential resources for breeding and shelter. Examples of common microhabitats utilised by Bornean frogs are illustrated in Figure 2.4.



Figure 2.4: Representative of frog microhabitats in Sarawak: (A) forest floor used by terrestrial species, (B) arboreal vegetation occupied by treefrogs, and (C) streamside sampling site representing lotic habitat use.

However, anthropogenic activities, such as large-scale developments, demand for forestry products, agriculture, and livestock farming, contribute to widespread habitat destruction, which threatens species extinction and population decline. This loss of vegetation cover increases the risk of soil drying out, endangering amphibians at all life stages. Furthermore, forest fires often worsened by human encroachment and El Nino events, damage these habitats, particularly in peat swamps, where underground fires can persist for

weeks (Coroniti III, 2022). Climate change is also altering ecosystem distributions, pushing frog populations into new areas, especially in montane forests. The combined impacts of deforestation, fires, and climate change reduce available microhabitats, further threatening frog survival. Such pressures are particularly critical for species that depend heavily on their environment, like anurans, which are vulnerable to their limited physical defences (Covarrubias et al., 2020; Kabanze et al., 2024).

An example is a study by Zulkefli and Zainudin (2022) that examines the compositions of frog species and establishes the ecological clusters of frog species from specified environments in Malaysian Borneo. The most significant threats to frogs, especially in Borneo, include deforestation and habitat fragmentation, which contribute to terrestrial biodiversity loss, along with overhunting for local use (Sodhi et al., 2013; Teow et al., 2022). The ecological assemblages of frog species in this study were grouped into six groups which are terrestrial frogs of disturbed and forest areas, tree-dwelling frogs of disturbed and forest areas, and partially arboreal frogs of disturbed and forest areas, all based on their use of habitat and microhabitat. Frogs with similar ecological needs were seen to coexist. From this, frogs display ecological clustering depending on habitat and microhabitat utilisation, and identifying ecological guilds is critical for prioritising conservation efforts (Jins et al., 2022). By protecting habitats extensively utilised by frog species, as indicated by ecological guilds, it is possible to advance and optimize faunal management, targeting several sites for conservation aims.

2.3.2 Biotic Interactions

Biotic interactions refer to the relationships among organisms within an ecosystem, which can be intraspecific (within the same species) or interspecific (between different

species) and include dynamics like predation, mutualism, and competition (Ha & Schleiger, n.d.). Biotic interactions are essential for preserving ecological balance and providing essential ecosystem contributions, highlighting the need to integrate sociological and ecological sciences to better understand human-wildlife dynamics and promote coexistence within a social-ecological framework (Carter et al., 2014; Carter et al., 2019). Human activities significantly impact species relationships and ecosystem functions, making it essential to govern human-wildlife interactions and landscape sharing to ensure wildlife populations persist with socially acceptable risk levels (Herrera & Doblas-Miranda, 2013; Pooley et al., 2020). Human activities, like pesticide runoff into aquatic systems, can disrupt predator-prey relationships by causing behavioural changes, sublethal effects, and mortality, which threaten the health of ecosystems (Robinson, 2022). Pesticides, which disrupt thyroid function and affect amphibian metamorphosis, pose a constant risk to amphibians by impacting their survival, growth, and development throughout their life stages in both marine and land environments. (Sparling et al., 2010; Egea-Serrano et al., 2012; Pinelli et al., 2019).

Controlling insect pests remains a significant challenge in agriculture globally, and while strategies like ecological control and holistic pest control are recognized as cost-effective, they complement more traditional methods such as pesticides, which, despite their potential harm to both pests and humans, are crucial for reducing diseases and boosting crop yields (Stenberg, 2017; Boedeker et al., 2020; Tudi et al., 2021). Anurans, or frogs, are particularly valuable in pest control due to their role as generalist predators. They prey on diverse invertebrates and small vertebrates, including harmful arthropods like ants and mites, and occasionally engage in cannibalism. Their diverse diet and predatory behaviour make them essential for managing pest populations and supporting agricultural health (Measey et al., 2015; Tripathi et al., 2024).

Sah and Grafe (2020) study conducted in Ulu Temburong National Park, Brunei Darussalam investigates the composition, distribution, and ecological roles of larval frog communities in rainforest stream environments. The study examines how stream characteristics and microhabitats shape the diversity and abundance of anuran larvae, revealing that distinct stream conditions support specialized larval assemblages, underscoring their ecological complexity. Predation may influence larval populations, with potential predators including aquatic insects, fish, or other amphibians. While fish are the main predators of tadpoles in streams and permanent habitats, invertebrates like dragonfly larvae exert more influence in ponds and temporary environments. The study suggests that resilient larval anuran communities help maintain ecological balance by preserving natural predator-prey dynamics, which is crucial for managing human-affected ecosystems and mitigating environmental changes.

2.3.3 Life Cycle and Breeding

Breeding activities in anurans, which are affected by climatic conditions like temperature, humidity, and light, must be synchronized with favourable conditions, leading to variations in breeding timing across different climates for widely distributed species to ensure successful reproduction (Ulloa et al., 2019; Forti et al., 2022). When climate conditions are favourable, such as during rainfall or mild temperatures, anurans have improved access to essential reproductive resources. Conversely, during unfavourable conditions like droughts or extreme heat, restricted access to these resources reduces reproductive success and affects population reductions (Ogotu et al., 2015; Hall et al., 2018). This may result in reduced reproductive success, eventually causing population declines due to fewer individuals available to sustain and replace those that perish. According to recent

studies, climate change can impact time and duration of animal reproduction, resulting in detrimental consequences on anuran populations, such as population decreases or possibly species extinction (Bobrek, 2021; Coppes et al., 2021). Climate change has an impact on anuran reproduction that is not limited to demographic impacts; it may also affect anuran behaviour and fitness (Cahill et al., 2013; Cappello & Boersma, 2021; Curtis et al., 2021), which limits their mating season, resulting in regulated breeding interval (Cappello & Boersma, 2021).

Freshwater and riparian environments provide critical habitat for a diverse range of species, including many terrestrial animals that require them for breeding and eating throughout the early stages of their life cycle (Alahuhta et al., 2019; Hanson et al., 2020; Reshetnikov et al., 2021). Anurans undergo a major evolutionary progression from an aquatic larval stage as tadpoles to a fully terrestrial adult phase, with their biphasic life cycle encompassing distinctly adapted aquatic and terrestrial lifestyles (Elinson & del Pino, 2012; Shrimpton et al., 2021; Schweiger, 2022). Breeding, a crucial aspect of anuran life cycles, is intrinsically linked to the availability of either standing (lentic) or flowing (lotic) water, which is essential for species with biphasic development (Schweiger, 2022). Anurans deposit their eggs in bodies of water such as ponds, streams, and marshes, and the tadpoles that emerge from these eggs require water to survive and develop before becoming terrestrial juveniles or adults (Camacho-Rozo & Urbina-Cardona, 2021). Therefore, changes in climate that influence the availability of water can have a substantial impact on anurans reproductive success due to their dependence on precipitation-driven hydro regime parameters (Greenberg et al., 2013; Forti et al., 2022).

An example is a study by Sah and Grafe (2020) that investigates the variety and variables influencing the species composition of larval anurans in northeast Borneo rainforest streams. They discovered that stream velocity, microhabitat breadth, and the quantity of odonate larvae all had a substantial effect on the larval assemblage composition, indicating that these aspects should be included in conservation and management efforts. According to the study, tadpoles in Borneo preferred smaller microhabitats as it provides a good setting for opportunistic breeders' reproductive success since such breeders often deposit a large clutch of eggs in small, transient environments, and often splitting clutches between oviposition locations.

However, according to Pyke & White (2022), warmer water temperatures driven by climate change are expected to alter stream flows, affecting various freshwater ecosystem attributes like depth, temperature, and salinity. This climate shift will likely increase global surface water temperatures, leading to unpredictable and intense precipitation patterns, and extend the intervals between precipitation events. As a result, anurans associated with arid streams and riparian zones, which are highly specialized and vulnerable, may experience significant impacts due to changes in hydrology and habitat conditions (Lawler et al., 2010; Griffis-Kyle et al., 2018). Beranek et al. (2022) mentioned that climate change significantly affects amphibian reproduction and survival by altering microhabitats essential for breeding and increasing aridification, which limits habitat availability and species richness. Changes in hydrological conditions and increased drought and heatwaves can severely disrupt reproduction and lifespan, as amphibians rely on specific moisture and temperature conditions. Additionally, climate-induced aridification and barriers to migration may fragment habitats, restricting amphibian dispersion and impacting their overall survival (Anderson et al., 2015; Zylstra et al., 2019; Mathwin et al., 2023).

2.4 Species Distribution Modelling

One of the cornerstones of ecology, conservation science and evolution is modelling population demography and species distribution (A. Lee-Yaw et al., 2022). Theoretically, species are predicted to exist in areas with steady or positive rates of population expansions. Favourable conditions tend to increase birth rates and survival, leading to higher population fitness and stability, but without mechanisms like aestivation to endure droughts that match or surpass a species' reproductive lifespan, local extinction becomes more likely (Mathwin et al., 2023). For future conservation planning and to learn more about the ecological and evolutionary causes of spatial variation of biodiversity, extensive information on the ecology of species and geographic distribution patterns is crucial.

One approach to projecting population demographics is to simulate a species' ecological niche using environmental factors influencing species occurrence, though presence-background or presence-only methods may be more suitable for identifying habitat suitability that matches the species' environmental requirements (Peterson & Soberón, 2012; Sillero et al., 2021). This correlative strategy is referred to by the term species distribution model (SDM), but notice that it also goes by other names, such as ecological niche model (ENM), and bioclimatic niche model, for a more neutral term (Araújo & Peterson, 2012; Sillero et al., 2021). Presence-background models are intriguing because they only require occurrence points to run, and they assess the suitability of habitats by comparing the environmental conditions of the study area with those where the species is found. While presence-absence methods might more closely align with species distributions, presence-background methods often predict a broader realized niche by distinguishing between suitable and unsuitable habitats (Sánchez-Montes et al., 2019; Sillero et al., 2021). However, the right training circumstances are needed for accurate predictions because a set of

occurrence points by themselves might not have a large impact on model predictions (Elith et al., 2010; Kramer-Schadt et al., 2013; Phillips & Elith, 2013).

Species distribution modelling (SDM) is a powerful tool widely used in conservation management, ecological and epidemiological studies, and disaster risk management, helping to estimate species' range areas, identify potential invasion risks, and support the protection of endangered species across diverse geographical settings (Kariyawasam et al., 2019; Rahman et al., 2019). Species Distribution Models (SDMs) are predictive tools that analyse the relationships between species occurrences and environmental variables to forecast undiscovered areas and understand species interactions with their surroundings, emphasizing distribution patterns influenced by historical, anthropogenic, and population dynamics factors (Shcheglovitova & Anderson, 2013; Srivastava et al., 2019; Sillero et al., 2021). One drawback of SDMs is that the predictor factors do not go beyond abiotic variables, which can cause species to have inaccurate estimates. This is because biotic effects from interactions (e.g., competition or predation) are frequently key drivers of the distribution of species.

A study by Zainudin et al. (2024) uses Species Distribution Models (SDMs), particularly MaxEnt, to predict gene flow and habitat connectivity for *Limnonectes leporinus* across Sarawak, revealing that geographical barriers, such as the Lupar Gap that reduces gene flow and leading to population subdivision. However, the study also proposes that overland movement of frogs could facilitate gene flow, particularly from the west to the north of Sarawak. MaxEnt has been shown to perform well even with limited sample sizes, which makes it a useful tool for conservation planning, as indicated by previous research, Escalante et al. (2013). The model's projections reveal that many non-protected areas should

be prioritized for conservation to support migration routes and prevent local extinction. This underscores the importance of considering anthropogenic impacts and fostering community engagement in conservation strategies. By incorporating environmental data into SDMs, it becomes possible to gain a deeper understanding of landscape connectivity patterns, which can guide informed conservation decisions. Additionally, the findings suggest with similar ecological requirements, especially in regions experiencing significant habitat change.

Another study by Zainudin et al. (2017) highlights the use of Species Distribution Models (SDMs) in understanding the distribution patterns of Sarawak frogs, especially in relation to their habitat and microhabitat preferences. It reveals that certain frog species, such as *Pulchrana baramica* and *Pulchrana glandulosa*, are commonly found in specific environments like coastal lowlands and swamps, while others are more associated with permanent streams. This aligns with previous observations on the habitat preferences of frogs in the region. Furthermore, the study discusses how ecological guilds and microhabitat utilisation may play a significant role in species coexistence, with closely related species often partitioning their habitat space to avoid competition. These findings suggest that the frogs' distribution is influenced not only by their phylogenetic relationships but also by ecological factors like microhabitat availability, water depth, and elevation, which are key elements in SDM modelling. By analysing these factors, SDMs can provide valuable insights into species distribution patterns, helping to identify critical habitats for conservation and guiding efforts to protect species that are vulnerable to habitat degradation.

CHAPTER 3

MATERIALS AND METHODS

3.1 Study Locations

This study was conducted at five different study locations in the state of Sarawak, located in East Malaysia (the north-western Borneo) from 2022 to 2023, as shown in Figure 3.1, including two protected areas, Matang Wildlife Centre and Mulu National Park. Study site coordinates are listed in Table 3.1.

Matang Wildlife Centre is located at the western corner of Kubah National Park and is reachable through the Rayu Trekking Trail from Kubah. Matang Wildlife Centre is about 22 kilometres from the State capital, Kuching city and it consists of 180 hectares of lowland forest that provides a natural habitat for orangutans and other local wildlife (Bakar et al., 2016; Teo et al., 2019). However, it is not a zoo but shelters threatened species in big, enclosed forest regions or in large cages. The orangutan adoption programme, which teaches juvenile orangutans that have been orphaned or rescued from captivity how to thrive in the wild, is the centre's major appeal. It is a specific facility where endangered animals like orangutans are rehabilitated and released back into the wild. Other than seeing animals in the centre, there are a series of tide pools, a swimming zone, picnic spots, camping grounds, scenic trails, three cascades, an observation area, and semi-wild animal habitats. At Matang Wildlife Centre, ecotourism projects such as Heart to Heart with Orang Utan and the Orang Utan Junior Programme are being carried out (Abang Abdurahman et al., 2021; Sarawak Forestry Corporation, 2024).

Gunung Mulu National Park is a national park located in Miri Division, Sarawak, Malaysia, and is Sarawak's second tallest mountain. MASwings, a Malaysian Airlines subsidiary, offers flights to Mulu and there is a daily direct flight from Kuching that takes one hour and 35 minutes. Mulu National Park is the world's most researched tropical karst region. It boasts 295 kilometres of caverns that have been explored and are home to a multitude of bats and swiftlets. The national park is 100 kilometres (330,000 feet) from Brunei and is between the headwaters of the Tutoh and Mendalam rivers, the latter which is a branch of the Limbang rivers (WWF, 2017; Sarawak Forestry, 2024; Gunung Mulu National Park [GMNP], n.d.). The park's western side is lowland (38% of the park), while its eastern side is limestone and sandstone ridges. The park has 52,000 hectares of primary rainforest and is dominated by three mountains; Mount Mulu [2,376 m (7,795 ft)], Mount Api [1,750 m (5,740 ft)], and Mount Benarat [1,858 m (6,096 ft)]. Mulu has 15 distinct types of forest, including mixed dipterocarp, heathland, swamp forest, byophyte forest, and highland flora, as well as hundreds of species of floras, making it as diverse as its cave system. Different faunal species may also be found inhabiting in the park (Hazebroek et al., 2001; Fukuyama et al., 2021).

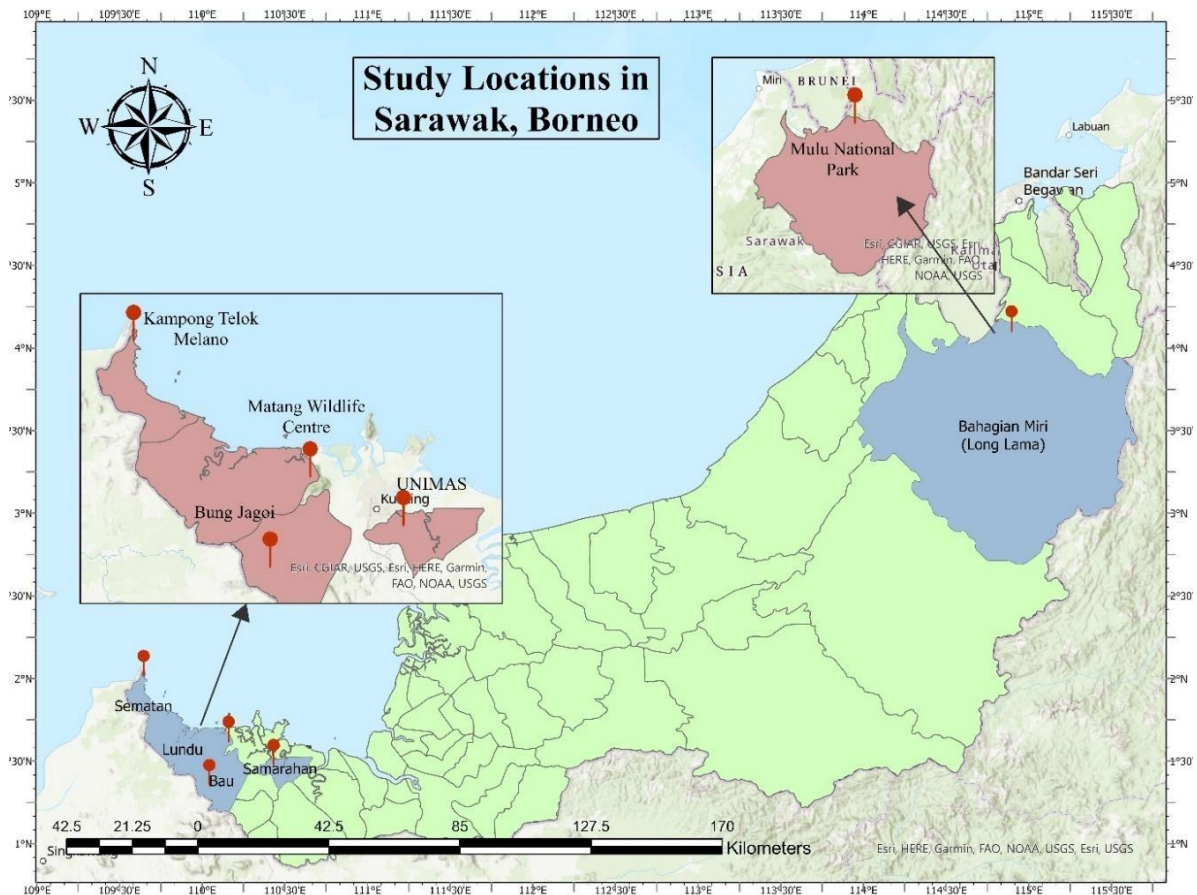


Figure 3.1: Study locations in Sarawak, Borneo generated by ArcGIS Pro 3.0.1

Sampling also took place in Bung Jagoi, which is in the Jagoi-Bratak district of Bau, Sarawak, in the westernmost part of Borneo. Bung Jagoi is hours' drive from Kuching city and lies close to the Malaysia-Kalimantan, Indonesia border. Bung means 'peak' in Bidayuh Bau dialect; hence the region is near the hilltop, approximately 280 metres above sea level, and surrounded by a 500-hectare of mixed dipterocarp forest (Campbell & Mikeng, 2021; Nelson et al., 2023). The residents of Bung Jagoi (i.e., Bijagoi community) flourished by growing vegetables and fruits on the fertile area around them. However, as their population grew, as did their desire for additional agricultural land, the people began to migrate out of Bung Jagoi and established the settlements of Stass, Serasot, Serikin, Duyoh, and Skibang. Aside from cultural exploration, Bung Jagoi attracts individuals who want to go for mountain

trekking as it is relatively easy to climb. The beautiful panoramas of the jagoi area created the perfect backdrop for the sunset view by walking for another 15 minutes from the old village of Bung Jagoi to the summit, Bung Tsen (Sarok & Britin, 2016).

Universiti Malaysia Sarawak (UNIMAS) West Campus was also chosen as a sampling site in this study. Sampling was only done around large clearing areas within the campus, such as the area near Allamanda Blue Cafe, UNIMAS Sports Complex (football field and behind the tennis court), around the side of the UNIMAS lake, and around the small natural pond before Pusat Islam Tun Abg Salahuddin (PITAS), UNIMAS near the golf course.

Kampung Telok Melano is also one of the non-protected areas sampled for this study. It is located 33.7 kilometres from Sematan and 140 kilometres from Kuching. With the neighbouring Tanjung Datu National Park and Samunsan Wildlife Sanctuary, which provides a spectacular view of the beach and the South China Sea's azure waters, it has a potential for ecotourism. Sampling was done at a villager's banana plantation, along the main road of Telok Melano, and around the Telok Melano Village, involving a large clearing of football field and temporary ponds.

3.2 Sampling Periods

Data on Bornean frogs were collected from five locations/sites throughout Sarawak, Borneo. A total of five field trips were made from November 2022 until May 2023. The breakdown of time spent in sampling at each location is displayed in Table 3.1, including the four protected areas.

Figure 3.3 portrays the sampling site in Bung Jagoi from 5th – 10th November 2022. The first night (5th November) was sampled around the side stream (**Figure 3.2 (A)**) and in

an oil palm plantation in Kampung Sigon Duyoh. On the 6th November, sampling was done at the Upstream of Bung Jagoi. 7th November was sampled along the Bung Jagoi Trail (**Figure 3.2, (B)**), and 8th November was sampled around the Fish Pond behind the Homestay of Sigon Duyoh, Bau. Sampling was not able to be conducted on the 9th November because it was raining heavily. Sampling in Matang Wildlife was supposed to be conducted from 12th – 16th December 2023, however, only 3 days of sampling (12th – 14th December) was only able to cover due to bad weather conditions.

For UNIMAS West Campus, sampling was only able to be conducted from 3th – 5th January 2023 around Kolej Allamanda, UNIMAS Sports Complex, and around the small natural pond before Pusat Islam Tun Abg Salahuddin (PITAS), UNIMAS near the golf course. Sampling around Kampung Telok Melano was conducted from 26th February – 3rd March 2023 but was only able to go sampling for 3 nights (27th February, 1st and 2nd March 2023) due to a seriously bad weather condition. Figure 3.4 depicts the sampling site in Mulu National Park from 9th – 15th May 2023. On the first night (9th May) was sampled around the Forbidden Night Trail in the HQ area. 10th and 11th May were sampled at Camp 1 Trekking Trail and Camp 1, Upstream (**Figure 3.3 (A)**). Hiking from HQ to Camp 1 and vice versa was three hours hike long. 12th May was sampled around the Botanical Garden Trail in HQ, and on the 13th May was sampled around the Mulu Village outside the National Park. On the last night of sampling (14th May), sampling was done around the Long Iman Village (**Figure 3.3 (B)**).

Table 3.1: The study location of study and sampling period of Bornean frogs from November 2022 to May 2023 in Sarawak, Borneo

No	Location	Coordinates	Date	
			Start	Finish
1	Bung Jagoi, Bau	1.3464° N; 110.0437° E	5 November, 2022	10 November, 2022
2	Matang Wildlife Centre, Lundu	1.6094° N; 110.1602° E	12 December, 2022	16 December, 2022
3	UNIMAS West Campus, Samarahan	1.4677° N; 110.4319° E	3 January, 2023	5 January, 2023
4	Kampung Telok Melano, Sematan	2.007 ° N; 109.6460° E	26 February, 2023	3 March, 2023
5	Mulu National Park, Long Lama, Miri	4.0921° N; 114.8959° E	9 May, 2023	15 May, 2023

The relatively short sampling duration of under 30 days was primarily due to logistical and environmental constraints. Fieldwork also started later than expected because research permits were only approved toward the end of the first year of the program, leaving less time to complete the study. The field sampling mostly took place during Sarawak's monsoon season (between November and March), when heavy rain frequently interrupted plans, resulting in only a few nights of each scheduled trip. This also caused extended visits a challenge due to the weather. Furthermore, limited funding and permit limitations on specific areas restricted the ability to spend more time in the field.



Figure 3.2: (A) Side Stream Picnic Area; (B) Bung Jagoi Trail in Mount Bung Jagoi

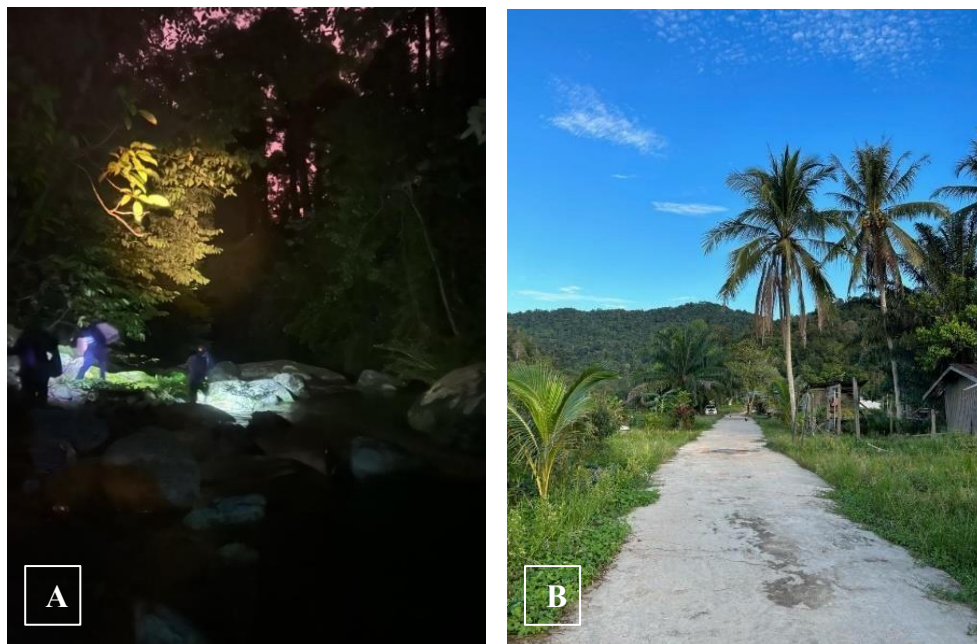


Figure 3.3: (A) Camp 1, Upstream, Mulu National Park; (B) Kampung Long Iman, Mulu

3.3 Sampling Methods

3.3.1 Sampling Techniques

Every individual anuran species was collected from the study sites during these samplings via stream line transect and established sampling techniques, including visual encounter survey (VES) with headlamps (Heyer et al., 1994) and acoustic encounter survey (AES). Stream line transects were mainly linear and occasionally following stream banks by walking down the line with set sections of five metres on both sides of the transects, observing and searching for anurans with the aid of headlamps or torchlights. Individuals were caught by hand on the forest floor, on rock, and on tree branches based on sightings and vocalization. No transects were created in the two National Parks (Matang Wildlife Centre and Mulu National Park) where existing park pathways were utilised, given the lack of human habitation.

Sampling was conducted at night, between 1830 and 2300 hours, but sometimes depending on the weather conditions. Locations of study sites, trails and individuals found during sampling were recorded using the Global Positioning System (Garmin GPS 78s), as shown in Figure 3.4, which is equipped with a barometric altimeter that give elevation information. Ecological details, such as place, date and time of capture, and habitat specifics were recorded for each collected frog using Heyer et al. (1994) techniques. Every individual captured were transferred into plastic bags to be taken back to the base camp for further identification and measurement where information will be recorded into a datasheet.



Figure 3.4: Handheld Global Positioning System (Garmin GPS 78s)

3.3.2 Handling and Identification

Species identification of the frogs captured were done with the aid of ‘A Field Guide to the Frogs of Borneo’ book by Inger et al. (2017). There are also several ways to tell apart male and female frogs. In most frog species, the female is bigger and heavier than the male. Females oversee holding the eggs, and larger females may hold more eggs (possibly resulting in more offspring) (Bridges, 2000). Singing is among the most noticeable differences between males and females. Males call and females are a mute in almost every frog species. According to Legett et al. (2019), male frogs call from strategic locations to entice female frogs, who select the most appealing caller and move towards them.

The throats of certain frogs may also be used to determine their sex. Many species have males who expand their throats when inflating their vocal sacs. As a result, when males are not calling, they have noticeable thin, saggy skin on their neck that is often coloured differently than the ventral side of the body (Starnberger et al., 2013). Looking at the nuptial pads is another approach to determine the sex of frogs. During the mating season. Several

species of male frogs develop an enlarged thumb with a patch of rough skin called the nuptial pad, which aids the male frog in clinging tightly to the female, a behaviour known as amplexus (Lentini, 2013).

Additionally, each collected frog individuals were measured using a digital calliper, specifically the snout-vent length (SVL; snout to the posterior margin of the vent) and the tibia length (TL) to the nearest 0.01mm (Wartenberg et al., 2017). Body mass (W; to the closest 0.01g) was measured with a digital balance to estimate the body size range of both juveniles and adults (Brodeur et al., 2022).

3.3.3 Environmental Parameters

Temperature influences the physiological function and affects individuals behavioural and ecological performance, therefore assessing a frog's body temperature by obtaining measurements from its external skin temperature can give useful insights into its thermal physiology (Navas et al., 2008). During sampling before capturing the frog individuals by hand, temperature of frogs was determined by the infrared thermometer (Extech 42510A Wide Range Mini Infrared Thermometer), as shown in Figure 3.5. Body temperatures of frog individuals were measured to the nearest 0.1°C at the dorsal part of the body. After successfully taking the frog's body temperature, the infrared laser thermometer was then used to capture substrate temperatures that are directly in contact with the frog individuals (e.g., ground, rocks, plant leaves).

Ecological parameters can also affect frogs' behaviour and physiology. Frog's skin moisture, respiration and hydration are all affected by humidity conditions. According to Feder (1992), frogs' skin is porous, allowing them to exchange moisture with their surroundings. To escape desiccation, frogs may become nocturnal in drier settings, and much

more active during the day in wetter circumstances. High ambient temperatures improve frog performance but causes significant water loss. However, low temperatures produce sluggish desiccation, which might impair their effectiveness. This is because temperature influences their metabolic rates, activity levels, and overall behaviour (Hertz et al., 1993). Artificial light pollution (e.g., street lamps, illuminated signboards) can interfere with natural behaviours and cycles, potentially influencing mating calls, predation risks, and other behaviours in frogs (Rich & Longcore, 2013).

Figure 3.6 shows the environmental meter and a thermocouple that are used to measure ecological parameters during the research sampling. Ecological parameters such as humidity, ambient temperature, and light intensity of the spot the individual was found resting or calling on in this study were measured with the environmental meter (Extech 45170 4-in-1 Environmental Meter) (**Figure 3.6 (A)**) after every individual captured. Additionally, by plugging the Type K thermocouple (**Figure 3.6 (B)**) into the environmental meter, high temperature measurements of holes of tree, burrows, in pitcher plants, or in pipe holes can be made.



Figure 3.5: Extech 42510A Infrared Thermometer



Figure 3.6: (A) Extech 45170 4-in-1 Environmental Meter; (B) Type K Thermocouple

3.3.4 Microhabitat Characteristics

Anurans are often scattered randomly within a habitat, especially in complex ecosystems. Individual anurans can be found in microhabitats within the broader environment. Zimmerman and Bierregaard (1986) assert that recording microhabitat data for each individual anuran seen is important because some anuran species that are limited to specific microhabitats might have significant conservation consequences.

Four microhabitat attributes of each individual observed during sampling are described according to the environmental feature checklist seen in Table 3.2. Vegetation type is recorded based on the type of habitat the individual was found in, such as in what kind of primary or secondary forest it was found in, in agricultural area or in large clearings. The horizontal position refers to the distance the individuals were found in from any water sources. Vertical position refers to the height of the individuals found above ground, for example when they are found on leaf of plants, on fallen tree trunk, or on rock. It is also

noted the type of substrates the individuals were found resting or calling on, such as on soil, dead leaves, on leaf of seedling or plant, on rocks and many more.

Table 3.2: Characteristics of microhabitat checklist (Inger's Habitat Code in Hayer et al., 1994)

Characteristics	Codes	Notes
Habitat: Vegetation type	VA	Primary rain forest, hilly
	VB	Primary rain forest, flat
	VC	Deciduous dipterocarp
	VW	Peat swamp
	VK	Kerangas
	VRF	Riverine forest
	Vagr	Agriculture
	VS	Marsh
	VE	Edge MDF
	VF	Large clearing (camp etc.)
	VG	Secondary growth, immature or regenerating forest
	VH	Gallery forest
	VJ	Selectively logged forest
	VRF	Rubber or oil palm planting
	VT	Oak/ chestnut montane forest
Microhabitat: Horizontal position	HPA	Permanent stream: In stream (in water)
	HPB	Permanent stream: Midstream on bar, rock, or snag
	HPC	Permanent stream: On bank (distance to water)
	HPD	Intermittent stream: In stream (in water)
	HPE	Intermittent stream: Midstream on bar, rock or snag
	HPF	Intermittent stream: On bank (distance to water)
	HPG	Distant from any water body, distance (m) to nearest stream
	HPH	In dried bed of intermittent stream
	HPJ	Temporary pond: In water
	HPK	Temporary pond: On bank, distance (m) from water
	HPL	Temporary pond: On vegetation
	HPM	Permanent stream: On exposed bed, distance (m) from water
	HPN	Permanent pond
	HPP	Permanent swamp
	HPQ	On or in building
	HPR	Permanent pond: On bank, distance (m) to water
	HPS	Permanent swamp: In water
	HPT	Permanent stream: On vegetation
	HPU	Permanent drainage: In plantation, on bank
	HPV	Permanent drainage: In plantation, in water

Table 3.2 continued

Microhabitat: Vertical position	VPA	Under surface of soil: Depth (cm)
	VPB	In or under dead leaves
	VPC	Under rock: Maximum dimension (cm) of rock
	VPD	Under log: Diameter (cm) of log
	VPE	In log: Diameter (cm) of log
	VPF	On surface of bare soil
	VPG	On surface of leaf litter or dead leaves
	VPH	On rock: Maximum dimension (cm) of rock
	VPJ	On log: Diameter (cm) of log
	VPK	On seedling or herbaceous plant: < 1m tall
	VPL	On shrub or young sapling (plant 1-7 m): Height (m) above ground
	VPM	On tree or large vine (plant > 7 m): Height (m) above ground or water, at breast height DBH) of woody plant
	VPN	On dead stump: Height (m) above ground
	VPO	In crown of fallen dead shrub or tree: Height (m) above ground
	VPQ	On grass blade: Height (m) above ground
	VPP	In grass
Microhabitat: Substrate	SA	Leaf of plant: Maximum dimensions (cm) of leaf
	SB	Stem or branch of herbaceous plant
	SC	Twig or branch of woody plant: Diameter (cm) of perch
	SD	Trunk of shrub or tree
	SE	In epiphyte
	SF	Under bark of log, stump, or tree
	SG	Bank mud
	SH	Bank sand or gravel
	SJ	Bank rock

3.4 Statistical Analyses

Data analysis used descriptive and inferential statistics to investigate connections between body temperature, environmental conditions, and microhabitat factors, as well as to create species distribution models. IBM SPSS version 26 and RStudio were used for the analyses, while MaxEnt version 3.4.4 and ArcGIS Pro 3.0.1 were used for modelling and visualisation. The upcoming chapters of this study (Chapter 4, Chapter 5, and Chapter 6) include detailed descriptions of the analytical techniques.

CHAPTER 4

FIELD BODY TEMPERATURE OF BORNEAN FROGS OF 5 STUDY

LOCATIONS

4.1 Introduction

Ectothermic animals have evolved unique mechanisms for regulating their body temperatures, which they rely on both behavioural and physiological adjustments to adapt to their environmental condition (Huey & Kingsolver, 1989). The foundation for further research on habitat and environmental factors was laid by Brattstrom's (1963) pioneering review, which first emphasised the significance of body temperature data in understanding amphibian thermoregulatory techniques. Building on this basis, the current chapter examines Bornean frogs' field body temperatures un various habitat types. Temperature has shown to have major effects on anurans, including metabolic rate regulation (Pough et al., 2007), control in activity and behaviour (Huey & Slatkin, 1976), growth and development (Angilletta Jr, 2009), anuran reproduction (Shine, 2003), and physiological performance (Hochachka & Somero, 2002). Anurans exhibit varying degrees of temperature sensitivity in relation to their physiological activities (Martin & Huey, 2008). Throughout their life stages, anurans may encounter different microenvironments and experience fluctuations in body temperature, which can influence their physiological functions (Colinet et al., 2015; Levy et al., 2015). Additionally, continuous contact with specific thermal conditions can impact the temperature-related reactions of physiological activities in anurans, potentially resulting in illness, especially in elevated temperature conditions (Kingsolver & Woods, 2016).

Amphibians stand as one of the most imperilled animal species on a global scale, facing unparalleled rates of decline over the past few decades (Stuart et al., 2004). The thermal physiology of amphibians is affected by global anthropogenic change (Katzenberger et al., 2014; Quiroga et al., 2019), as the greenhouse effect intensifies, contributing to global warming, there is a swift increase in the overall global temperature. Recent research indicates that the elevated localised heat driven by deforestation and global warming in Borneo are leading to a rise in global temperature (Dungey, 2021). Recent studies show that over 34% of Borneo's old-growth forests were lost between 1973 and 2015, with an average deforestation rate of approximately 0.25 million hectares per year, and Sarawak lost about 80% of its primary forest during this time (Gaveau et al., 2016; Gaveau et al., 2019, as cited in Keuffner, 2023; Mohd-Azlan et al., 2023). Temperature fluctuations can also be caused by a variety of variables, including geographic location, elevation, proximity to bodies of water, plant cover, and local weather patterns (Callendar, 1961).

Sarawak is renowned for its vast and diverse forests, each possessing distinctive ecosystem attributes and abundant biodiversity (Choy, 2014). Sarawak encompasses a variety of forest and vegetation categories that are widely acknowledged, encompassing tropical rainforests, peat swamp forests, mangrove forests, hill dipterocarp forests, kerangas forests, montane forests, limestone forests, freshwater swamp forests, and secondary forests (Forest Department Sarawak, 2020). For this study, we only sampled around the lowland mixed dipterocarp forests of Mount Bung Jagoi, Matang Wildlife Centre, and Mulu National Park, while we sampled in an open field for West Campus, UNIMAS, and Kampong Telok Melano.

4.1.1 Problem Statement

Borneo's ecosystem is facing significant changes due to rising temperatures, deforestation, and land-use changes, which collectively impact biodiversity, particularly ectothermic species like frogs. Recent studies have shown an increase in land surface temperature (LST) on Borneo Island, rising by approximately 0.2 °C per decade, with deforestation intensifying regional temperature fluctuations (Wolff et al., 2018). These temperature fluctuations can cause thermal stress, influencing frog growth and survival (Burraco et al., 2020). Additionally, deforestation has reduced habitat connectivity by 35%, isolating species and hindering adaptation to climate change (Scriven et al., 2017). For ectotherms, higher temperatures may boost growth, but prolonged exposure to extreme conditions can result in lethargy or death (Burraco et al., 2020). Despite the increasing concern over these environmental shifts, the impact of temperature changes on the body temperature and health of Bornean frogs remains understudied. This underscores the need for targeted research on how land-use change and climate change jointly affect temperature regulation in Bornean frog's diverse species.

4.1.2 Research Questions

This research sought to address the following questions:

- i. Does body temperature of Bornean frogs vary across different habitat types (e.g., lentic, lotic, and terrestrial)?
- ii. How are the body temperatures of frogs influenced by their surrounding habitat conditions, and what might this suggest about potential physiological constraints?

To explore these research questions, the aims of this study were to:

- i. Evaluate the body temperatures of Bornean frogs and their correlation with different habitat types (e.g., lentic, lotic, and terrestrial).
- ii. Investigate how habitat-associated temperature differences may reflect potential physiological pressures faced by frogs in these environments.

4.2 Materials and Methods

4.2.1 Study Locations and Sampling Methods

Five field study locations across Sarawak, East Malaysia (Northwestern Borneo) were included in this study: Bung Jagoi (Bau), Matang Wildlife Centre (Lundu), UNIMAS West Campus (Samarahan), Kampung Telok Melano (Sematan), and Mulu National Park (Bahagian Long Lama, Miri). Geographic coordinates and detailed site descriptions can be found in Section 3.1 (see **Figure 3.1**; **Table 3.1**).

Field sampling, thermal and ecological measurements analysed in this chapter were obtained following the procedures described in Section 3.3. Body temperatures (T_b), substrate temperature (T_s), ambient temperature (T_a), and humidity (RH) were recorded for each individual using the instruments detailed in Chapter 3.

This study evaluated the body temperatures of 261 individuals from 40 distinct frog species across five research sites in Sarawak. Samples represented various habitats: terrestrial, arboreal, and semi-aquatic. Frogs were categorised into several habitat and substrate groups according to the location and conditions of observation, as follows:

Based on the specific circumstances in which they were located, frogs were divided into three sorts of habitat, which are flowing water, non-flowing water, and non-aquatic. If located in the water itself or within one metre of a water source, frogs were classified under

flowing water or non-flowing water. Frogs were placed in the non-aquatic region if they were found far from any water body, often more than 100 metres away.

Depending on the substrate that a frog was sitting on, several kinds of substrates were allocated to them, which are aquatic (in-water) and non-aquatic (out-of-water). Frogs in the non-aquatic habitat category were all counted in the non-aquatic substrate category, but frogs in the flowing water and non-flowing water habitat categories might be in either the aquatic or non-aquatic substrate categories.

4.2.2 Data Analysis

The relationship between body temperature (T_b) and environmental variables, including substrate temperature (T_s), ambient temperature (T_a), and relative humidity (RH), including mean temperature, standard deviation, and variances were analysed with IBM SPSS version 26 (IBM Corp, 2019). The changes of these variables were used to examine how it affects body temperatures of frogs that were recorded during sampling. Pearson's correlation coefficient analysis, in IBM SPSS version 26 was used to test the autocorrelation of dependent variables (e.g., T_b) with independent variables (e.g., T_s , T_a , and RH) of different habitat types. Pearson's correlation coefficient was used because the indicators selected in this study follow a Gaussian or normal distribution.

Since frogs generally exhibit a narrow range of body temperatures, all temperature and humidity variables (T_b , T_s , T_a , RH) were log10-transformed to improve linearity and normalise residuals before regression analysis. Linear regression models were performed to assess the strength of the relationship between T_b and predictor variables. When subjected to modelling, the degree of thermoregulation is determined by the gradient of the linear correlation between the external temperature and body temperature ($0 \leq k \leq 1$). A value of k

= 0 signifies an ideal thermoregulator, whereas a value of $k = 1$ indicates an ideal thermoconformer (Huey & Slatkin, 1976; Angilletta Jr, 2009).

4.3 Results

4.3.1 Number of Individuals Found

Figure 4.1 and Table 4.1 represent a total of 261 frog individuals from 40 different species of six families were found and recorded during sampling in 2022/2023. About 27.20 % ($n = 71$) of the total species were primarily represented by family Dicroglossidae, with family Ranidae accounting for 21.84 % ($n = 57$), family Bufonidae for 21.07 % ($n = 55$), family Rhacophoridae for 19.92 % ($n = 52$), family Megophryidae for 5.36 % ($n = 14$), and family Microhylidae for 4.60 % ($n = 12$). *Fejervarya limnocharis* (Grass Frog) from family Dicroglossidae was found the most abundant individual in five locations (11.49 %; $n = 30$), followed by *Polypedates leucomystax* (Four-lined Tree Frog) from family Rhacophoridae (10.3 %; $n = 27$), and *Duttaphrynus melanostictus* (Common Sunda Toad) from family Bufonidae (9.96 %; $n = 26$).

Twenty species discovered during the 2022/2023 sampling period are endemic to the Borneo region, including *Ansonia spinulifer*, *Ingerophrynus divergens*, *Phrynoidis juxtasper*, *Fejervarya cancrivora*, *Limnonectes ibanorum*, *Limnonectes ingeri*, *Limnonectes leporinus*, *Occidozyga baluensis*, *Leptobrachium abbotti*, *Leptolalax fritinniens*, *Leptolalax gracilis*, *Kalophrynus meizon*, *Microhyla borneensis*, *Huia cavitympanum*, *Chalcorana megalonesa*, *Chalcorana raniceps*, *Meristogenys jerboa*, *Staurois guttatus*, *Staurois latopalmaris*, and *Philautus tectus* (Inger et al., 2017).

All frog species in Sarawak, Borneo, except for one, were categorized as least concern (LC) in the IUCN Red List Category, 2023. *Meristogenys jerboa* stands out as the

only species classified as vulnerable (VU) from 2004 to 2023. Nine species, including *Ansonia spinulifer*, *Limnonectes ibanorum*, *Limnonectes ingeri*, *Limnonectes malesianus*, *Limnonectes paramacrodon*, *Occidozyga baluensis*, *Leptolalax gracilis*, *Nyctixalus pictus*, and *Philautus tectus*, held the classification of near threatened (NT) until the year 2018 to 2022. Subsequently, their conservation status evolved, with updated assessments reflecting changes in their threat levels or vulnerability in subsequent years.

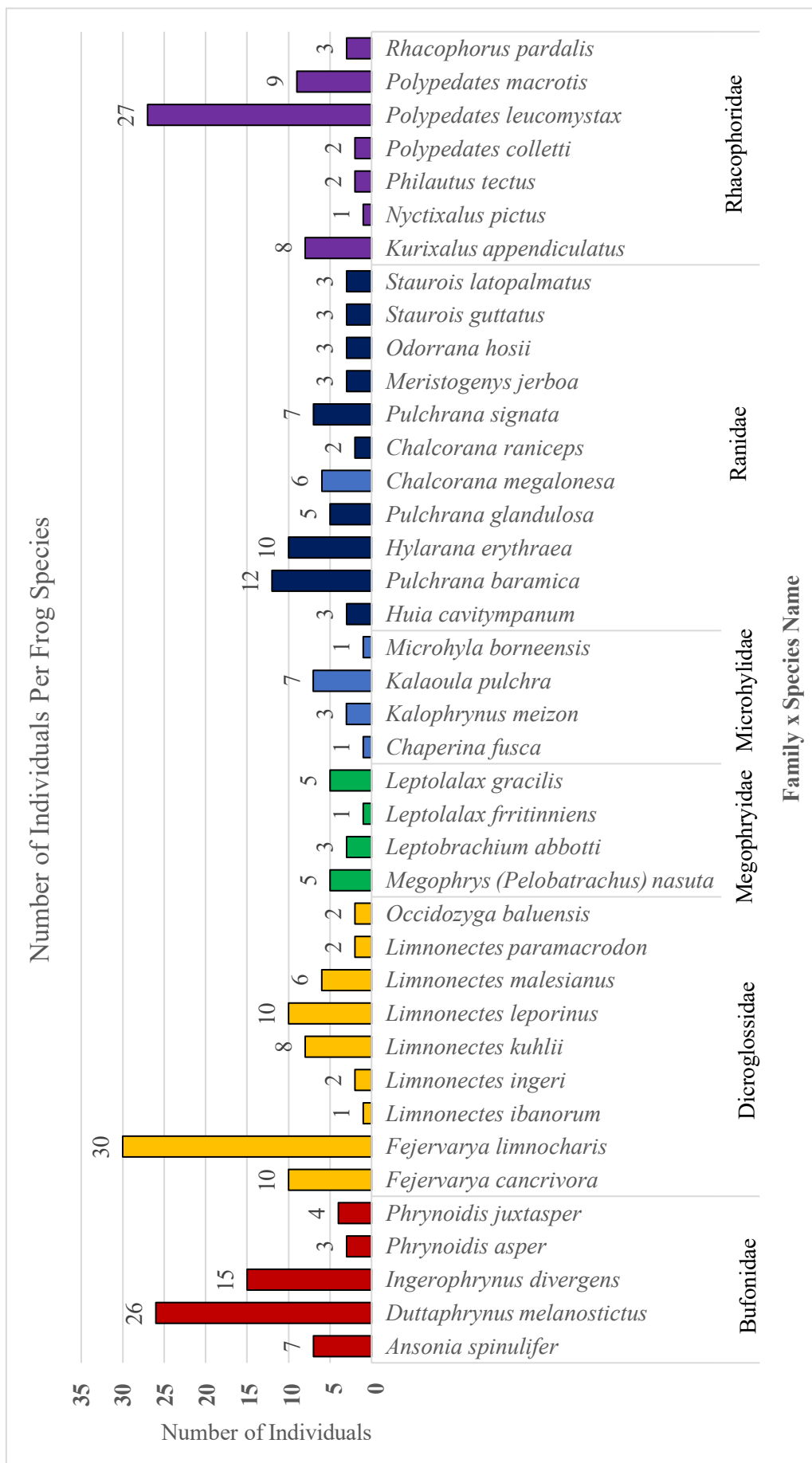


Figure 4.1: Number of individual frog species found during sampling in Sarawak, Borneo 2022/2023

Table 4.1: Number of individual frog species found sampled in Sarawak, Borneo

Family	Species Name	No. of individuals	IUCN Status 2025	Species Distribution
Bufonidae	<i>Ansonia spinulifer</i> *	7	Least Concern	Endemic
	<i>Duttaphrynus melanostictus</i>	26	Least concern	Widely distributed
	<i>Ingerophrynus divergens</i> *	15	Least Concern	Endemic
	<i>Phrynoidis asper</i>	3	Least Concern	Widely distributed
	<i>Phrynoidis juxtasper</i> *	4	Least Concern	Endemic
Dicroglossidae	<i>Fejervarya cancrivora</i> *	10	Least Concern	Endemic
	<i>Fejervarya limnocharis</i>	30	Least Concern	Widely distributed
	<i>Limnonectes ibanorum</i> *	1	Least Concern	Endemic
	<i>Limnonectes ingeri</i> *	2	Least Concern	Endemic
	<i>Limnonectes kuhlii</i>	8	Least Concern	Widely distributed
	<i>Limnonectes leporinus</i> *	10	Least Concern	Endemic
	<i>Limnonectes malesianus</i>	6	Least Concern	Widely distributed
	<i>Limnonectes paramacrodon</i>	2	Least Concern	Widely distributed
	<i>Occidozyga baluensis</i> *	2	Least Concern	Endemic
Megophryidae	<i>Megophrys nasuta</i>	5	Least Concern	Widely distributed
	<i>Leptobrachium abbotti</i> *	3	Least Concern	Endemic
	<i>Leptolalax fritinniensis</i> *	1	Data Deficient	Endemic
	<i>Leptolalax gracilis</i> *	5	Least Concern	Endemic
Microhylidae	<i>Chaperina fusca</i>	1	Least Concern	Widely distributed
	<i>Kalophrynus meizon</i> *	3	Least Concern	Endemic
	<i>Kaloula pulchra</i>	7	Least Concern	Widely distributed
	<i>Microhyla borneensis</i> *	1	Least Concern	Endemic
Ranidae	<i>Huia cavitympanum</i> *	3	Least Concern	Endemic
	<i>Pulchrana baramica</i>	12	Least Concern	Widely distributed

Table 4.1 continued

	<i>Hylarana erythraea</i>	10	Least Concern	Widely distributed
	<i>Pulchrana glandulosa</i>	5	Least Concern	Widely distributed
	<i>Chalcorana megalonesa</i> *	6	Least Concern	Endemic
	<i>Chalcorana raniceps</i> *	2	Least Concern	Endemic
	<i>Pulchrana signata</i>	7	Least Concern	Widely distributed
	<i>Meristogenys jerboa</i> *	3	Vulnerable	Endemic
	<i>Odorrana hosii</i>	3	Least Concern	Widely distributed
	<i>Staurois guttatus</i> *	3	Least Concern	Endemic
	<i>Staurois latopalmatus</i> *	3	Least Concern	Endemic
Rhacophoridae	<i>Kurixalus appendiculatus</i>	8	Least Concern	Widely distributed
	<i>Nyctixalus pictus</i>	1	Least Concern	Widely distributed
	<i>Philautus tectus</i> *	2	Least Concern	Endemic
	<i>Polypedates colletti</i>	2	Least Concern	Widely distributed
	<i>Polypedates leucomystax</i>	27	Least Concern	Widely distributed
	<i>Polypedates macrotis</i>	9	Least Concern	Widely distributed
	<i>Rhacophorus pardalis</i>	3	Least Concern	Widely distributed
Total species		40		
Total individuals		261		

*Species endemic to Borneo based on Inger et al. (2017)

4.3.2 Temperature Ranges of Bornean Frogs and their Habitat Types

Table 4.2 presents the correlation between frog body temperature and environmental factors, including substrate temperature (T_s), ambient temperature (T_a), and relative humidity (RH). Table 4.3 further details the correlation between: T_b and T_s , T_b and T_a , T_b and RH, providing y-intercept (c), slope (k), and coefficient of determination (r^2).

Regression analysis using log10-transformed data showed that T_b was strongly predicted by substrate temperature (T_s), with an r^2 value of 0.963 (**Table 4.3, Figure 4.2 A**). In contrast, regressions with ambient temperature (T_a) and relative humidity (RH) were weak ($r^2 < 0.05$; **Figures 4.2 B and C**), indicating that these variables contributed little to variation in frog body temperatures.

Pearson's correlation coefficients (r) (**Table 4.2**) showed a consistently strong positive relationship association between T_b and T_s across all three habitat types; flowing water = 0.992, non-flowing water = 0.903, non-aquatic = 0.940, further supporting the regression analysis. In contrast, relationships between T_b and T_a , as well as between T_b and RH, were weak and inconsistent, with no clear patterns across habitats.

These findings show that in Bornean environments, substrate temperature is the main factor influencing frog body temperature, with humidity and ambient temperature having little to no influence. This pattern shows how frogs' thermoregulation is highly dependent on the conditions of their immediate substrate rather than broader environmental factors.

Table 4.2: The autocorrelation between dependent variable (body temperature, T_b) and independent variables (substrate temperature, T_s ; ambient temperature, T_a ; humidity, RH) with Pearson's correlation coefficient, r

Habitat Types	Pearson's correlation coefficient, r		
	T_b & T_s	T_b & T_a	T_b & RH
Flowing water	0.992*	-0.189	0.523
Non-flowing water	0.903*	-0.143	-0.143
Non-aquatic	0.940*	0.102	0.348

*Variables with strong positive correlation

Table 4.3: Results of linear regression analysis between log10-transformed frog body temperature (T_b) and environmental variables (substrate temperature, T_s ; ambient temperature, T_a ; humidity, RH)

Variables	Slope-intercept form		
	y-intercept, c	Slope, k	R^2 Linear, r^2
T_b vs T_s	0.04	0.97	0.963
T_b vs T_a	1.38	-1.51E-03	7.82E-07
T_b vs RH	1.09	0.07	0.022

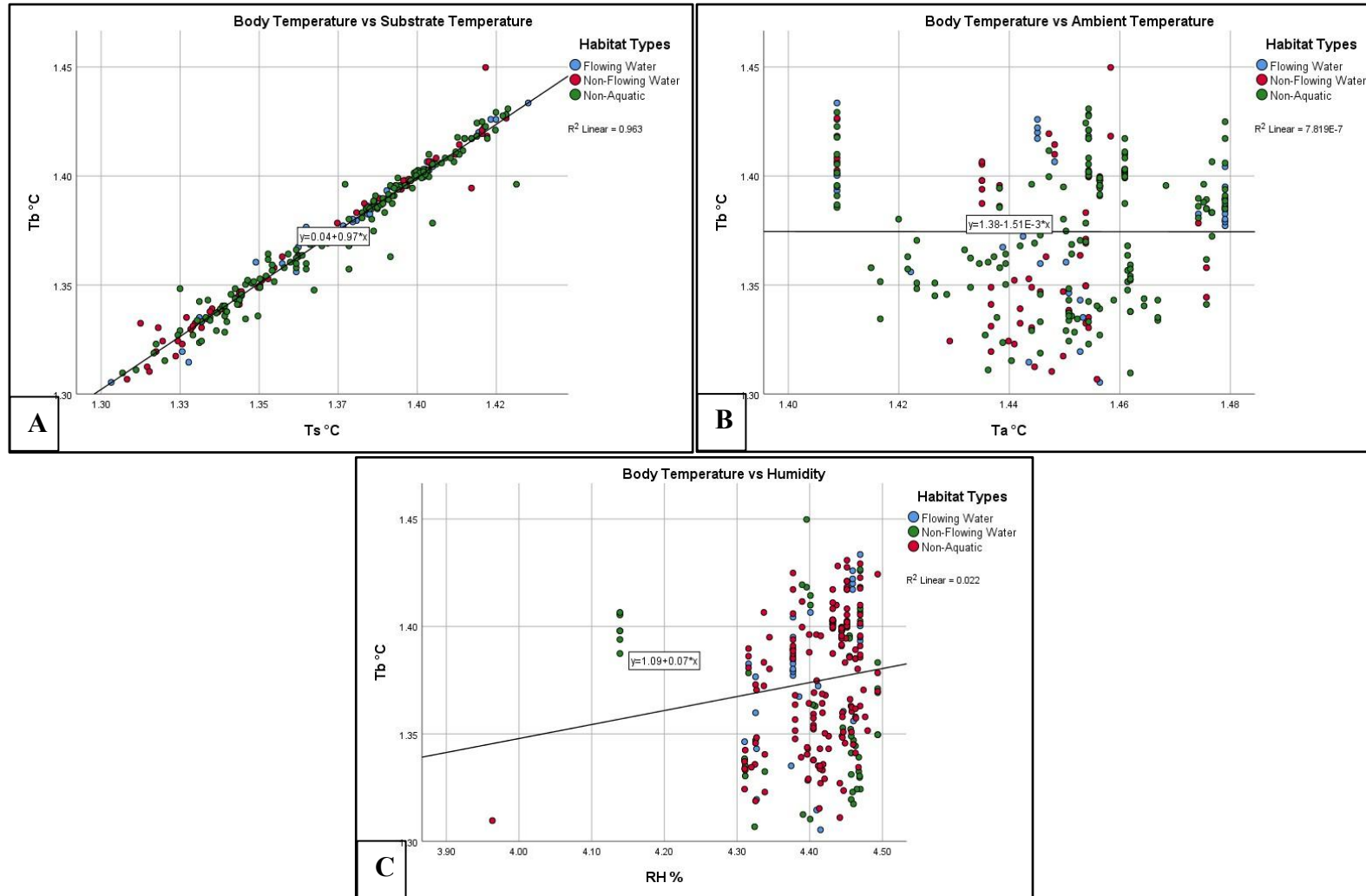


Figure 4.2: The interplay of Bornean frog body temperatures and independent variables are depicted graphically in three distinct environments is shown; flowing water (blue), non-flowing water (green), and non-aquatic (red): (A) T_b vs T_s ; (B) T_b vs T_a ; (C) T_b vs RH

Table 4.3 summarizes body temperature (T_b) and substrate temperature (T_s) across three habitats in Sarawak, Borneo, including mean $\pm$ standard deviation, variance, minimum-maximum ranges, and Pearson's correlation coefficient (r), with all comparisons statistically significant ($p < 0.01$).

The body temperatures (T_b) of frogs across all sites ranged from 19.9 °C to 28.2 °C, with a mean $\pm$ standard deviation of 23.7 °C $\pm$ 1.7 °C. The lowest T_b (19.9 °C) was recorded in a non-aquatic (forested) habitat after a heavy rainfall, while the highest T_b (28.2 °C) occurred in a non-flowing water habitat (temporary pond). These values differed significantly among habitat types ($p < 0.01$), reflecting variation in thermal environments across sites.

The k -value for each habitat type are as follows; flowing water = 1.01, non-flowing water = 0.86, non-aquatic = 0.91. The variance in body temperature (T_b) across habitats was relatively similar, with the highest variance in the non-flowing water habitat (3.7 °C) and lower, comparable variance in flowing water and non-aquatic habitats (both 2.8 °C) (**Table 4.4**).

The substrate temperature (T_s) across three habitats exhibited some variability, with the mean values being similar at 23.7 $\pm$ 1.8 °C. The non-flowing water habitat had the lowest T_s recorded of 18.1 °C, and the highest was found in the non-aquatic habitat at 28.8 °C, shown in **Table 4.4**. The overall variance of T_s was 3.3 °C, with non-flowing water habitats showing the highest variance at 4.2 °C, and lowest in flowing water habitats at 2.7 °C. These patterns were consistent with the observed range of temperatures, with non-flowing water having a broader range of 18.1 °C to 26.8 °C, compared to 20.1 °C to 27.2 °C in flowing water and 20.3 °C to 28.8 °C in non-aquatic habitats.

Table 4.4: Body temperature (T_b) and substrate temperature (T_s) values were acquired from a varied collection of frogs in Borneo, Sarawak, in three habitat types. The correlations between T_b and T_s are shown by ranges with means $\pm$ standard deviations, variances, and Pearson's correlation coefficient (r) and slope value (k). p value < 0.01 was the significance level for each comparison.

Habitat	n	Mean $\pm$ SD T_b ($^{\circ}\text{C}$)	Mean $\pm$ SD T_{subs} ($^{\circ}\text{C}$)	Var T_b	Var T_{subs}	Min-Max T_b ($^{\circ}\text{C}$)	Range ($^{\circ}\text{C}$)	Min-Max T_{subs} ($^{\circ}\text{C}$)	k	r	p value (0.01)
Flowing Water	37	24.1 ± 1.7	24.1 ± 1.7	2.8	2.7	20.2 - 27.1	6.9	20.1 - 27.2	1.01	0.992	$0.000 < 0.01$
Non-flowing Water	69	23.6 ± 1.9	23.4 ± 2.0	3.7	4.2	20.3 - 28.2	7.9	18.1 - 26.8	0.86	0.903	$0.000 < 0.01$
Non-aquatic	155	23.7 ± 1.7	23.8 ± 1.7	2.8	3.0	19.9 - 27.0	7.1	20.3 - 28.8	0.91	0.940	$0.000 < 0.01$

4.4 Discussion

Across the five study sites, 261 individuals representing 40 species from six families were identified and recorded (**Table 4.1**), indicating a comparatively high level of anuran diversity despite the two locations were in protected areas and three in human-modified habitats. However, the assemblage was dominated by disturbance-tolerant species, like *Fejervarya limnocharis*, *Polypedates leucomystax*, and *Duttaphrynus melanostictus*, which are known for their ability to adapt to both agricultural and urban environments (Inger et al., 2017; Licata et al., 2020). The result implies that although semiurban habitats can still sustain a high level of species richness, the community structure is directed towards generalist taxa, with specialists that depend on forests likely underrepresented. In contrast to forested habitats, which maintain higher richness, greater endemism, and more balanced assemblages, previous studies in Borneo consistently demonstrate that oil palm plantations and other non-forest habitats support lower species richness and are dominated by terrestrial, disturbance-tolerant generalist (Gillespie et al., 2012; Konopik et al., 2015; Aguilar-León, 2020).

The mean body temperature recorded across the five study locations was 23.7 ± 1.7 °C, with frogs residing in non-flowing habitats, such as ponds, exhibit higher body temperatures compared to those in stream and terrestrial habitats. This variance suggests that the ecological preferences of Bornean frogs significantly influence their body temperatures, with aquatic habitats buffer temperature fluctuations while terrestrial conditions exposing individuals to a broader range of temperatures based on shade and wetness (Williams & Newbold, 2019). Measuring these patterns contributes in understanding the ecology of frogs and offers insights into how environmental change affect their physiology and survival. These results are consistent from 2013 until 2022 with the body temperatures of other anuran

species that have been recorded in tropical areas (Navas et al., 2013; Rasolonjatovo et al., 2020; Ruthsatz et al., 2022), and highlight the value of thermal data for predicting ecological responses and guiding conservation efforts (Kozak & Wiens, 2010; Lowe, 2012).

This study highlighted habitat-specific variations in thermoregulatory behaviour, particularly using microhabitats and water balance adaptations to regulate body temperatures. For example, individuals were seen in shaded, moist, or aquatic environments to avoid overheating, or basking to raise their body temperature when needed. Compared to terrestrial frogs, aquatic and semi-aquatic species can retain moisture better due to their thinner epidermis and wider intercellular spacing, which allows for higher body temperatures and better locomotor performance (Toledo & Jared, 1993; Mokhatla et al., 2019; Akat Çömnden et al., 2023). This shows how skin structure and hydration state limit their thermoregulation. Conversely, dehydration limits the thermal flexibility of terrestrial species by decreasing their movement and reducing their thermoregulatory choices (Navas et al., 2008; Rozen-Rechels et al., 2019; Ortega et al., 2023). In summary, these results imply that variations in skin physiology and water balance support frogs' ecological strategies in various habitats, consistent with previous findings that their niche specialisation is closely related to their thermoregulatory ability (Schulte, 2015; Sinclair et al., 2016; González-del-Pliego et al., 2020).

The results confirmed that both stream-dwelling and pond-dwelling frogs exhibit thermoconforming behaviour, as their body temperatures closely matched substrate temperatures, reflected in the k-values (**Table 4.4**) for flowing water (1.01), non-flowing water (0.86), and non-aquatic habitats (0.91). Frogs residing in streams showed relatively low body temperature variance (2.8), while those in ponds exhibited the highest variance (3.7), indicating that stream habitats offer a more uniform thermal regime than ponds, which

have stratified conditions with both warm surface layers and cooler substrates. This shows that the buffering effect of water helps maintain stable temperatures and lowers intrapopulation variability for frogs in flowing habitats (von Tschirnhaus & Correa, 2021). Duellman and Trueb (1994) emphasised this stability by noting out that stream frogs spend most of their time in waters that are thermally consistent. In contrast, pond habitats are especially susceptible to warming due to human activity and global warming increase evapotranspiration and surface heat accumulation in small freshwater bodies, as greenhouse gases trap heat in the atmosphere and raise water temperatures (Islam et al., 2012a; Hussain et al., 2021).

Across all three habitats, frog body temperatures (T_b) were strongly and significantly correlated with substrate temperatures (T_s), with Pearson's coefficient of $r = 0.992$ (flowing water), $r = 0.903$ (non-flowing water), and $r = 0.940$ (non-aquatic), all at $p < 0.01$ (**Table 4.2**). This indicates that even small changes in substrate temperature resulted in a direct change in the body temperature of the frog, hence strengthening their dependence on environmental thermal parameters. This significant link between T_b and T_s indicates a thigmothermic tendency, in which frogs passively absorb heat during nocturnal activities by making direct contact with surfaces (Lazcano et al., 2022). Strong correlations like these are consistent with the framework of Huey and Slatkin (1976), who suggested that T_b-T_s comparisons serve as markers of thermoregulatory strategies. Khatiwada et al. (2020) also found that changes in substrate temperature accurately predicted changes in amphibian body temperature.

The highest frog body temperature recorded was 28.2°C in non-flowing aquatic habitats, while the lowest substrate temperature was also recorded in the same habitat type at 18.1°C (**Table 4.4**). The distinct thermal dynamics of non-flowing water bodies, such as

ponds, are shown in this broad range, where limited water flow and depth cause heat to build up at the surface while deeper layers stay colder due to thermal stratification (Bergey, 2024). This stability can support ectothermic frogs' survival and activity under changing environmental conditions by providing both colder refuges to prevent overheating and warm microhabitats to bask in (Evans et al., 2020; González-del-Pliego et al., 2020; Ruthsatz et al., 2022). In contrast, frogs in non-aquatic terrestrial habitats experienced the highest substrate temperatures, up to 28.8°C (**Table 4.4**), due to the intense solar radiation, minimal vegetation cover, and limited moisture, all of which increase heating effects (Inforsato et al., 2019; Dubiner et al., 2024; Ovenden et al., 2021). These results demonstrate habitat-specific extremes influence thermal possibilities and restrictions, with terrestrial habitats exposing anurans to higher levels of desiccation and heat stress whereas ponds provide both risks and refuges based on depth and exposure (Longhini et al., 2021; Brettschneider et al., 2023).

The body temperature of frogs in this study ranged from 19.9°C to 28.2°C across the three habitats (**Table 4.4**). This range partially overlaps with the thermal optimum for the chytrid fungus, *Batrachochytrium dendrobatidis* (Bd), with optimal growth at 17–23°C (Stevenson et al., 2013; Sonn et al., 2017). Frogs in non-flowing aquatic habitats had the highest body temperatures (up to 28.2°C), surpassing Bd's thermal optimum and indicating species that inhabit ponds might be less prone to infection. In contrast, frogs in non-aquatic and stream habitats remained slightly cooler (maximum at 27.0–27.1°C), and those occupying shaded or moist microhabitats may experience body temperatures close to Bd's favourable range, thereby increasing their risk of infection. Previous research shows that chytridiomycosis outbreaks are more severe when host body temperature coincides with Bd's growth optimum, leading to widespread amphibian declines (Stevenson et al., 2013; Stevenson et al., 2020). Through behavioural thermoregulation, such as basking in warmer

spots or shifting microhabitats, tropical frogs can lower their risk of infection. However, the success of this behavioural strategy is dependent on the availability of appropriate thermal microclimates (Richards-Zawacki, 2010; Rowley & Alford, 2013; Beukema et al., 2021). These results highlight the importance of linking frog thermal ecology to disease risk, as even the slightest variation in body temperature can alter susceptibility to infection (Sauer et al., 2018; von May et al., 2018; Rasolonjatovo et al., 2020).

4.5 Conclusion

In conclusion, Bornean frogs use physiological and behavioural methods to regulate their body temperature in response to substrate and ambient temperatures, which helps them survive in the diverse Bornean habitats. Although assemblages were dominated generalists, a comparatively high diversity of 40 species from six families was seen across the five study sites, indicating that specialised forest species are underrepresented in altered habitats. Habitat-associated thermal variations were highlighted with frogs in non-flowing aquatic habitats had higher body temperatures than those in streams and terrestrial habitats. The significant relationship between frog body temperature and substrate temperature illustrates the microhabitat variables influence towards thermal patterns and supports the thigmothermic tendency of frogs. Further research is necessary to compare body temperatures across different elevation zones and diel cycles to better understand species-specific thermal ecology. Lastly, these results emphasise the importance of thermal biology in assessing disease susceptibility, where even slight variations in body temperature may change infection risk, since frog body temperatures primarily overlap with the thermal optimum for *Batrachochytrium dendrobatidis* (Bd).

CHAPTER 5

ECOSYSTEM HEALTH AND MICROHABITAT PREFERENCES OF BORNEAN FROGS

5.1 Introduction

Anthropogenic activities such as forest clearing, urbanisation, pollution, and climate change are the key contributors to declines in animal population and pushing many species toward extinction (Okorundu et al., 2022). Amphibians are among the most threatened classifications, with a 41% global species loss rate due to destruction of habitat and pollution (IUCN, 2024). Wetlands, essential for the breeding and feeding of anurans, are being rapidly destroyed and degraded due to urban and agricultural expansion. This disruption causes reduced population sizes and genetic diversity among frog species. (Becker et al., 2007; Luedtke et al., 2023). Furthermore, pollution from agricultural runoff and industrial waste, such as pesticides and heavy metals, contaminate aquatic habitats with toxic substances, further threatening amphibian health and increasing their vulnerability to diseases such as chytridiomycosis, a major driver of amphibian biodiversity loss (Ohmer, 2016; Shelly & Singh, 2024). These combined stressors are driving the global decline of amphibians, highlighting the urgent need for effective conservation efforts.

Frog's reliance on both aquatic and terrestrial habitats throughout their life cycle means that they are particularly vulnerable to disturbances like pollution, habitat fragmentation, and climate change (Evans et al., 2020). Anuran species' ecological guilds, which are characterised by their microhabitat preferences, are critical for understanding amphibian population dynamics and interactions with the environment (Goutte et al., 2013). Microhabitats supply necessities such as sustenance, shelter, and breeding places that are

required for the survival of many anuran species. Understanding their microhabitat preferences - such ground-dwelling frogs might favour leaf litter or moist soil, whereas arboreal species require vegetation for foraging and reproduction (Earl & Semlitsch, 2015; Zulkefli & Zainudin, 2022) – is crucial for assessing their ecological groupings and responses to environmental changes (Alias et al., 2022; Shelly & Singh, 2024). Understanding these ecological guilds and their microhabitat preferences is important for developing successful conservation measures to protect these vulnerable species and maintain ecological balance in their habitat.

5.1.1 Problem Statement

Anurans, as a sensitive subgroup of amphibians, serve as a valuable bio-indicator due to their ability to detect minor environmental changes through their highly permeable thin skin, which absorbs toxins (Malonza, 2008; Britton, 2020). Their reliance on both terrestrial and aquatic ecosystems makes them highly susceptible to environmental disturbances, resulting in more significant environmental concerns such as pollution and habitat degradation (Dutta, 2018; Nolan et al., 2023). Despite their widely known importance in ecological monitoring, there is a significant research gap in assessing anuran ecosystem health in Sarawak, particularly in recognising the ecological groupings of Bornean frogs and how their microhabitat preferences may change over time due to environmental pressures. Addressing these gaps is critical for designing successful conservation strategies and sustaining the long-term viability of regional amphibian populations.

5.1.2 Research Questions

The following research questions sought to explore various aspects of anuran populations and their habitats, specifically focusing on the following inquiries:

- i. How does habitat quality influence the microhabitat use and diversity of Bornean frogs across different sites in Sarawak?
- ii. What are the distinct ecological groups of Bornean frogs, and how did their microhabitat preferences vary across different study locations in Sarawak?
- iii. How do anthropogenic stressors impact the microhabitat preferences and overall ecosystem health of anuran populations in Sarawak?

To address these research questions, the objectives of this study were to:

- i. Assess anuran ecosystem health in five different study locations in Sarawak.
- ii. Determine ecological groups of Bornean frogs based on their microhabitat preferences.

5.2 Materials and Methods

5.2.1 Study Locations and Sampling Methods

Data were collected at five study locations in Sarawak, East Malaysia (Northwestern Borneo): Bung Jagoi in Bau, Matang Wildlife Centre in Lundu, UNIMAS West Campus in Samarahan, Kampung Telok Melano in Sematan, and Mulu National Park in Bahagian Long Lama Miri (see Section 3.1 for detailed descriptions).

Frog sampling employed the same procedures described in Section 3.3.1, using VES and AES. For each individual encountered, ecological data such as location, date, time, and microhabitat attributes were recorded following the protocol outlined in Section 3.3.4 (**Table 3.2**). These attributes included vegetation type, horizontal position, vertical position, and substrate type following Heyer et al. (1994).

5.2.2 Data Analysis

Building on the analytical framework described in Section 3.4, this chapter focused on assessing the overall health and quality of an ecosystem using the Anuran Ecosystem Health Indicator (AEHI) version 1.1 (Zainudin et al., 2022). This tool provided insights into ecosystem health and biodiversity by evaluating anuran species diversity, habitat use, environmental quality, and species sustainability. A non-metric multidimensional scaling (NMDS) generated in IBM SPSS version 26 was performed to identify major frog microhabitats and categorise species guilds across the five study sites.

5.3 Results

5.3.1 Anuran Ecosystem Health Assessment

A comparative analysis of various ecological outcomes observed at five different locations during the 2022 and 2023 fieldwork presented in Figure 5.1. Mulu National Park, Matang Wildlife, and Bung Jagoi exhibit healthy species diversity. Conversely, Kampung Telok Melano and UNIMAS West Campus are rated as having “ecosystem degraded” status, showing that these areas are under substantial stress affecting their biodiversity. Despite fluctuating conditions for species diversity, the overall ecosystem health across these sites is assessed as moderate to outstanding, implying stability in the ecosystem’s overall health.

Habitat and vegetation conditions across all locations are generally in moderate health, effectively sustaining the ecological needs of the species present. Horizontal position, vertical position, and substrate areas are all evaluated as moderately healthy, showing that microhabitats are stable and meet the ecological requirements of different anuran species. All four areas consistently show a “moderately healthy” status, while Bung Jagoi has an

excellent health status. Environmental factors such as air, water, and soil quality are within acceptable ranges for maintaining ecosystem health.

Location	Outcome of Species Diversity	Outcome of Species Ecosystem	Outcome of Species Habitat & Vegetation	Outcome of Species Microhabitat: Horizontal Position	Outcome of Species Microhabitat: Vertical Position	Outcome of Species Microhabitat: Substrate	Outcome of Environmental Quality Parameters	Outcome of Species Distribution	Outcome of Genetic Diversification / Species Connectivity
Mulu National Park 2023	Moderate Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Ecosystem Degraded
Telok Melano 2023	Ecosystem Degraded	Moderate Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Ecosystem Degraded
UNIMAS West Campus 2022	Ecosystem Degraded	Moderate Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Ecosystem Degraded
Matang Wildlife Centre 2022	Moderate Healthy and Sustain Ecosystem	Excellent Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Ecosystem Degraded
Bung Jagoi 2022	Moderate Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Excellent Healthy and Sustain Ecosystem	Moderate Healthy and Sustain Ecosystem	Ecosystem Degraded

Figure 5.1: Ecosystem health in five different study locations generated by Anuran Ecosystem Health Indicator (AEHI) version 1.1. From *AEHI*, by Zainudin et al. (2022), *EcoHealth Frog* (<https://ecohealthfrog.com/>)

For species distribution, each location maintains a moderate health status, showing that anuran species are well-distributed within their habitats, a crucial for ecological balance. Across all locations, the persistent “ecosystem degraded” outcome raises significant concerns about genetic diversity and species connectivity. The issues of habitat fragmentation, mobility restrictions, and reduced gene flow significantly impact these ecosystems, highlighting the need for targeted conservation efforts.

5.3.2 Microhabitat Preferences of Bornean Frogs

Table 5.1 and 5.2, along with Figure 5.2, summarize the NMDS analysis of habitat and microhabitat variations among Bornean frogs. Table 5.1 presents goodness-of-fit values, confirming the model’s reliability. Table 5.2 details final coordinate dimensions (FCD 1 and FCD 2), identifying key environmental factors influencing frog distribution. Figure 5.2 visually illustrates habitat differentiation, providing insights into species microhabitat preferences.

The goodness of fit values (**Table 5.1**) demonstrates that the primary stress measure, normalized raw stress, is 0.030, which is considered a very good fit since it is below 0.5. Low stresses (Stress-1=0.174, Stress-2=0.282, and S-stress=0.043), a high D.A.F level (0.970), and a high Tucker’s coefficient of congruence (0.985) reflect a notable depiction of the habitat and microhabitat disparities of Bornean frogs in Sarawak.

Table 5.1: Goodness of fit values of the NMDS configuration

Stress and Fit Measures	Values
Normalized Raw Stress	0.030
Stress-I	0.174a
Stress-II	0.282a
S-Stress	0.043b
Dispersion Accounted For (D.A.F.)	0.970
Tucker's Coefficient of Congruence	0.985
PROXSCAL minimizes Normalized Raw Stress a. Optimal scaling factor = 1.031. b. Optimal scaling factor = 0.971.	

A total of 47 variables were relevant in characterising the habitat and microhabitat use of Bornean frog species. Five meaningful variables were identified along dimension 1 (**Table 5.2, Figure 5.2**) with high positive loadings: agriculture (VAg = 0.923), distant from any water body (HPG = 2.345), on seedling or herbaceous plant (VPK = 0.905), leaf of plant (SA = 0.922), and bank sand or gravel (SH = 0.969); and two high negative loadings: permanent stream midstream (HPB = -0.555) and bank of permanent stream (HPC = -0.542).

In dimension 2 (**Table 5.2, Figure 5.2**), four variables had high positive loadings: agriculture (VAg = 0.905), large clearing (VF = 0.720), in grass (VPP = 0.706), and leaf of plant (SA = 1.143); and four variables with high negative loadings: edge mixed dipterocarp (VE = -0.673), secondary growth forest (VG = -1.153), distant from any water body (HPG = -0.692), and on surface of leaf litters (VPG = -0.645). The prominent characteristics along dimension 1 are distant from any body of water (HPG) (**Figure 5.2**) with the highest positive loading of 2.345 (**Table 5.2**), while leaf of plant (SA) (**Figure 5.2**) exhibits the highest positive loading of 1.143 (**Table 5.2**) in dimension 2.

The results revealed that the two dimensions of the final coordinates had varying degrees of influence on habitat and microhabitat usage. Specifically, the types of microhabitats, such as horizontal position (HPG) and substrate type (SA), were the primary

factor distinguishing habitat and microhabitat use among Bornean frog species. Furthermore, the results also show that individuals of Bornean frog species are likely to use agricultural areas ($VA_{gr} = 0.923$), vegetations away from water bodies ($HPG = 2.345$), and are semi-arboreal, resting on seedling or herbaceous plant leaves ($VPK = 0.905$; $SA = 0.922$) in their recorded vertical positions and substrate types. However, individuals of Bornean frogs tend to avoid leaf litter surfaces ($VPG = -0.645$) along the banks of permanent streams ($HPC = -0.542$) in secondary growth forests ($VG = -1.153$).

Table 5.2: Final coordinate dimension for each habitat and microhabitat variables of Bornean frogs

No.		Habitat/Microhabitat	Code	FCD 1	FCD 2
1	Vegetation Type	Primary rain forest, hilly	VA	-0.431	-0.211
2		Kerangas	VK	-0.385	-0.089
3		Agriculture	VAgr	0.923	0.905
4		Marsh	VS	-0.329	0.408
5		Edge mixed dipterocarp forest	VE	0.445	-0.673
6		Large clearing	VF	-0.020	0.720
7		Secondary growth, immature or regenerating forest	VG	0.655	-1.153
8		Rubber or oil palm planting	VR	0.514	0.215
9	Horizontal Position	Permanent stream: actually, in water	HPA	-0.367	-0.089
10		Permanent stream: midstream on bar, rock, or snag	HPB	-0.555	-0.183
11		Permanent stream: on bank	HPC	-0.542	0.069
12		Intermittent stream: in stream, in water	HPD	-0.306	-0.011
13		Intermittent stream: midstream on bar, rock, or snag	HPE	-0.439	-0.061
14		Intermittent stream: on bank	HPF	-0.417	-0.039
15		Distant from any body of water	HPG	2.345	-0.692
16		In dried bed of intermittent stream	HPH	-0.375	-0.068
17		Temporary pond, in water	HPJ	-0.160	0.125
18		Temporary pond, on vegetation	HPL	0.194	0.542
19		Permanent stream, on exposed bed	HPM	-0.320	-0.082
20		On or in building	HPQ	-0.336	-0.050
21		Permanent pond, on bank	HPR	-0.364	0.026
22		Permanent swamp, in water	HPS	-0.275	0.219
23		Permanent drainage, in plantation	HPV	-0.423	0.558
24	Vertical Position	Under surface of soil	VPA	-0.099	0.141
25		In or under dead leaves	VPB	-0.441	0.042
26		Under rock	VPC	-0.273	0.044

Table 5.2 continued

27		Under log	VPD	-0.273	-0.062
28		In log	VPE	-0.336	-0.130
29		On surface of bare soil	VPF	0.420	0.004
30		On surface of leaf litter or dead leaves	VPG	-0.070	-0.645
31		On rock	VPH	0.257	0.153
32		On log	VPJ	-0.196	-0.072
33		On seedling or herbaceous plant (<1m tall)	VPK	0.905	0.068
34		On shrub or young seedling (1m-7m)	VPL	0.053	0.179
35		On tree or large vine (>7m tall)	VPM	-0.269	-0.233
36		On dead stump	VPN	-0.338	-0.311
37		In crown of fallen dead shrub or tree	VPO	-0.428	-0.149
38		On grass blade	VPQ	-0.164	-0.135
39		In grass	VPP	0.297	0.706
40	Substrate Type	Leaf of plant	SA	0.922	1.143
41		Stem or branch of herbaceous plant	SB	0.027	-0.369
42		Twig or branch of woody plant	SC	-0.353	-0.215
43		Trunk or shrub of tree	SD	-0.325	-0.198
44		Under bark of log, stump, or tree	SF	-0.181	-0.269
45		Bank mud	SG	0.613	0.621
46		Bank sand or gravel	SH	0.969	-0.451
47		Bank rock	SJ	0.250	-0.250

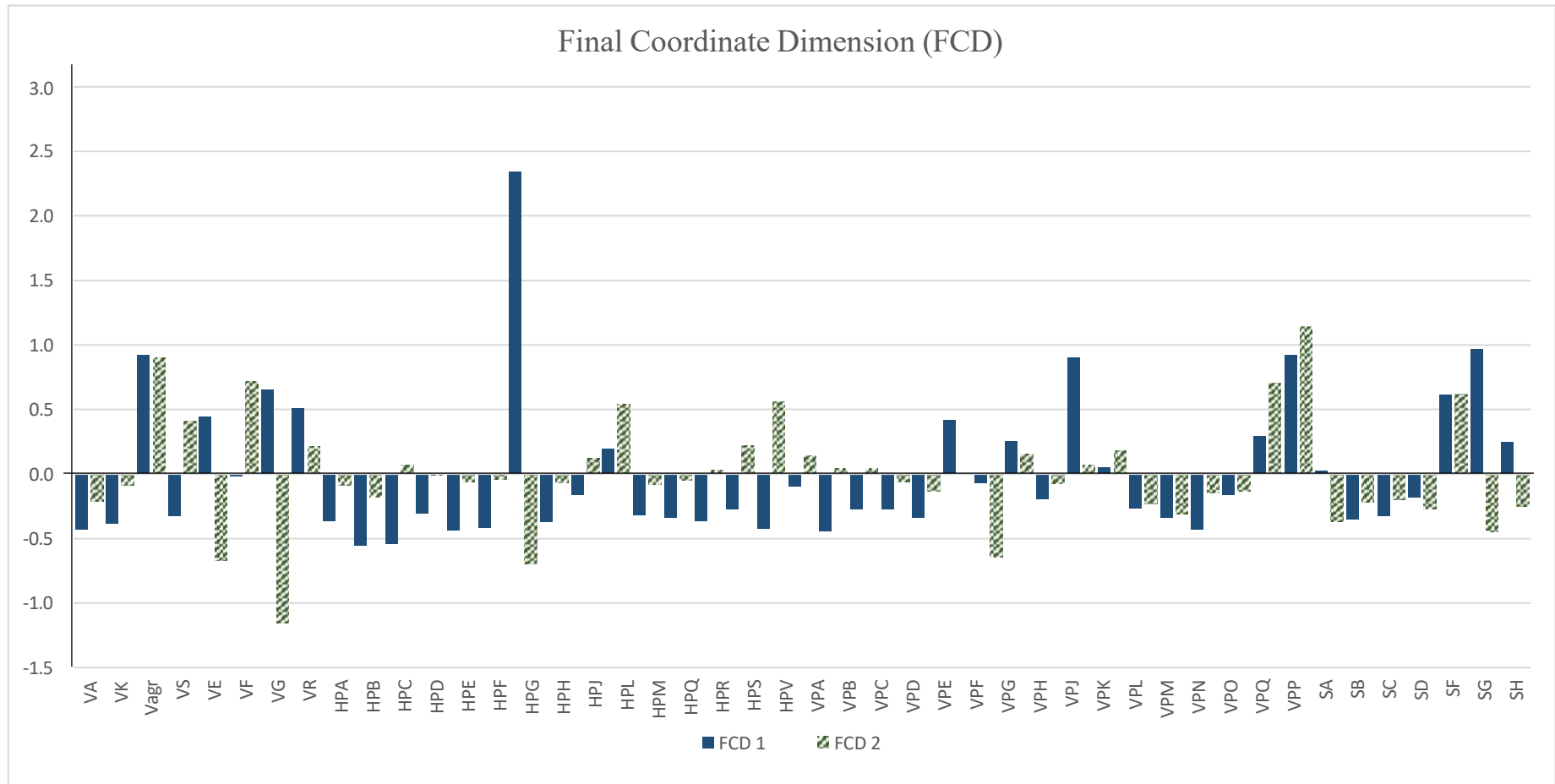


Figure 5.2: Final coordinate dimension, FCD 1 and FCD 2 for each habitat and microhabitat characteristic of Bornean frogs

Ecological guilds determined through non-metric multidimensional scaling (NMDS) of habitat and microhabitat assemblages identified five distinct categories, as shown in Figure 5.3. These include: (i) ground-dwelling frogs from non-forested areas comprising *Fejervarya limnocharis*, *Duttaphrynus melanostictus*, *Fejervarya cancrivora*, *Meristogenys jerboa*, and *Kaloula pulchra*; (ii) semi-arboreal frog from non-forested regions including *Hylarana erythraea* and *Polypedates leucomystax*; (iii) ground-dwelling frogs from forested environments encompassing species *Megophrys nasuta*, *Ingerophrynus divergens*, *Limnonectes leporinus*, and *Ansonia spinulifer*; (iv) semi-arboreal frogs in forested environments with species *Pulchrana baramica*, *Chalcorana megalonesa*, and *Chaperina fusca*; (v) arboreal frogs within forested habitats also comprising species *Polypedates macrotis*, *Philautus tectus*, *Rhacophorus pardalis*, *Polypedates colleti*, and *Nyctixalus pictus*.

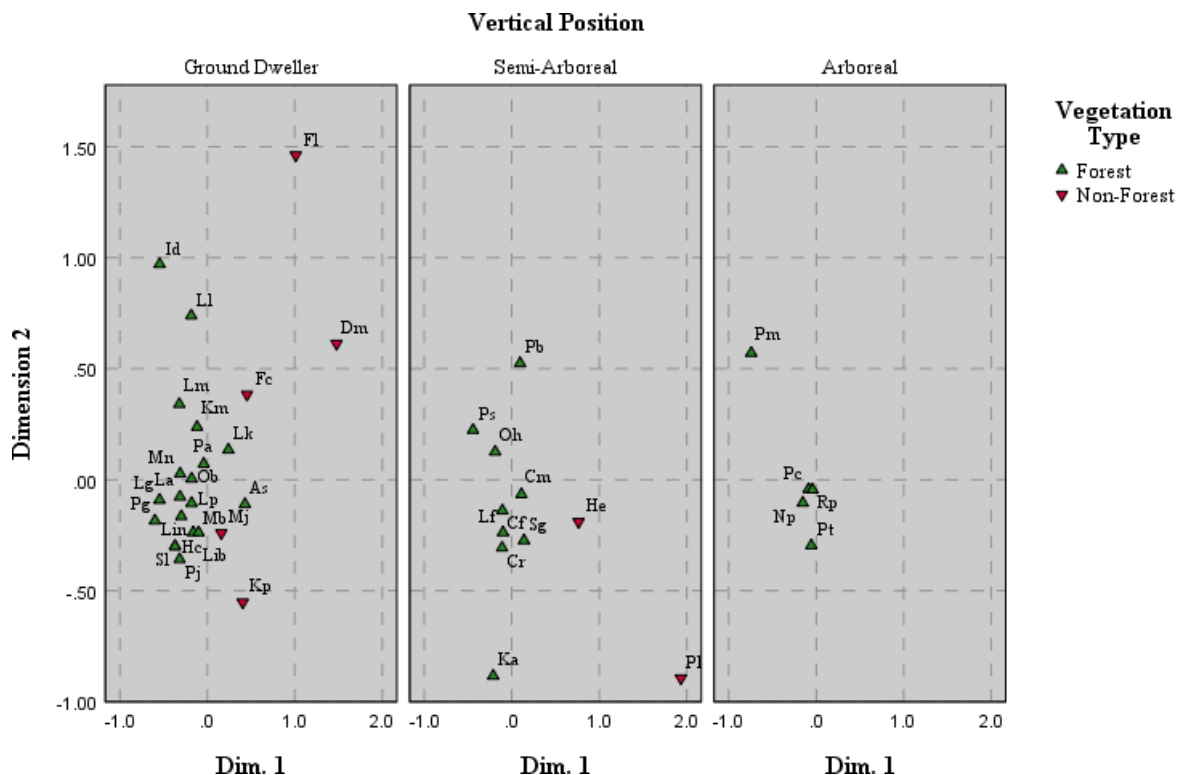


Figure 5.3: NMDS configuration showing the ecological groups of each Bornean frog species

5.4 Discussion

Mulu National Park, Matang Wildlife Centre, and Bung Jagoi were found to be healthy ecosystems, with higher species diversity. Bung Jagoi maintained good ecological health despite the lack of official protection. This finding highlights the importance of both protected areas and community-led activities in preserving biodiversity and ecological stability. However, these ecosystems remain vulnerable to habitat fragmentation, pollution, and other anthropogenic pressures, emphasising the need for ongoing conservation efforts (Gray et al., 2016; Mi et al., 2023; Sheldon et al., 2023). Similar findings have been reported by Sarok and Britin (2016), that emphasised the significance of community-based conservation, while Zulkefli and Zainudin (2022) noted that biodiversity hotspots sustain diverse animals, boosting genetic diversity, and encouraging ecological balance to prevent species extinction. Zainudin et al. (2024) highlighted the role of prioritising conservation areas for facilitating species migration and preventing local extinction.

In this study, Bung Jagoi exhibited excellent health quality parameters (**Figure 5.1**), showing high species diversity and environmental stability. The finding indicates the importance of maintaining habitat and microhabitat quality for the amphibian population survival, as these provides vital resources for breeding, feeding, and safety. This structural diversity reduces predation, supports food availability, and enhances the adaptability and resilience of amphibian population. This is supported by Nyboer et al. (2019), who emphasised that microhabitat architecture and diversity of microhabitats provides vital microclimates and resources, such as vegetation and aquatic features, to maintain suitable conditions for amphibians. Similarly, Zulkefli and Zainudin (2022) highlighted the importance of habitat complexity in supporting amphibian populations.

Bornean frog species under family Bufonidae, Dicroglossidae, Megophryidae, Microhylidae, and some Ranidae were classified as ground dwellers. Ground-dwelling frogs are amphibians that live and feed on forest floors and other terrestrial environments. They have adaptations such as strong limbs for hopping or burrowing, minimal webbing, and small toe pads that allow them to navigate these environments while gaining access to moisture, protection, and abundant food (Deka et al., 2019; Zulkefli & Zainudin, 2022;). According to Sumarli et al. (2015), certain species may even nest on sandy or gravelly soils near streams, which makes forest floors ideal for egg laying and crucial for their survival and reproduction. These findings are supported by Zainudin et al. (2017) and Dehling and Dehling (2021), that pointed out the environmental benefits for survival, and with Sah et al. (2019) and Badli-Sham et al. (2023), who noted that leaf litters and other ground substrates in terrestrial ecosystems provide essential protection and feeding opportunities.

Arboreal frogs were identified in the family Rhacophoridae of Bornean tree frogs (**Figure 5.3**), including *Polypedates macrotis*, *Philautus tectus*, *Rhacophorus pardalis*, *Polypedates colleti*, and *Nyctixalus pictus*, all of which inhabit trees or high-growing vegetation (Inger et al., 2017). These results indicate that arboreal frogs utilise these habitats for foraging and breeding. They also display morphological adaptations, including dilated finger and toe discs with adhesion, moderately long forelimbs, and extended hindlimbs (Gray et al., 1997; Manzano et al., 2008; Hill et al., 2018). Previous studies supported these findings, noting that tree frogs from Rhacophoridae family have developed physical adaptations like specialised toe pads and extended limbs (Wu et al., 2022). Additionally, their dilated fingers and toes allow them to adhere to surfaces like stems and branches (Barnes, 2007; Hill et al., 2018), which also facilitate predator avoidance by allowing them to climb into arboreal habitats (Byrnes & Spence, 2011; Taverne et al., 2018).

Polypedates leucomystax (Pl) (**Figure 5.3**) was found to be semi-arboreal, predominantly occupying agricultural vegetation and observed on the surface of soil or on stem of seedling or herbaceous plants near permanent ponds. As previously shown in Figure 4.2 of Chapter 4, *Polypedates leucomystax* was one of the most prevalent species observed during field sampling, making it a typical species for semi-arboreal frog, while the other semi-arboreal species were only found in very limited numbers. These results suggest that semi-arboreal frogs, which have smaller toe pads than arboreal species due to reduced need for vertical climbing (Vidal-García & Keogh, 2015; Butefish & Moen, 2019), can utilise both terrestrial and arboreal environments to access a variety of resources for feed, breed, and avoid predators. Their habitat flexibility enhances their ability to survive in diverse ecological niches and adapt to changing environmental (del Pliego Castaneda, 2017; Mendoza et al., 2020). This is consistent with Kuraishi et al. (2013), that mention the four-lined tree frog (*Polypedates leucomystax*) is known to reside in diverse environments, such as forest borders, agricultural areas, and semi-urban locales, demonstrating its ability to use both arboreal and terrestrial substrates.

This study demonstrates that adult frogs have their own microhabitat affinities, which is in line with Zuklefli and Zainudin (2022). This discussion indicates that anthropogenic activities including pollution, urbanisation, habitat fragmentation, and deforestation are causing population decreases for numerous amphibian species (Riemann et al., 2017). The bi-phasic life cycle of amphibians, which depends on both aquatic and terrestrial environment, is threatened by these activities, which alter ecosystem structure and lower water quality in aquatic systems (González et al., 2014; Calderon et al., 2017; Hernandez-Caballero et al., 2022). Habitat disturbance frequently results in changes in canopy cover, leaf litter, understory density, and climatic factors such as temperature and rainfall, further

influencing amphibian diversity and distribution (Urbina-Cardona et al., 2006; Jongsma et al., 2014; Russildi et al., 2016). Temperature and precipitation also affect breeding, morphology, development, and survival, with warmer temperatures affecting body sizes and rainy periods influencing amphibian survivability (Ficetola & Maiorano, 2016).

5.5 Conclusion

This study emphasises the need of preserving natural ecosystems and identifying frog species and their microhabitats to aid conservation efforts. The findings show that while some places have healthy ecosystems, such as Mulu National Park, Matang Wildlife Centre, and Bung Jagoi, others, including Kampung Telok Melano and UNIMAS West Campus, have experienced considerable degradation, affecting species diversity and genetic linkage. The study also emphasises the importance of different microhabitats in providing essential resources for frog populations to survive in various environmental situations. Preserving diverse and healthy microhabitats are important for frogs to thrive, especially as human activities have an increasing impact on their environments.

Additionally, constant monitoring and research should be carried out to assess the health of anuran populations and their microhabitat preferences, to make sure conservation efforts are adaptable and sensitive to environmental changes. Community-led conservation initiatives, such as those in Bung Jagoi, play a crucial role by maintaining ecological health and help anuran species to survive. Integrating these measures allows for the maintenance of ecological balance and the long-term survival of frog species in Sarawak, Borneo.

The following chapter will focus on *Fejervarya limnocharis*, a species well-adapted to disturbed environments, widely distributed across South and Southeast Asia, and a valuable bioindicator for assessing ecosystem health in Borneo. Through its detailed

distribution patterns, this species will offer further insights into the broader environmental conditions impacting Bornean frogs.

CHAPTER 6

CURRENT AND FUTURE PREDICTIONS OF POTENTIAL AREAS FOR BORNEAN FROGS UNDER CLIMATE CHANGE IN SARAWAK; LESSON LEARNT FROM A WIDELY DISTRIBUTED URBAN FROG, *FEJERVARYA LIMNOCHARIS*

6.1 Introduction

Many of the diverse frog species found in Sarawak, a state on the island of Borneo, are indigenous to the area. The island's various ecosystems, which range from lowland rainforests to montane highlands, make perfect habitats for these amphibians. Amphibians are essential to Sarawak's ecosystems in several ways. They act as natural predators, which is essential to the wellbeing of forested and agricultural areas. By breaking down organic materials, their larvae aid in the cycle of nutrients in aquatic habitats, hence sustaining other aquatic species (Altig & Johnston, 1989; Wells, 2007). Furthermore, frogs serve as a vital food supply for a variety of predators, maintaining the biodiversity of the area. Frogs are also effective bioindicators, indicating environmental changes like pollution, climate change, and habitat degradation because of their permeable skin and aquatic lifestyle (Blaustein, 1990; Duellman & Trueb, 1994). Due to pollution, habitat loss from deforestation, and climate change, Sarawak's frogs are particularly vulnerable. They become more susceptible to toxins, which also throws off their reproductive cycles and raises mortality rates (Carey & Alexander, 2003). Environmental factors compound the destructive effects of diseases like chytridiomycosis, which further reduce global frog populations (Berger et al., 1998; Stuart et al., 2004).

The "Asian grass frog," *Fejervarya limnocharis*, is a widely dispersed species in South and Southeast Asia (Zhao et al., 2022). It is found in all regions of lowland Borneo where forests have been destroyed. This species usually lives in a range of habitats, including urban areas and lowland grasslands and rice fields (Inger et al., 2017). It grows well in moist areas, particularly rice paddies, which offer an abundance of food and breeding places. Due to its adaptability, the species can also be found in disturbed environments like suburban and urban areas (Huang & Liao, 2021). On the IUCN Red List, *Fejervarya limnocharis* is categorised as Least Concern (LC) because of its wide distribution, estimated big population, and ability to tolerate a variety of environments. However, localised threats like as pollution and habitat destruction can continue to have an impact on some populations.

In ecological research, ecological niche models (ENMs), often called species distribution models (SDMs), are essential instruments for forecasting species distribution across geographical regions determined by ecological conditions and species presence. To help with biodiversity conservation and management measures, these models are commonly employed to predict species' possible ranges under present and future climatic scenarios (Guisan & Zimmermann, 2000; Elith & Leathwick, 2009). By offering insights into the environmental requirements and spatial distribution patterns of species, ENMs and SDMs aid in the identification of essential habitats, evaluation of climate change impacts, direction of conservation planning, and management of invasive species (Sánchez-Mercado et al., 2010).

6.1.1 Problem Statement

In Sarawak, the frog *Fejervarya limnocharis* is a widespread urban and disturbance-tolerant species. Climate change may have an impact on its distribution patterns even if it is

not directly a conservation concern. The Malaysian Borneo state of Sarawak is seeing notable changes in its climate patterns, which could influence the distribution and habitat of amphibian species. According to recent studies, amphibians are especially vulnerable to climatic changes and habitat loss (Chen et al., 2011; Bellard et al., 2012; Goutte et al., 2017), including several frog species found in Borneo. This increased susceptibility highlights the importance of examining how even adaptable species, such as *Fejervarya limnococharis*, responds to climate change. Due to its tolerance of human-modified environments, *Fejervarya limnococharis* provides a useful model for understanding how generalist species may expand under future scenarios. Such expansion could indirectly affect native amphibians, potentially altering community composition and ecosystem health. Although Bornean frogs have been studied in relation to climate change (Ridzuan, 2016; Sah & Grafe, 2019), little is known on how potential climatic scenarios can affect the distribution areas for *Fejervarya limnococharis*. By mapping *Fejervarya limnococharis*'s present and anticipated future range, this study aims to highlight the ecological effects of its expansion and how climate change may favour disturbance-adapted species while disadvantaging more sensitive species.

Fejervarya limnococharis is the most abundant species recorded and can be found in all five study locations conducted during 2022 to 2023 fieldwork. Distribution data of *Fejervarya limnococharis* were compiled based on field survey that was taken place in 2022 to 2023 and secondary data recorded from 2011 to 2021. The objectives of this study were as follows:

- i. To identify the environmental factors that were associated with the potential distribution of *Fejervarya limnococharis*

- ii. To map the current potential distribution of *Fejervarya limnocharis* using occurrence records from secondary data and our field survey
- iii. To map the future potential distribution (2050) of *Fejervarya limnocharis* under two distinct climate change projections

6.2 Materials and Methods

6.2.1 Species Occurrence and Environmental Variables

Figure 6.1 shows a total of eleven locations with *Fejervarya limnocharis* occurrence were recorded from 2011-2023 by Global Positioning System (GPS) coordinates. Two categories of environmental variable (ENV) predictors, including the 19 bioclimatic variables and elevation. The 19 bioclimatic variables emerged from sustained measurements of monthly rainfall and temperature value (1970-2000) (Hijmans et al., 2005). The ENV data had a spatial resolution of approximately 1km² (30 seconds) were downloaded from WorldClim (www.worldclim.org) and clipped to an extent covering Sarawak, Malaysia.

Of the eleven occurrence records shown in Figure 6.1, five were obtained from own field surveys between November 2022 and May 2023, while the remaining data (2011–2021) were collected during earlier research projects in Sarawak. Similar restrictions on funding, logistical difficulties, and research permits applied to both sets of surveys, limiting coverage to specific places rather than all of Sarawak (green areas in **Figure 6.1**).

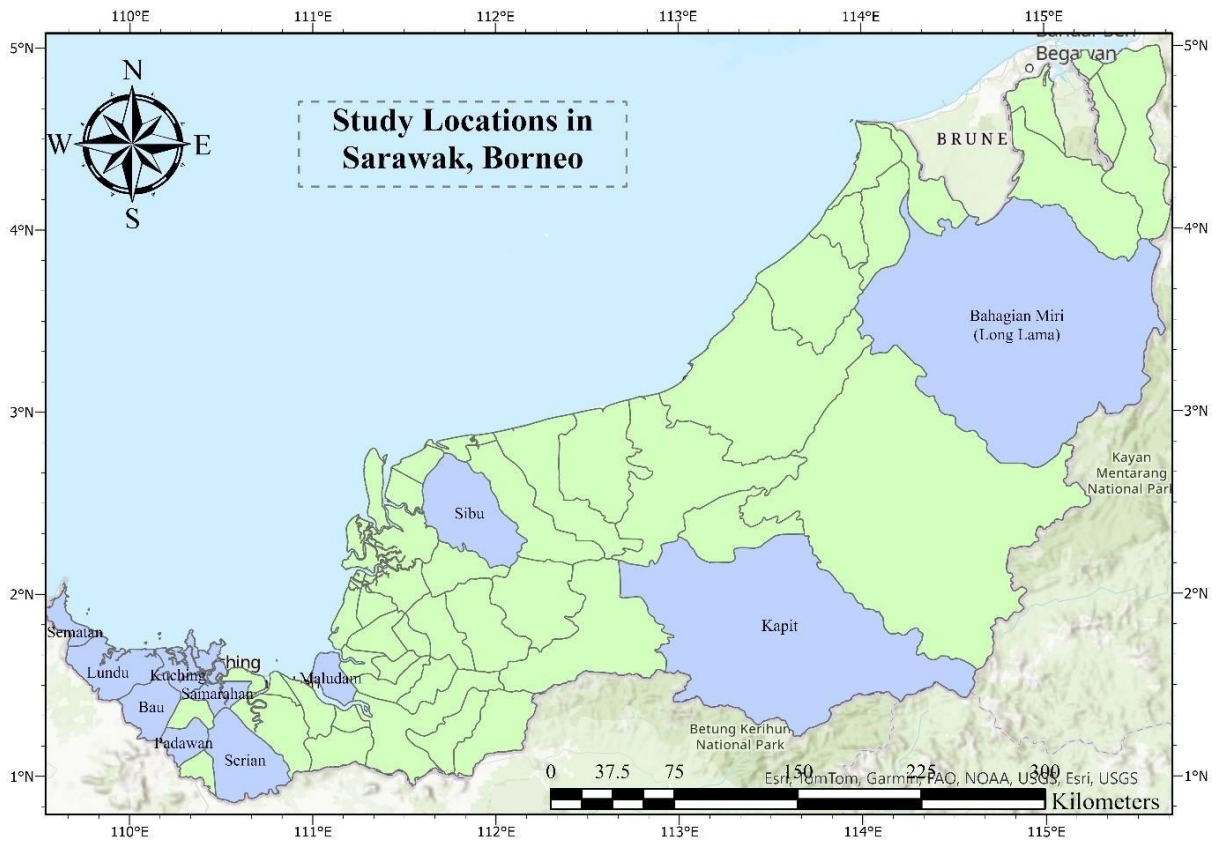


Figure 6.1: Study locations where *Fejervarya limnocharis* was recorded in Sarawak, Borneo generated by ArcGIS Pro 3.0.1

To develop environmental models (ENMs) for future climates, we used climate scenarios for the year 2050. The layers were downloaded from WorldClim (www.worldclim.org) for two projections, medium (SSP2-4.5) and high (SSP5-8.5) climate change scenarios, and at a resolution of 1km² (30 seconds). We used three Global Climate Models (GCM), Australian Research Council Centre of Excellence for Climate System Science (ACCESS-CM2), EC-Earth Consortium (EC-Earth3-Veg), and Max Planck Institute for Meteorology (MPI-ESM1-2-HR).

According to Hamed et al. (2022) on CMIP6 models over Southeast Asia, ACCESS-CM2 exhibits optimal rainfall simulation, EC-Earth performed optimally in reproducing all variables (minimum temperature, maximum temperature, and rainfall), and MPI-ESM1-2-

HR was best in simulating maximum temperature. The aggregate value of each bioclimatic layer from all three GCMs assessed and incorporated into this research.

6.2.2 Data Analysis for Current Period and Future Scenarios

The environmental variables used for predicting the geographic distribution of *Fejervarya limnocharis* were carefully selected to minimize multicollinearity. Variables with a correlation coefficient of ≥ 0.7 were removed before model construction using SDM Toolbox in ArcGIS software version 10.8.2. The final model incorporated 10 bioclimatic variables and elevation, as detailed in Table 6.1.

Table 6.1: Environmental data used in predicting the geographic distribution models for *Fejervarya limnocharis*

Code	Environmental Variables	Unit
bio_1	Annual Mean Temperature	°C
bio_2	Mean Diurnal Range (Mean of monthly (max. temp. - min. temp))	°C
bio_3	Isothermality ((bio_2/bio_7) x 100)	-
bio_7	Temperature Annual Range (bio_5 - bio_6)	°C
bio_11	Mean Temperature of Warmest Quarter	°C
bio_13	Precipitation of Wettest Month	mm
bio_14	Precipitation of Driest Month	mm
bio_15	Precipitation of Seasonality (Coefficient of Variation)	-
bio_18	Precipitation of Warmest Quarter	mm
bio_19	Precipitation of Coldest Quarter	mm
elevation	Elevation	m

According to Phillips et al. (2006), species distribution models, or SDMs, were created using maximum entropy, or MaxEnt. MaxEnt simply employs presence data and has been shown to be stable, dependable, and superior to other models in species distribution prediction (Fourcade et al., 2014). It makes use of the occurrence of species in unknown event locations and the maximum entropy approach (Phillips et al., 2006). To avoid overfitting, a series of Maxent models with increasing complexities for a range of regularisation multipliers (1-3.5) were first created. Linear, quadratic, and hinge

characteristics are modelled using the chosen procedure. The model's forecasting performance is measured using the area under the curve (AUC) of the receiver operating characteristics (ROC) curve (Phillips et al., 2006). The AUC, which is extensively used to evaluate model performance, is a threshold-free metric that ranges from 0 to 1, with 1 representing perfect discrimination (Swets, 1988). The MaxEnt jackknife technique was performed to determine the relative relevance of the environmental variables included, according to their individual training gain values. The MaxEnt parameters were configured at “randomseed” “convergence threshold = 0.00001” “maximum iterations = 500” and “maximum background points = 10,000”.

6.3 Results

6.3.1 Current and Future Potential Distribution of *Fejervarya limnocharis*

Figure 6.2 illustrates the current distribution, highlighting areas with high, good, and moderate habitat suitability. Meanwhile, Figure 6.3 presents the projected distribution for 2050 under two climate scenarios: intermediate emissions (SSP2-4.5) (**Figure 6.3 (A)**) and high emissions (SSP5-8.5) (**Figure 6.3 (B)**). These projections reveal shifts in habitat suitability based on changing climatic conditions.

Species distribution maps showed that 5.40%, 7.41% and 14.17% of the study area respectively were designated as high, good, and moderate potential habitats of *Fejervarya limnocharis* in Sarawak (**Figure 6.2**). Mainly the centre of the Western Sarawak was recognised as the primary distribution areas. The suitable conditions are predicted to be highly probable through all lowland areas of Sematan, Lundu, Bau, Kuching, Siburan, Samarahan, Asajaya, and Oya. It is also highly probable through part of Padawan, Serian, Simunjan, Matu, Mukah, and along the coastline areas of Pendam.

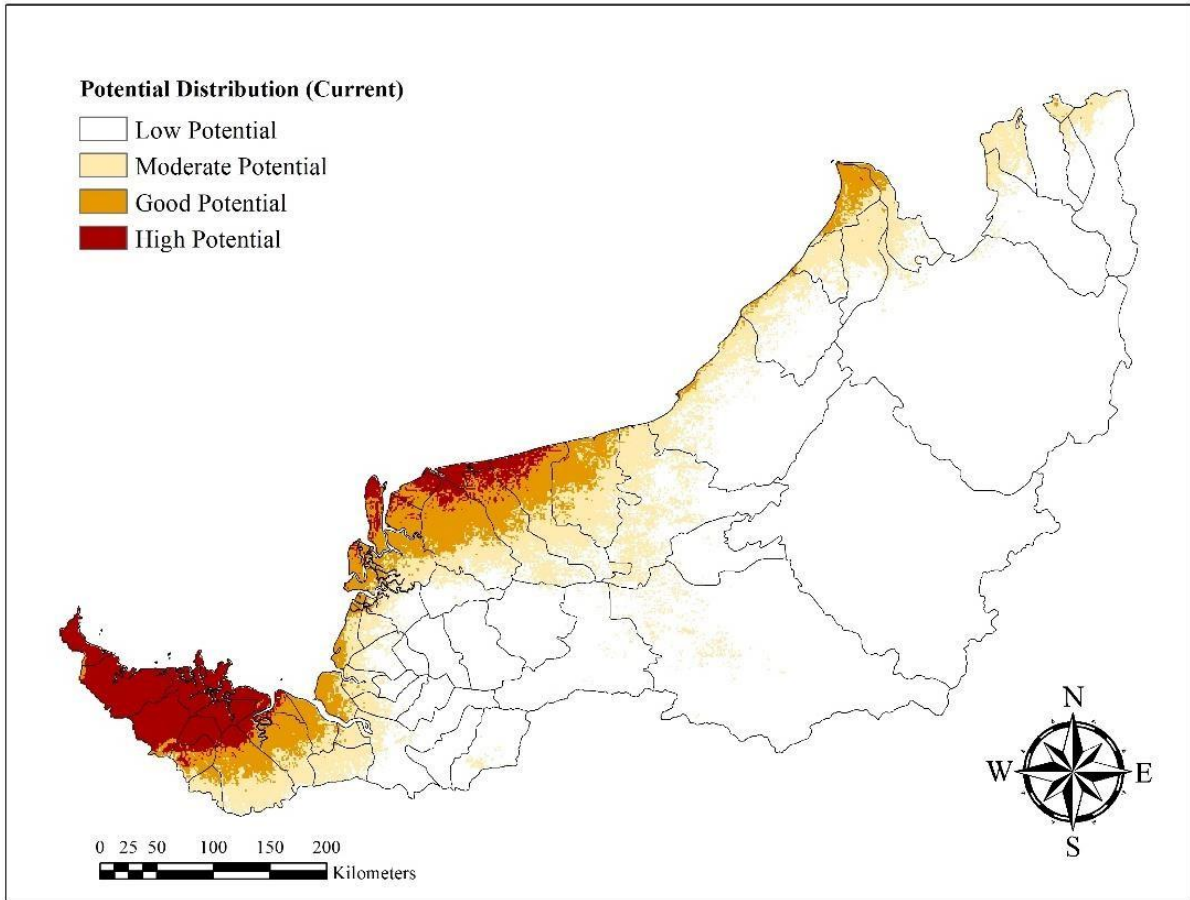


Figure 6.2: Potential distribution of *Fejervarya limnocharis* under current climate condition in Sarawak

Predicted future species distribution for mid-century (2050) illustrates of intermediate emission scenario (SSP2-4.5) for high, good, and moderate potential habitats of *Fejervarya limnocharis* were 9.82%, 10.37% and 18.49%. The future projections for high emission scenario (SSP5-8.5) were 10.45%, 11% and 20.3% for high, good, and moderate potential habitats of *Fejervarya limnocharis*. Most of Padawan, Pendam, and Daro are seen as highly probable, while Serian, Sebuyao, Maludam, Sibul, Dalat Mukah, and Balingan were classified as partly highly probable (**Figure 6.3**).

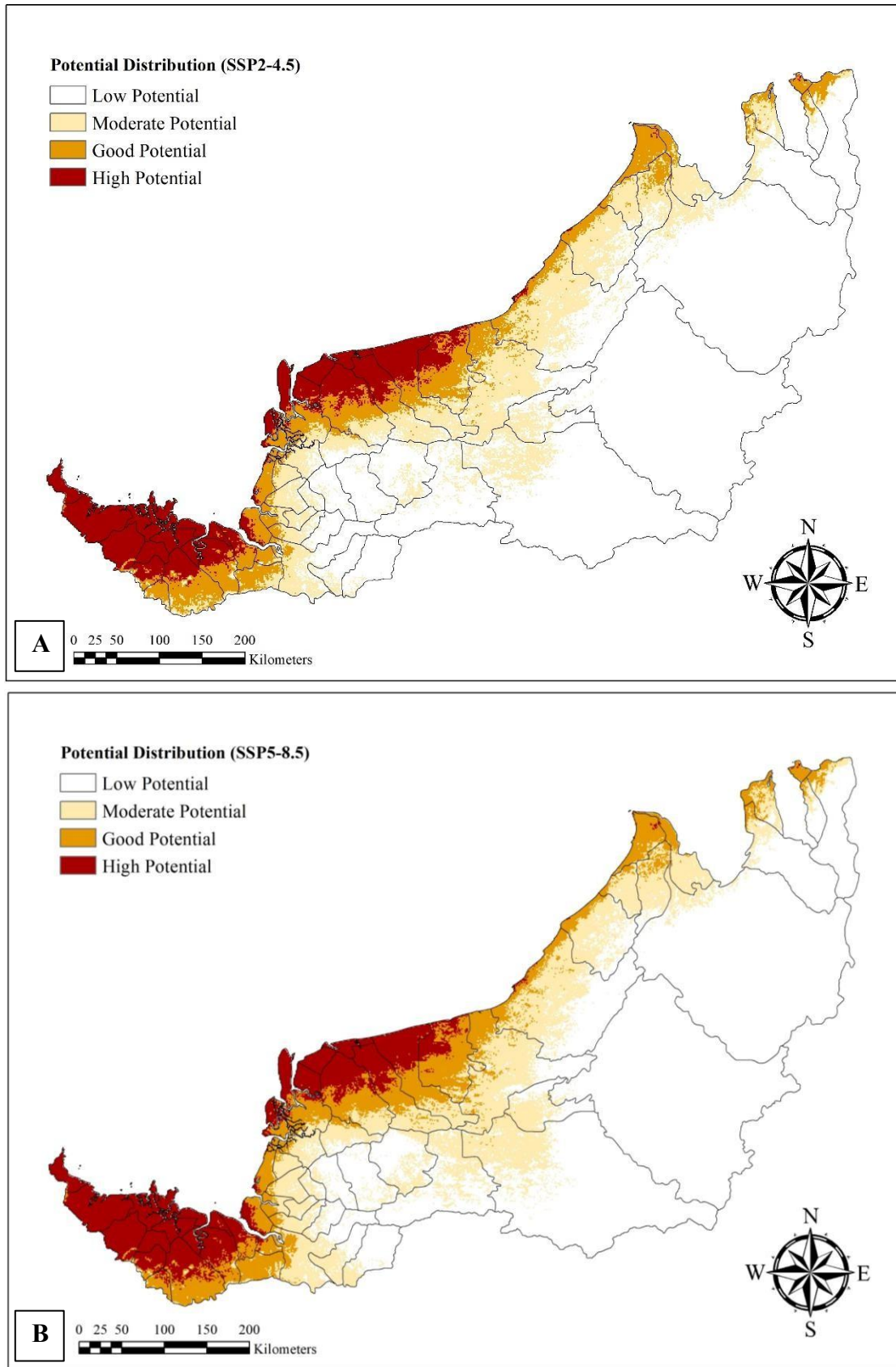


Figure 6.3: Potential suitable habitat for *Fejervarya limnocharis* in 2050 under (A) SSP2-4.5 and (B) SSP5-8.5

Both future scenarios (SSP2-4.5 and SSP5-8.5) show a transition from moderate to high potential classes. With intermediate emissions (SSP2-4.5), a greater part of the land becomes more appropriate due to changes in environmental circumstances that support *Fejervarya limnocharis*. The trend continues, with a further increase in moderate to higher potential areas with higher emissions (SSP5-8.5), showing that climate change appears to improve the overall habitat appropriateness of *Fejervarya limnocharis*. The changes in temperature, precipitation, or other climatic conditions that make the habitat more conducive to the species.

6.3.2 Model Evaluations and its Importance to Variables under Different Climatic Conditions

Figure 6.4 presents the model's accuracy in predicting habitat suitability for *Fejervarya limnocharis* based on the area under curve (AUC) value, which indicates the model's ability to distinguish between suitable and unsuitable habitats. Table 6.2 summarizes the AUC values for future climate projections under different emission scenarios, providing insights into how climate change may influence model performance.

The mean test AUC value for current model is 0.8749, demonstrating a high model performance in the current climate scenario (**Figure 6.4**). With the AUC value > 0.8, this means that the model has an excellent performance and can accurately predict outcomes based on the available data (Safari et al., 2016). High AUC reflects the model's strong ability to differentiate between suitable and unsuitable habitats for *Fejervarya limnocharis*.

The AUC value for 2050 scenarios of SSP2-4.5 and SSP5-8.5 are 0.8487 and 0.8467 (**Table 6.2**), which are slightly lower than current model, showing that both models perform comparably under a more extreme climate change scenario. SSP2-4.5 represents a moderate

climate change scenario where greenhouse gas emissions peak around mid-century and then decline (Hamed et al., 2022). SSP5-8.5 represents a high-emission pathway where greenhouse gas emissions continue to rise throughout the 21st century (Hamed et al., 2022).

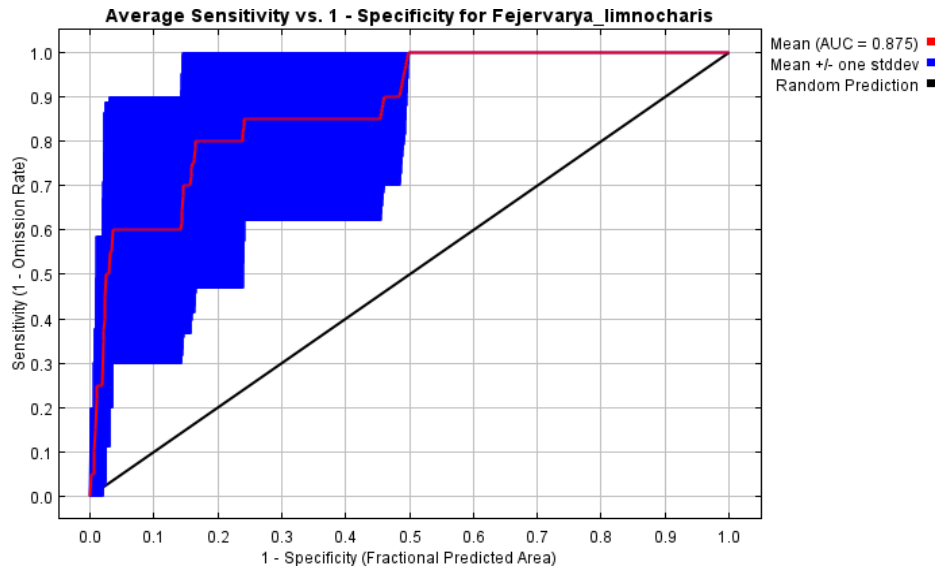


Figure 6.4: ROC and AUC value under the current period (10 replicated runs)

The slight drop in AUC values from 0.8749 to 0.8487 and 0.8467 shows that the model's predictive capability is affected by the change in climate conditions in SSP2-4.5 and SSP5-8.5, leading to slightly reduced predictive performance. The minor difference in AUC values between SSP2-4.5 and SSP5-8.5 highlights the model's performance is resilient to significant changes in climate conditions.

The SSP5-8.5 shows lower variability in model performance (standard deviation of 0.0469) compared to current (0.0607) and SSP2-4.5 (0.0945), reflecting a more consistent predictions under intermediate climate. SSP2-4.5 has the highest variability indicating that predictions are less consistent under high emissions, possibly due to greater uncertainty in environmental conditions.

Table 6.2: Mean AUC and standard deviation of different models in different scenarios

Time	SSPs	Mean Training AUC	Mean Test AUC	Standard Deviation
Current		0.9047	0.8749	0.0607
2050	SSP2-4.5	0.9038	0.8487	0.0945
	SSP5-8.5	0.9053	0.8467	0.0469

Figure 6.5 and Figure 6.6 illustrates the results of the jackknife test, which identifies the most influential environmental variables affecting the distribution of *Fejervarya limnocharis*. By analysing how model gain changes when each variable is excluded or used in isolation, these figures highlight the key predictors under both current and future climate scenarios.

The test of the jackknife shows the distribution of *Fejervarya limnocharis* under current conditions was strongly associated with precipitation of wettest month (bio_13), precipitation of seasonality (bio_15), isothermality (bio_3), and elevation (**Figure 6.5** and **Figure 6.6**). This is evidenced by the significant drop in gain when these variables are excluded and the high gain when these variables are used. Variables such as annual mean temperature (bio_1) and mean temperature of the coldest quarter (bio_11) are less important as indicated by minimal changes in gain when excluded and low gain when used alone.

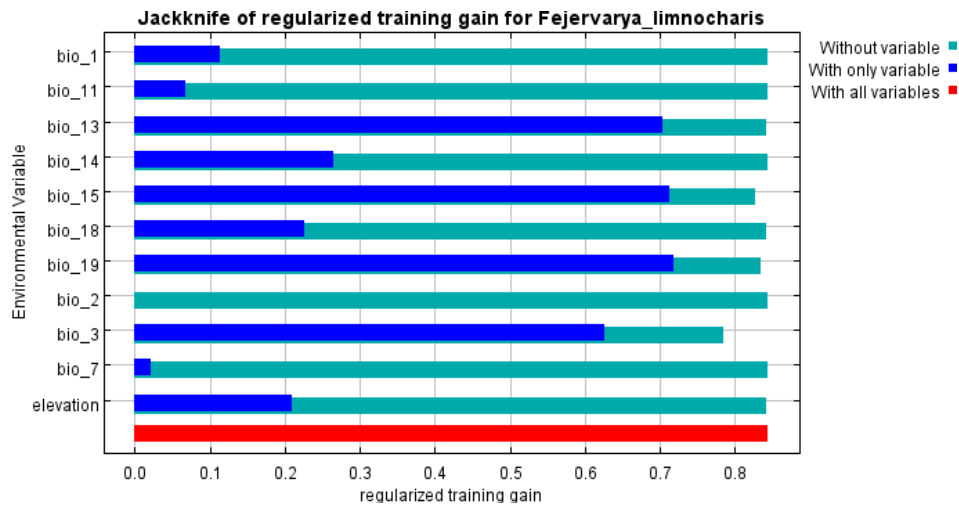


Figure 6.5: Jackknife of regularised training gain for *Fejervarya limnocharis* under current conditions

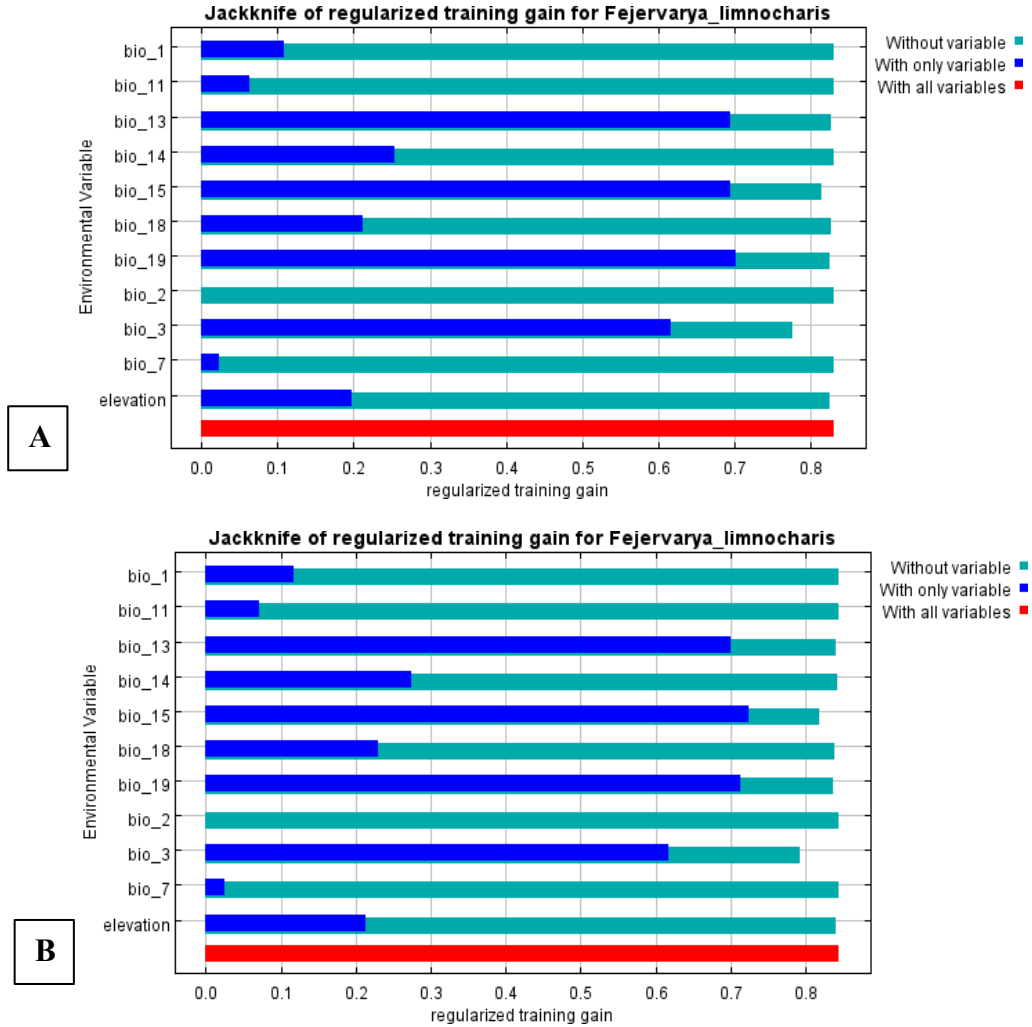


Figure 6.6: Jackknife of regularised training gain for *Fejervarya limnocharis* under future climate conditions: (A) SSP2-4.5 (B) SSP5-8.5

Table 6.3 outlines key bioclimatic variables influencing *Fejervarya limnocharis* distribution across current and future climates, identifying consistent and shifting factors under SSP2-4.5 and SSP5-8.5 scenarios.

Precipitation of seasonality (bio_15) and precipitation of wettest month (bio_13) with the contributions of 49.7% and 40.6% are seen as the most influential variables to the MaxEnt model (**Table 6.3**). The species habitat model was also collectively contributed by 3 bioclimatic variables of 9.2% and elevation of 0.5%.

In addition, when considering permutation importance to determine the impact of variables on habitat suitability, only six bioclimatic factors were crucial to the model's findings (**Table 6.3**). Among the six bioclimatic variables, isothermality (bio_3) had a maximum influence on habitat suitability model for 68.3%, while precipitation of coldest quarter (bio_19) and precipitation of seasonality (bio_15) together contributed 28% (**Table 6.3**).

The distribution of *Fejervarya limnocharis* under SSP2-4.5 scenario was strongly associated with precipitation of wettest month (bio_13) and precipitation of seasonality (bio_15) with contributions of 54.1% and 37.2%. The permutation importance for this species habitat model shows a significant shift, with isothermality (bio_3) and precipitation of seasonality (bio_15) becoming more influential (56.1% and 19.6%) (**Table 6.3**). For SSP5-8.5, the distribution of *Fejervarya limnocharis* stayed relatively consistent from SSP2-4.5, with bio_15 and bio_13 being the dominant factors (50.9% and 36.3%). However, the permutation importance shifts in this model scenario as well, with bio_3 dropping to 47.3% but an increase in bio_15 (25.9%).

From (**Table 6.3**), it is shown that precipitation of wettest month (bio_13) and precipitation of seasonality (bio_15) consistently have high percent contributions across all three different climate conditions. This highlights the importance of precipitation patterns in determining habitat suitability. Isothermality (bio_3) plays a critical role in model accuracy as it has the highest permutation importance across all three different climate conditions, pointing to temperature stability as a key predictor for the species or phenomenon being modelled. Under future scenarios (SSP2-4.5 and SSP5-8.5), there is an increased influence of precipitation of wettest month (bio_13) (from 6.2% to 9.0%), making changes in precipitation during the wettest month will become more critical.

Table 6.3: Percent contribution and permutation importance of the predictor environmental variables in predicting geographic distribution models for *Fejervarya limnocharis*

Time	Bioclimatic variables	bio_1	bio_2	bio_3	bio_7	bio_11	bio_13	bio_14	bio_15	bio_18	bio_19	elevation
	Percent Contribution	0.0	0.0	5.2	0.0	0.0	40.6	0.0	49.7	0.2	3.8	0.5
Current	Permutation Importance	0.0	0.0	68.3	0.0	0.0	2.6	0.3	13.2	0.8	14.8	0.0
	Percent Contribution	0.0	0.0	4.5	0.0	0.0	54.1	0.0	37.2	0.4	1.6	2.3
SSP2-4.5	Permutation Importance	0.0	0.0	56.1	0.0	0.0	6.2	0.6	19.6	1.4	9.4	6.8
	Percent Contribution	0.1	0.0	5.0	0.0	0.0	36.3	0.0	50.9	0.5	6.1	1.1
SSP5-8.5	Permutation Importance	0.0	0.0	47.3	0.4	0.0	9.0	0.3	25.9	1.5	13.1	2.5

Figure 6.7 presents the species response curve, illustrating the relationship between environmental factors and the likelihood of species occurrence. This curve highlights the biological limits of the studied species and its habitat affinities. According to the model, three environmental variables, isothermality (bio_3), precipitation of driest month (bio_14), and precipitation of warmest quarter (bio_18) had a negative relationship with species occurrence, showing that elevated temperatures and minimal precipitation are unfavourable for the species studied. On the contrary, positive relation to precipitation of wettest month (bio_13), precipitation of seasonality (bio_15), and precipitation of coldest quarter (bio_19) was observed. The model results highlight that fluctuations in precipitation are key environmental factors considered as predictor of distribution of *Fejervarya limnocharis*.

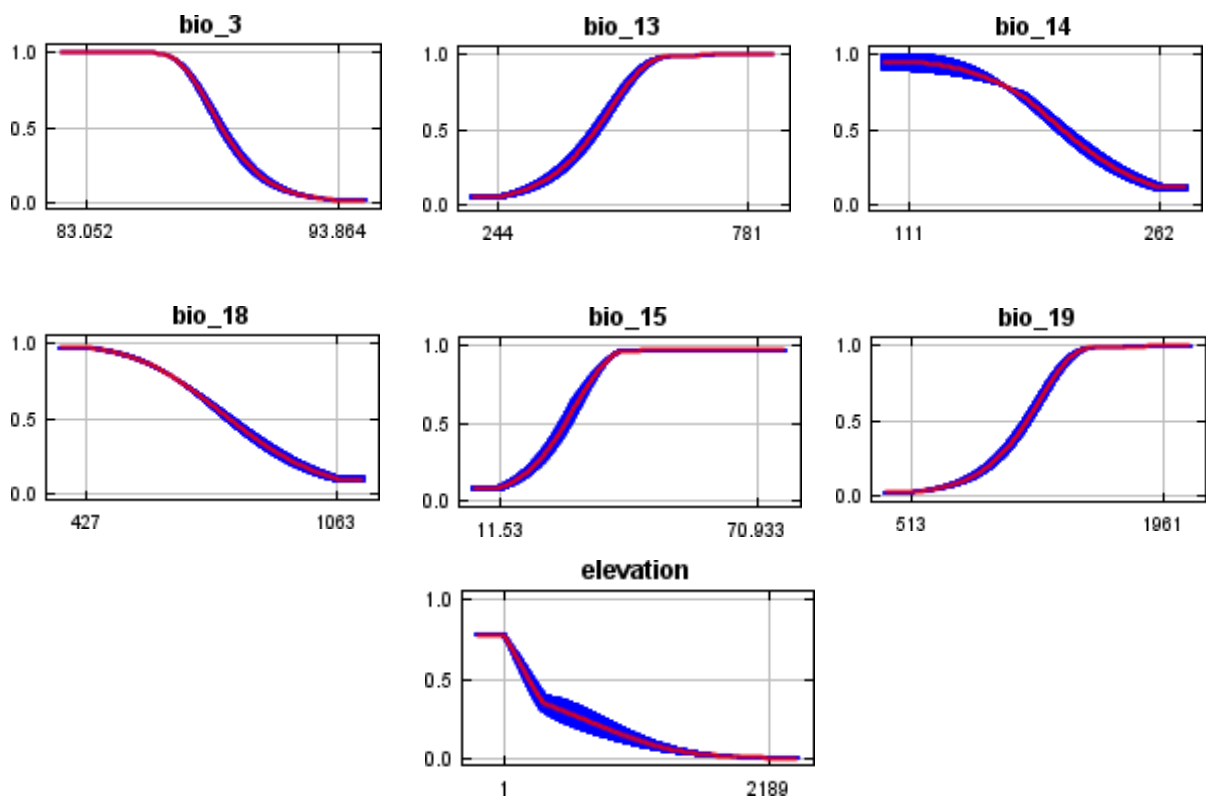


Figure 6.7: Marginal response curves of the contribution variables to predict presence probability of *Fejervarya limnocharis* with MaxEnt

6.4 Discussion

The mean area under curve (AUC) values of the receiver operating curve (ROC) (Table 6.2) provides insights into the predictive performance of the species distribution models (SDMs) for *Fejervarya limnocharis* under current and future climate conditions. Although there is a slight decrease in the future AUC values (SSP2-4.5 = 0.8487 and SSP5-8.5 = 0.8467) from current AUC value (0.8749), these values still fall within the range of excellent model performance (>0.8) (Hosmer et al., 2013). The minor reduction in AUC values indicates that while the model's predictive power under future climate scenarios remains strong, there is a small decrease in accuracy, likely due to increased uncertainty and variability in future climate conditions such as temperature fluctuations, changes in precipitation patterns, extreme weather events, land use changes, inter-specific interactions, and microclimatic variability (Donnelly & Crump, 1998; Corn, 2005; Thuiller et al., 2005; Pounds et al., 2006; McMenamin et al., 2008; Buckley et al., 2010; Ficetola & Maiorano, 2016).

The high AUC values across current and future scenarios suggest that *Fejervarya limnocharis* has the potential to maintain its distribution under varying climate conditions. This adaptability can be attributed to its wide ecological tolerance and ability to thrive in both natural and urban environments (Huang & Liao, 2021). The future models, despite their slight decrease in AUC values, remain valuable tools for anticipating potential shifts in the distribution of *Fejervarya limnocharis*. These projections can help identify future critical habitats that may need protection and management to ensure the species' survival under climate change scenarios (Franklin, 2013). These results demonstrate the model's reliability and their capacity for identifying vital habitats for the species under changing climate conditions.

From Table 6.3, bioclimatic variables bio_13 (precipitation of wettest month) and bio_15 (precipitation of seasonality) consistently showed high percent contribution and permutation importance across all scenarios (current, SSP2-4.5, SSP5-8.5) which indicates that precipitation related variables are more influential than temperature-related variables in determining the distribution of *Fejervarya limnocharis* in Sarawak. Precipitation directly affects the availability of breeding sites and the duration of water bodies where larvae develop. High and consistent precipitation ensures longer periods of suitable breeding conditions, leading to higher survival rates of tadpoles and juveniles (Todd et al., 2011). Changes in precipitation patterns due to climate change can alter these rates, potentially affecting the population dynamics and distribution range (Moreno-Rueda & Comas, 2023).

During the dry season in Sarawak, *Fejervarya limnocharis* may use behaviours such as burrowing into moist substrates, such as under logs, leaf litter, or burrowing into the soil, seeking shade, or remaining inactive during the hottest parts of the day to minimize water loss through evaporation. This species also possesses a permeable skin that allows for cutaneous water absorptions, enabling them to rehydrate from moist surfaces. Additionally, they may have specialized glands that reduces water loss (Hillman et al., 2008). *Fejervarya limnocharis* can move to new areas with suitable environmental conditions climate change makes their current habitats less viable. This capability is crucial for their survival, as it allows them to track changing climates and maintain viable populations (Gibbs, 1998). The species' ability to adapt to a wide range of environmental conditions through phenotypic flexibility can help it survive in new habitats as it shifts its range in response to climate changes (Hoffman & Sgrò, 2011).

Changes in precipitation patterns, including both increased and decreased rainfall, can significantly affect the habitat suitability and survival of *Fejervarya limnocharis*. An

increased in rainfall can lead to enhanced breeding opportunities by providing more aquatic habitats for laying eggs and supporting larval development, while their ability to disperse to new, water-filled habitat supports feeding and breeding activities (Beranek et al., 2022). However, excessive rainfall can also result in habitat flooding, which might wash away eggs and larvae, thereby reducing reproductive success. Furthermore, Chuang et al. (2022) mentioned that a decrease in rainfall will lead to drying up of breeding sites, making it challenging for frogs to find suitable habitats for reproduction and larval development. This increases mortality rates due to desiccation and lack of suitable breeding habitats.

The projected expansion of *Fejervarya limnocharis* in 2050 for SSP2-4.5 and SSP5-8.5 (**Figure 6.3**) illustrates how habitat generalists, particularly disturbance-tolerant species, are more likely to survive and thrive in fragmented and altered landscapes, often negatively impacting more sensitive anuran species. By regulating invertebrate populations, nutrient cycling, supporting food webs through eggs and larvae, and influencing primary productivity, its expansion may promote biotic homogenisation within anuran communities and have broader ecological ramifications (Connelly et al., 2008; Whiles et al., 2013; Hocking & Babbitt., 2014; Phadmacanty et al., 2019). This is consistent with findings that indicates generalists adapt better to altered landscapes and frequently thrive in degraded ecosystems through biotic homogenisation, whereas specialists are more susceptible to extinction in fragmented landscapes (Olden, 2006; Solar et al., 2015; Nowakowski et al., 2017). As a result, the decline of sensitive anurans may lead to a series of disturbance across ecosystem functions. However, despite these strengths, *Fejervarya limnocharis* still faces a range of anthropogenic and climate-related pressures.

In Sarawak, the mortality of *Fejervarya limnocharis* is primarily driven by habitat loss due to deforestation and agricultural expansion, which leads to habitat fragmentation and

reduced availability of breeding sites. Predation by native and introduced species, along with exposure to pesticides and other pollutants from agricultural practices, further contributes to mortality. Climate change impacts, such as modifications in rainfall patterns and temperature extremes, exacerbate these challenges by making habitats less suitable for survival and reproduction (Huang & Liao, 2021; Septiadi, 2021).

Additionally, habitat loss and degradation due to urbanization reduces breeding sites and increases exposure to pollutants, leading to lower reproductive success and higher mortality rates. Urban development causes habitat fragmentation, isolating populations and reducing genetic diversity, which weakens populations' resilience to environmental changes and diseases. Precipitation directly affects the accessibility of breeding grounds and the duration of water bodies where larvae develop. High and consistent precipitation ensures longer periods of suitable breeding conditions, leading to higher survival rates of tadpoles and juveniles (Patar et al., 2021).

Although primary field data were gathered from five key locations described in Chapter 3, secondary occurrence records from 2011 to 2021 were also included in this study, bringing the total to eleven distinct localities across Sarawak. This broader spatial dataset improves the ecological representativeness and accuracy of the species distribution models by capturing a wider range of habitat conditions. However, due to accessibility and time constraints, certain isolated locations were not physically researched, which could limit the full representation of the species' ecological niche and introduce spatial bias. In order to fully capture Sarawak's entire environmental variety and validate long-term forecasts, future research should extend sampling coverage to under-represented places, considering the inclusion of historical records helps decrease this bias.

6.5 Conclusion

The efficiency of species distribution models (SDMs) in predicting habitat suitability and potential distribution for *Fejervarya limnocharis* under current and future climate change scenarios has been demonstrated to be highly effective. These models provide valuable insights into how environmental factors influence the distribution of this species, both currently and under projected climate changes. The SDMs indicate that habitat suitability for *Fejervarya limnocharis* is expected to increase significantly by 2050 under both moderate (SSP2-4.5) and high (SSP5-8.5) climate change scenarios. Specifically, the areas of high potential suitability are projected to increase from 5.40% to 9.82% under SSP2-4.5 and to 10.45% under SSP5-8.5.

To mitigate the impacts of climate change and protect *Fejervarya limnocharis*, it is crucial to enforce preservation practices that focus on protecting current habitats and facilitating the species' shift to new suitable niches. This involves enhancing habitat connectivity, preserving critical breeding sites, and implementing adaptive management practices that account for future climate scenarios. The finding of this research contributes significantly to for deeper awareness of the environmental determinants affecting the distribution of *Fejervarya limnocharis*, providing a foundation for informed conservation planning and policy-making. By integrating current restoration efforts with projections of future habitat shifts, conservationist can better protect sensitive species and ensure the sustainability of biodiversity in changing climates.

CHAPTER 7

GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATION

7.1 General Discussion and Conclusion

This study examined how climate and habitat changes influence Bornean frogs in Sarawak, with the first two parts focuses on assemblage-level patterns of thermal biology and habitat associations, while the third part focused on the widespread generalist *Fejervarya limnocharis* as a case study for predicting future distributional shifts. These chapters collectively offer a comprehensive perspective on how environmental change influences frogs across multiple biological scales, from individual physiology to community structure and species-level distribution shifts.

The thermal analysis in Chapter 4 revealed a strong association between frog body temperature and substrate temperature, consistent with their thigmothermic tendency. Frogs inhabiting lentic (non-flowing) habitats exhibited higher body temperatures compared to those in stream and terrestrial environments, demonstrating how habitat type influences regulation. Since frog body temperatures often overlap with the optimal growth range of *Batrachochytrium dendrobatidis* (Bd), even small shifts in microhabitat temperatures could affect infection risk. This underscores how physiological responses to environmental factors shape susceptibility to disease and environmental stress, highlighting the importance of thermal ecology in amphibian conservation.

The habitat and microhabitat assessments in Chapter 5 expanded the physiological findings to the community level. Protected areas such as Mulu National Park, Matang Wildlife Centre, and Bung Jagoi maintained healthier ecosystems with higher species diversity and the presence of habitat specialists, whereas disturbed areas such as UNIMAS

West Campus and Kampung Telok Melano were dominated by generalist species. These results highlight the importance of well-preserved habitats, which sustain diverse microhabitats essential for amphibian survival. This also revealed how human disturbance disrupts ecological balance, reducing diversity and leading to community homogenisation. Notably, Bung Jagoi's community-led conservation initiatives demonstrated how local involvement can effectively support ecosystem health and the persistence of amphibian populations.

The species distribution modelling of *Fejervarya limnocharis* in Chapter 6 linked these physiological and ecological observations to future scenarios. This disturbance-tolerant generalist was found across all study sites and is projected to experience a notable range expansion by 2050 under both moderate (SSP2-4.5) and high (SSP5-8.5) climate scenarios. Although the species is not currently a conservation priority, its predicted expansion shows how climate change may benefit generalist species while placing additional pressure on more sensitive species, thereby altering community structure. These projections highlight the need for conservation strategies that consider not only species declines but also the ecological consequences of expanding generalist in fragmented landscapes and warming environments.

Bringing these findings together, the study shows that Bornean frogs respond to environmental change in complex and interconnected ways. Thermal ecology shapes the way individuals interact with their surroundings, while habitat condition influences community diversity and resilience. At the broader scale, climate change is projected to shift species distributions, further increasing pressure on habitat specialists. Collectively, the results achieve the main aim of the research by revealing how climate and habitat changes influence frog physiology and distribution in Sarawak. This study enhances understanding of both the

vulnerability and adaptability of amphibians under changing environmental conditions by combining field-based thermal and ecological data with predictive modelling.

7.2 Recommendations

This study encountered several limitations and obstacles that should be considered when interpreting its outcomes. Field sampling lasted fewer than 30 days, constrained by delayed permit approval, logistical challenges, and frequent disruptions during the monsoon season. These factors reduced the number of effective survey nights and restricted opportunities for extended sampling across different seasons. Therefore, the dataset may not fully represent seasonal patterns in frog activity or thermal biology. Surveys were also limited to only five study sites, leaving large parts of Sarawak underrepresented due to funding and access limitations. The species distribution modelling of *Fejervarya limnocharis* also relied partly on secondary occurrence records, which were uneven in spatial and temporal coverage, while the models themselves did not account for biotic factors such as predation, competition, or disease. Moreover, the climate projections were based on a 26-year timeframe, which may not fully reflect the long-term impacts of global change.

Despite these challenges, its findings offer valuable applications for amphibian conservation in Sarawak. Results on thermal ecology emphasise the role of microhabitats in shaping body temperature and disease risk, providing useful guidance for habitat management strategies aimed at lowering susceptibility to chytrid fungus (*Batrachochytrium dendrobatidis*). The comparison of habitat and diversity revealed clear contrasts between protected and disturbed areas, underscoring the importance of well-managed forests such as Mulu National Parks, while also highlighting how community-based efforts like Bung Jagoi can strengthen ecological resilience. These findings provide a basis for conservation

planning by identifying priority habitats for protection, restoration, and enhanced connectivity. Additionally, the predictive maps for *Fejervarya limnocharis* act as an early indicator, showing how disturbance-tolerant generalists may expand under future climate scenarios. This information can support adaptive management policies by anticipating shifts in species composition and their potential ecological impacts.

Future studies should build on these findings by expanding both the temporal and spatial scope of field sampling, covering wet and dry seasons to better capture shifts in frog thermal ecology and habitat use. Extending surveys into remote and under-sampled areas of Sarawak would make diversity and distribution data more representative. For predictive modelling, adding biotic interactions such as predation, competition, and disease would improve ecological accuracy, while modelling more frog species with varied ecological traits would offer a fuller understanding of community-level responses to climate change. Establishing long-term monitoring programs is also essential to track trends in population health, diversity, and habitat use, ensuring that conservation strategies remain adaptive and effective under changing environmental conditions.

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APPENDICES

Appendix A: Data on body temperatures of Bornean frogs in different habitat types recorded from 2022 to 2023 in Sarawak.

Abbreviation: SVL, snout-vent-length: M, Male; F, Female; Juv, Juvenile; m, meter.

Field ID	Species Name	Locality		Coordinate in Decimal		Date
				Latitude	Longitude	
BJ01	<i>Duttaphrynus melanostictus</i>	Bung Jagoi, Bau	Side Stream, Sigon Duyoh	1.3516	110.3829	5/11/2022
BJ02	<i>Duttaphrynus melanostictus</i>		Side Stream, Sigon Duyoh	1.3406	110.0345	
BJ03	<i>Chalcorana megalonesa</i>		Side Stream, Sigon Duyoh	1.3406	110.0345	
BJ04	<i>Phrynoidis asper</i>		Side Stream, Sigon Duyoh	1.3390	110.0331	
BJ05	<i>Nyctixalus pictus</i>		Side Stream, Sigon Duyoh	1.3391	110.0331	
BJ06	<i>Fejervarya limnocharis</i>		Side Stream, Sigon Duyoh	1.3390	110.0333	
BJ07	<i>Ingerophrynus divergens</i>		Kebun Kelapa Sawit, Sigon Duyoh	1.3389	110.0331	
BJ08	<i>Chalcorana megalonesa</i>		Kebun Kelapa Sawit, Sigon Duyoh	1.3389	110.0331	
BJ09	<i>Polypedates leucomystax</i>		Kebun Kelapa Sawit, Sigon Duyoh	1.3389	110.0333	
BJ10	<i>Polypedates leucomystax</i>		Kebun Kelapa Sawit, Sigon Duyoh	1.3477	110.0393	
BJ11	<i>Polypedates leucomystax</i>		Kebun Kelapa Sawit, Sigon Duyoh	1.3477	110.0393	
BJ12	<i>Polypedates leucomystax</i>		Kebun Kelapa Sawit, Sigon Duyoh	1.3477	110.0393	

BJ13	<i>Polypedates leucomystax</i>		Kebun Kelapa Sawit, Sigon Duyoh	1.3389	110.0331	6/11/2022
BJ14	<i>Phrynoidis asper</i>		Kebun Kelapa Sawit, Sigon Duyoh	1.3477	110.0393	
BJ15	<i>Chalcorana megalonesa</i>		Kebun Kelapa Sawit, Sigon Duyoh	1.3478	110.0393	
BJ16	<i>Duttaphrynus melanostictus</i>		Kebun Kelapa Sawit, Sigon Duyoh	1.3479	110.0392	
BJ17	<i>Ingerophrynus divergens</i>		Kebun Kelapa Sawit, Sigon Duyoh	1.3479	110.0394	
BJ18	<i>Ansonia spinulifer</i>		Upstream, Bung Jagoi	1.3485	110.0396	
BJ19	<i>Limnonectes kuhlii</i>		Upstream, Bung Jagoi	1.3470	110.0394	
BJ20	<i>Staurois guttatus</i>		Upstream, Bung Jagoi	1.3569	110.0332	
BJ21	<i>Meristogenys jerboa</i>		Upstream, Bung Jagoi	1.3570	110.0331	
BJ22	<i>Staurois guttatus</i>		Upstream, Bung Jagoi	1.3570	110.0331	
BJ23	<i>Ansonia spinulifer</i>		Upstream, Bung Jagoi	1.3567	110.0330	
BJ24	<i>Ansonia spinulifer</i>		Upstream, Bung Jagoi	2.3567	111.0330	
BJ25	<i>Staurois guttatus</i>		Upstream, Bung Jagoi	3.3567	112.0330	
BJ26	<i>Limnonectes kuhlii</i>		Upstream, Bung Jagoi	4.3567	113.0330	
BJ27	<i>Ansonia spinulifer</i>		Upstream, Bung Jagoi	4.3567	113.0330	
BJ28	<i>Meristogenys jerboa</i>		Upstream, Bung Jagoi	4.3567	113.0330	

BJ29	<i>Ansonia spinulifer</i>		Upstream, Bung Jagoi	2.3567	111.0330	
BJ31	<i>Meristogenys jerboa</i>		Upstream, Bung Jagoi	1.3570	110.0331	
BJ32	<i>Limnonectes kuhlii</i>		Upstream, Bung Jagoi	1.3570	110.0331	
BJ33	<i>Leptotalax gracilis</i>		Upstream, Bung Jagoi	1.3570	110.0331	
BJ34	<i>Chalcorana megalonesa</i>		Upstream, Bung Jagoi	1.3570	110.0331	
BJ35	<i>Philautus tectus</i>		Bung Jagoi Trail, Bau	1.3567	110.0331	7/11/2022
BJ36	<i>Chalcorana raniceps</i>		Bung Jagoi Trail, Bau	1.3567	110.0331	
BJ37	<i>Duttaphrynus melanostictus</i>		Bung Jagoi Trail, Bau	1.3567	110.0331	
BJ38	<i>Chalcorana megalonesa</i>		Bung Jagoi Trail, Bau	1.3560	110.0328	
BJ39	<i>Chalcorana megalonesa</i>		Bung Jagoi Trail, Bau	1.3560	110.0326	
BJ40	<i>Limnonectes kuhlii</i>		Bung Jagoi Trail, Bau	1.3560	110.0326	
BJ41	<i>Chalcorana raniceps</i>		Bung Jagoi Trail, Bau	1.3475	110.0385	
BJ42	<i>Leptotalax gracilis</i>		Bung Jagoi Trail, Bau	1.3475	110.0385	
BJ43	<i>Leptotalax gracilis</i>		Bung Jagoi Trail, Bau	1.3475	110.0385	
BJ44	<i>Limnonectes kuhlii</i>		Bung Jagoi Trail, Bau	1.3475	110.0385	
BJ45	<i>Ansonia spinulifer</i>		Bung Jagoi Trail, Bau	1.3475	110.0385	

BJ46	<i>Ansonia spinulifer</i>		Bung Jagoi Trail, Bau	1.3475	110.0385	
BJ47	<i>Limnonectes kuhlii</i>		Bung Jagoi Trail, Bau	1.3475	110.0385	
BJ48	<i>Megophrys nasuta</i>		Bung Jagoi Trail, Bau	1.3475	110.0385	
BJ49	<i>Phrynoidis juxtasper</i>		Bung Jagoi Trail, Bau	1.3475	110.0385	
BJ50	<i>Hylarana erythraea</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	8/11/2022
BJ51	<i>Hylarana erythraea</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	
BJ52	<i>Hylarana erythraea</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	
BJ53	<i>Fejervarya cancrivora</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	
BJ54	<i>Hylarana erythraea</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	
BJ55	<i>Limnonectes kuhlii</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	
BJ56	<i>Hylarana erythraea</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	
BJ57	<i>Duttaphrynus melanostictus</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	
BJ58	<i>Hylarana erythraea</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	
BJ59	<i>Hylarana erythraea</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	
BJ60	<i>Duttaphrynus melanostictus</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	
BJ61	<i>Polypedates leucomystax</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	

BJ62	<i>Duttaphrynus melanostictus</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	
BJ63	<i>Duttaphrynus melanostictus</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	
BJ64	<i>Duttaphrynus melanostictus</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	
BJ65	<i>Megophrys nasuta</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	
MWC 1558	<i>Limnonectes paramacrodon</i>	Matang Wildlife Centre, Lundu	Picnic Trail	2.2276	112.2141	12/12/2022
MWC 1559	<i>Kurixalus appendiculatus</i>		Picnic Trail	2.2276	112.2141	
MWC 1560	<i>Leptobrachum abbotti</i>		Picnic Trail	2.2276	112.2141	
MWC 1561	<i>Phrynoidis asper</i>		Picnic Trail	2.2276	112.2141	
MWC 1562	<i>Polypedates macrotis</i>		Picnic Trail	2.2276	112.2141	
MWC 1563	<i>Polypedates macrotis</i>		Picnic Trail	2.2276	112.2141	
MWC 1564	<i>Polypedates macrotis</i>		Picnic Trail	2.2276	112.2141	
MWC 1565	<i>Kalophrynus meizon</i>		Picnic Trail	1.6119	110.1565	
MWC 1566	<i>Polypedates macrotis</i>		Picnic Trail	1.6119	110.1565	
MWC 1567	<i>Polypedates macrotis</i>		Picnic Trail	1.6119	110.1565	
MWC 1568	<i>Oocidozyga baluensis</i>		Picnic Trail	1.6119	110.1565	
MWC 1569	<i>Polypedates macrotis</i>		Picnic Trail	1.6119	110.1565	

MWC 1570	<i>Ingerophrynus divergens</i>		Picnic Trail	1.6119	110.1565	
MWC 1571	<i>Rhacophorus pardalis</i>		Picnic Trail	1.6119	110.1565	
MWC 1572	<i>Polypedates macrotis</i>		Picnic Trail	1.6119	110.1565	
MWC 1573	<i>Kurixalus appendiculatus</i>		Picnic Trail	1.6119	110.1565	
MWC 1574	<i>Kurixalus appendiculatus</i>		Picnic Trail	1.6119	110.1565	
MWC 1575	<i>Ingerophrynus divergens</i>		Picnic Trail	1.6119	110.1565	
MWC 1576	<i>Fejervarya limnocharis</i>		Picnic Trail	1.6119	110.1565	
MWC 1577	<i>Limnonectes leporinus</i>		Picnic Trail	1.6119	110.1565	
MWC 1578	<i>Polypedates macrotis</i>		Picnic Trail	1.6119	110.1565	
MWC 1579	<i>Fejervarya limnocharis</i>		Picnic Trail	1.6119	110.1565	
MWC 1580	<i>Polypedates colletti</i>		Trail to parking lot	1.6108	110.1564	13/12/2022
MWC 1581	<i>Kurixalis appendiculatus</i>		Trail to parking lot	1.6108	110.1564	
MWC 1582	<i>Ingerophrynus divergens</i>		Trail to parking lot	1.6108	110.1564	
MWC 1583	<i>Kurixalus appendiculatus</i>		Trail to parking lot	1.6108	110.1564	
MWC 1584	<i>Ingerophrynus divergens</i>		Trail to parking lot	1.6109	110.1563	
MWC 1585	<i>Kalophrynus meizon</i>		Trail to parking lot	1.6109	110.1563	

MWC 1586	<i>Pulchrana baramica</i>		Trail to parking lot	1.6109	110.1563	
MWC 1587	<i>Limnonectes leporinus</i>		Campsite	1.6103	110.1554	
MWC 1588	<i>Pulchrana signata</i>		Campsite	1.6103	110.1554	
MWC 1589	<i>Pulchrana baramica</i>		Campsite	1.6102	110.1552	
MWC 1590	<i>Limnonectes leporinus</i>		Campsite	1.6102	110.1552	
MWC 1591	<i>Limnonectes leporinus</i>		Campsite	1.6102	110.1552	
MWC 1592	<i>Odorrana hosii</i>		Campsite	1.6105	110.1549	
MWC 1593	<i>Odorrana hosii</i>		Campsite	1.6105	110.1549	
MWC 1594	<i>Megophrys nasuta</i>		Campsite	1.6105	110.1549	
MWC 1595	<i>Chaperina fusca</i>		Campsite	1.6105	110.1547	
MWC 1596	<i>Odorrana hosii</i>		Campsite	1.6106	110.1549	
MWC 1597	<i>Ingerophrynus divergens</i>		Campsite	1.6106	110.1549	
MWC 1598	<i>Pulchrana signata</i>		Campsite	1.6106	110.1549	
MWC 1599	<i>Pulchrana baramica</i>		Campsite	1.6102	110.1554	
MWC 1600	<i>Pulchrana signata</i>		Campsite	1.6102	110.1554	
MWC 1601	<i>Ingerophrynus divergens</i>		Campsite	1.6102	110.1554	

MWC 1602	<i>Limnonectes leporinus</i>		Campsite	1.6113	110.1566	
MWC 1603	<i>Ingerophrynus divergens</i>		Campsite	1.6113	110.1566	
MWC 1604	<i>Kalophrynus meizon</i>		Campsite	1.6113	110.1566	
MWC 1605	<i>Limnonectes malesianus</i>		Campsite	1.6122	110.1566	
MWC 1606	<i>Limnonectes leporinus</i>		Campsite	1.6122	110.1566	
MWC 1607	<i>Limnonectes leporinus</i>		Campsite	1.6122	110.1566	
MWC 1608	<i>Pulchrana signata</i>		Campsite	1.6122	110.1566	
MWC 1609	<i>Ingerophrynus divergens</i>		HQ	1.6095	110.1566	14/12/2022
MWC 1610	<i>Ingerophrynus divergens</i>		HQ	1.6095	110.1566	
MWC 1611	<i>Limnonectes malesianus</i>		HQ	1.6095	110.1566	
MWC 1612	<i>Pulchrana baramica</i>		HQ	1.6095	110.1566	
MWC 1613	<i>Polypedates macrotis</i>		HQ	1.6095	110.1566	
MWC 1614	<i>Polypedates colletti</i>		HQ	1.6112	110.1564	
MWC 1615	<i>Limnonectes malesianus</i>		HQ	1.6112	110.1564	
MWC 1616	<i>Kurixalus appendiculatus</i>		HQ	1.6108	110.1566	
MWC 1617	<i>Limnonectes malesianus</i>		HQ	1.6108	110.1567	

MWC 1618	<i>Fejervarya limnocharis</i>		HQ	1.6108	110.1567	
MWC 1619	<i>Rhacophorus pardalis</i>		HQ	1.6113	110.1562	
MWC 1620	<i>Fejervarya limnocharis</i>		HQ	1.6113	110.1562	
MWC 1621	<i>Ingerophrynus divergens</i>		HQ	1.6099	110.1569	
MWC 1622	<i>Ingerophrynus divergens</i>		HQ	1.6099	110.1569	
MWC 1623	<i>Fejervarya limnocharis</i>		HQ	1.6099	110.1569	
MWC 1624	<i>Limnonectes malesianus</i>		HQ	1.6099	110.1569	
MWC 1625	<i>Oocidozyga baluensis</i>		HQ	1.6099	110.1569	
UW166	<i>Duttaphrynus melanostictus</i>	West Campus, UNIMAS, Saramahan	Allamanda, UNIMAS	1.4677	110.4319	3/1/2023
UW167	<i>Duttaphrynus melanostictus</i>		Allamanda, UNIMAS	1.4677	110.4319	
UW168	<i>Duttaphrynus melanostictus</i>		Allamanda, UNIMAS	1.4677	110.4319	
UW169	<i>Duttaphrynus melanostictus</i>		Allamanda, UNIMAS	1.4677	110.4319	
UW170	<i>Limnonectes paramacrodon</i>		Allamanda, UNIMAS	1.4677	110.4319	
UW171	<i>Duttaphrynus melanostictus</i>		Allamanda, UNIMAS	1.4677	110.4319	
UW172	<i>Fejervarya limnocharis</i>		Allamanda, UNIMAS	1.4677	110.4319	
UW173	<i>Fejervarya limnocharis</i>		Arena Sukan, UNIMAS	1.4677	110.4319	4/1/2023

UW174	<i>Duttaphyrinus melanostictus</i>		Arena Sukan, UNIMAS	1.4677	110.4319	
UW175	<i>Pulcharana baramica</i>		Arena Sukan, UNIMAS	1.4677	110.4319	
UW176	<i>Duttaphyrinus melanostictus</i>		Arena Sukan, UNIMAS	1.4677	110.4319	
UW177	<i>Fejervarya limnocharis</i>		Arena Sukan, UNIMAS	1.4677	110.4319	
UW178	<i>Fejervarya limnocharis</i>		Arena Sukan, UNIMAS	1.4677	110.4319	
UW179	<i>Polypedates leucomystax</i>		Arena Sukan, UNIMAS	1.4677	110.4319	
UW180	<i>Fejervarya limnocharis</i>		Arena Sukan, UNIMAS	1.4677	110.4319	
UW181	<i>Hylarana erythraea</i>		Arena Sukan, UNIMAS	1.4677	110.4319	
UW182	<i>Duttaphyrinus melanostictus</i>		Arena Sukan, UNIMAS	1.4677	110.4319	
UW183	<i>Pulcharana baramica</i>		Allamanda, UNIMAS	1.4677	110.4319	5/1/2023
UW184	<i>Duttaphyrinus melanostictus</i>		Allamanda, UNIMAS	1.4677	110.4319	
UW185	<i>Duttaphyrinus melanostictus</i>		Allamanda, UNIMAS	1.4677	110.4319	
UW186	<i>Duttaphyrinus melanostictus</i>		Allamanda, UNIMAS	1.4677	110.4319	
UW187	<i>Duttaphyrinus melanostictus</i>		Allamanda, UNIMAS	1.4677	110.4319	
UW188	<i>Hylarana erythraea</i>		Jalan Merbau, UNIMAS	1.4677	110.4319	
UW189	<i>Fejervarya limnocharis</i>		Jalan Merbau, UNIMAS	1.4677	110.4319	

KTM1	<i>Duttaphyrinus melanostictus</i>	Kampong Telok Melano, Sematan	Kampung Telok Melano	2.007	109.6461	27/2/2023
KTM2	<i>Duttaphyrinus melanostictus</i>		Kampung Telok Melano	2.007	109.6461	
KTM3	<i>Duttaphyrinus melanostictus</i>		Kampung Telok Melano	2.007	109.6461	
KTM4	<i>Duttaphyrinus melanostictus</i>		Kampung Telok Melano	2.007	109.6461	
KTM5	<i>Duttaphyrinus melanostictus</i>		Kampung Telok Melano	2.007	109.6461	
KTM6	<i>Fejervarya limnocharis</i>		Kampung Telok Melano	2.007	109.6461	
KTM7	<i>Philautus sp.</i>		Kampung Telok Melano	2.007	109.6461	1/3/2023
KTM8	<i>Kaloula pulchra</i>		Kampung Telok Melano	2.007	109.6461	
KTM9	<i>Megophrys nasuta (Juvenile)</i>		Kampung Telok Melano	2.007	109.6461	
KTM10	<i>Fejervarya cancrivora</i>		Kampung Telok Melano	2.007	109.6461	
KTM11	<i>Kaloula pulchra</i>		Kampung Telok Melano	2.007	109.6461	
KTM12	<i>Fejervarya limnocharis</i>		Kampung Telok Melano	2.007	109.6461	
KTM13	<i>Fejervarya cancrivora</i>		Kampung Telok Melano	2.007	109.6461	
KTM14	<i>Fejervarya cancrivora</i>		Kampung Telok Melano	2.007	109.6461	
KTM15	<i>Fejervarya cancrivora</i>		Kampung Telok Melano	2.007	109.6461	
KTM16	<i>Fejervarya limnocharis</i>		Kampung Telok Melano	2.007	109.6461	

KTM17	<i>Kaloula pulchra</i>		Kampung Telok Melano	2.007	109.6461	2/3/2023
KTM18	<i>Fejervarya cancrivora</i>		Kampung Telok Melano	2.007	109.6461	
KTM19	<i>Fejervarya limnocharis</i>		Kampung Telok Melano	2.007	109.6461	
KTM20	<i>Hylarana erythraea</i>		Kampung Telok Melano	2.007	109.6461	
KTM21	<i>Fejervarya cancrivora</i>		Kampung Telok Melano	2.007	109.6461	
KTM22	<i>Fejervarya cancrivora</i>		Kampung Telok Melano	2.007	109.6461	
KTM23	<i>Kaloula pulchra</i>		Kampung Telok Melano	2.007	109.6461	
KTM24	<i>Fejervarya limnocharis</i>		Kampung Telok Melano	2.007	109.6461	
KTM25	<i>Kaloula pulchra</i>		Kampung Telok Melano	2.007	109.6461	
KTM26	<i>Kaloula pulchra</i>		Kampung Telok Melano	2.007	109.6461	
KTM27	<i>Kaloula pulchra</i>		Kampung Telok Melano	2.007	109.6461	
KTM28	<i>Fejervarya limnocharis</i>		Kampung Telok Melano	2.007	109.6461	
KTM29	<i>Fejervarya limnocharis</i>		Kampung Telok Melano	2.007	109.6461	
KTM30	<i>Fejervarya cancrivora</i>		Kampung Telok Melano	2.007	109.6461	
KTM31	<i>Fejervarya cancrivora</i>		Kampung Telok Melano	2.007	109.6461	
MNP01	<i>Pulchrana baramica</i>	Mulu National	Forbidden Nighttrail, HQ	4.1313	114.9099	9/5/2023

MNP02	<i>Pulchrana baramica</i>	Park, Long Lama Miri	Forbidden Nighttrail, HQ	4.1313	114.9099	
MNP15	<i>Leptolalax fritinniens</i>		Camp 1	4.0508	114.8546	10/5/2023
MNP16	<i>Leptolalax gracilis</i>		Camp 1	4.0508	114.8546	
MNP17	<i>Leptolalax gracilis</i>		Camp 1	4.0508	114.8546	
MNP18	<i>Leptobrachium abbotti</i>		Camp 1	4.0508	114.8546	
MNP19	<i>Pulchrana signata</i>		Camp 1	4.0508	114.8546	
MNP20	<i>Leptobrachium abbotti</i>		Camp 1	4.0508	114.8546	
MNP21	<i>Limnonectes kuhlii</i>		Camp 1	4.0508	114.8546	
MNP22	<i>Pulchrana signata</i>		Camp 1	4.0508	114.8546	
MNP23	<i>Phrynoidis juxtasper</i>		Camp 1; Stream Area	4.0508	114.8546	11/5/2023
MNP24	<i>Pulchrana signata</i>		Camp 1; Stream Area	4.0508	114.8546	
MNP25	<i>Huia cavitympanum</i>		Camp 1; Stream Area	4.0508	114.8546	
MNP26	<i>Megophrys nasuta</i>		Camp 1; Stream Area	4.0508	114.8546	
MNP27	<i>Huia cavitympanum</i>		Camp 1; Stream Area	4.0508	114.8546	
MNP28	<i>Limnonectes leporinus</i>		Camp 1; Stream Area	4.0508	114.8546	
MNP29	<i>Limnonectes leporinus</i>		Camp 1; Stream Area	4.0508	114.8546	

MNP30	<i>Limnonectes leporinus</i>		Camp 1; Stream Area	4.0508	114.8546	
MNP31	<i>Huia cavitympanum</i>		Camp 1; Stream Area	4.0508	114.8546	
MNP32	<i>Staurois latopalmatus</i>		Camp 1; Stream Area	4.0508	114.8546	
MNP33	<i>Limnonectes ibanorum</i>		Camp 1; Stream Area	4.0508	114.8546	
MNP34	<i>Staurois latopalmatus</i>		Camp 1; Stream Area	4.0508	114.8546	
MNP35	<i>Staurois latopalmatus</i>		Camp 1; Stream Area	4.0508	114.8546	
MNP36	<i>Phrynoidis juxtasper</i>		Camp 1; Stream Area	4.0508	114.8546	
MNP37	<i>Pulchrana baramica</i>		Botanical Garden Trail, HQ	4.1313	114.9099	12/5/2023
MNP38	<i>Pulchrana glandulosa</i>		Botanical Garden Trail, HQ	4.1313	114.9099	
MNP39	<i>Pulchrana glandulosa</i>		Botanical Garden Trail, HQ	4.1313	114.9099	
MNP40	<i>Pulchrana glandulosa</i>		Botanical Garden Trail, HQ	4.1313	114.9099	
MNP41	<i>Pulchrana glandulosa</i>		Botanical Garden Trail, HQ	4.1313	114.9099	
MNP42	<i>Limnonectes malesianus</i>		Botanical Garden Trail, HQ	4.1313	114.9099	
MNP43	<i>Limnonectes ingeri</i>		Botanical Garden Trail, HQ	4.1313	114.9099	
MNP44	<i>Limnonectes ingeri</i>		Botanical Garden Trail, HQ	4.1313	114.9099	
MNP45	<i>Kurixalus appendiculatus</i>		Botanical Garden Trail, HQ	4.1313	114.9099	

MNP46	<i>Microhyla borneensis</i>		Botanical Garden Trail, HQ	4.1313	114.9099	
MNP47	<i>Kurixalus appendiculatus</i>		Botanical Garden Trail, HQ	4.1313	114.9099	
MNP48	<i>Ingerophrynus divergens</i>		Botanical Garden Trail, HQ	4.1313	114.9099	
MNP49	<i>Pulchrana glandulosa</i>		Botanical Garden Trail, HQ	4.1313	114.9099	
MNP50	<i>Ingerophrynus divergens</i>		Botanical Garden Trail, HQ	4.1313	114.9099	
MNP51	<i>Phrynoidis juxtasper</i>		Botanical Garden Trail, HQ	4.1313	114.9099	
MNP52	<i>Pulchrana baramica</i>		Botanical Garden Trail, HQ	4.1313	114.9099	
MNP53	<i>Polypedates leucomystax</i>		Kampung Mulu	4.0330	114.7948	13/5/2023
MNP54	<i>Polypedates leucomystax</i>		Kampung Mulu	4.0330	114.7948	
MNP55	<i>Fejervarya limnocharis</i>		Kampung Mulu	4.0330	114.7948	
MNP56	<i>Rhacophorus pardalis</i>		Kampung Mulu	4.0330	114.7948	
MNP57	<i>Polypedates leucomystax</i>		Kampung Mulu	4.0330	114.7948	
MNP58	<i>Polypedates leucomystax</i>		Kampung Mulu	4.0330	114.7948	
MNP59	<i>Polypedates leucomystax</i>		Kampung Mulu	4.0330	114.7948	
MNP60	<i>Fejervarya limnocharis</i>		Kampung Mulu	4.0330	114.7948	
MNP61	<i>Fejervarya limnocharis</i>		Kampung Mulu	4.0330	114.7948	

MNP62	<i>Pulchrana baramica</i>		Kampung Mulu	4.0330	114.7948	
MNP63	<i>Fejervarya limnocharis</i>		Kampung Mulu	4.0330	114.7948	
MNP64	<i>Fejervarya limnocharis</i>		Kampung Mulu	4.0330	114.7948	
MNP65	<i>Pulchrana baramica</i>		Kampung Mulu	4.0330	114.7948	
MNP66	<i>Polypedates leucomystax</i>		Kampung Mulu	4.0330	114.7948	
MNP67	<i>Polypedates leucomystax</i>		Kampung Mulu	4.0330	114.7948	
MNP68	<i>Fejervarya limnocharis</i>		Kampung Mulu	4.0330	114.7948	
MNP87	<i>Polypedates leucomystax</i>		Kpg Long Iman	4.4447	114.0109	14/5/2023
MNP88	<i>Polypedates leucomystax</i>		Kpg Long Iman	4.4447	114.0109	
MNP89	<i>Polypedates leucomystax</i>		Kpg Long Iman	4.4447	114.0109	
MNP90	<i>Polypedates leucomystax</i>		Kpg Long Iman	4.4447	114.0109	
MNP91	<i>Polypedates leucomystax</i>		Kpg Long Iman	4.4447	114.0109	
MNP92	<i>Polypedates leucomystax</i>		Kpg Long Iman	4.4447	114.0109	
MNP93	<i>Polypedates leucomystax</i>		Kpg Long Iman	4.4447	114.0109	
MNP94	<i>Polypedates leucomystax</i>		Kpg Long Iman	4.4447	114.0109	
MNP95	<i>Polypedates leucomystax</i>		Kpg Long Iman	4.4447	114.0109	

MNP96	<i>Polypedates leucomystax</i>		Kpg Long Iman	4.4447	114.0109	
MNP97	<i>Polypedates leucomystax</i>		Kpg Long Iman	4.4447	114.0109	
MNP98	<i>Fejervarya limnocharis</i>		Kpg Long Iman	4.4447	114.0109	
MNP99	<i>Polypedates leucomystax</i>		Kpg Long Iman	4.4447	114.0109	
MNP100	<i>Fejervarya limnocharis</i>		Kpg Long Iman	4.4447	114.0109	
MNP101	<i>Polypedates leucomystax</i>		Kpg Long Iman	4.4447	114.0109	
MNP102	<i>Fejervarya limnocharis</i>		Kpg Long Iman	4.4447	114.0109	
MNP103	<i>Fejervarya limnocharis</i>		Kpg Long Iman	4.4447	114.0109	
MNP104	<i>Fejervarya limnocharis</i>		Kpg Long Iman	4.4447	114.0109	

Appendix B: Continuation on data on body temperatures of Bornean frogs in different habitat types recorded from 2022 to 2023 in Sarawak.

Abbreviation: SVL, snout-vent-length; M, Male; F, Female; Juv, Juvenile; m, meter.

Field ID	Sex (M/F/Juv)	Body Temperature °C			Substrate Temperature °C			Ambient Temperature °C			Relative Humidity %		
		1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
BJ01	F	24.9	24.9	24.9	27.0	27.0	27.0	27.8	27.8	27.8	82.2	82.2	82.2
BJ02	F	23.7	23.7	23.7	24.3	24.2	24.5	28.4	28.1	28.1	81.0	83.2	82.5
BJ03	F	23.5	23.4	23.3	23.5	23.6	23.5	27.8	27.8	27.9	82.0	81.9	81.9
BJ04	M	23.1	23.1	23.2	22.5	22.5	22.6	27.5	27.5	27.5	81.3	81.5	81.3
BJ05	F	23.2	23.2	23.5	23.0	23.0	23.1	27.4	27.5	27.5	80.2	80.3	80.3
BJ06	M	21.5	21.5	21.6	21.8	21.8	22.0	27.8	27.9	28.0	83.3	82.5	82.9
BJ07	F	23.1	23.1	23.0	22.8	22.6	22.9	28.1	27.9	27.9	81.6	82.4	82.2
BJ08	M	23.1	23.1	23.1	23.1	22.8	23.2	28.2	28.5	28.4	80.8	83.2	81.4
BJ09	M	20.4	20.6	20.6	20.7	20.6	20.6	27.8	27.8	27.9	80.7	80.7	80.7
BJ10	M	21.9	22.3	21.9	21.2	21.2	22.3	28.3	28.2	28.2	81.2	81.3	81.2
BJ11	M	21.3	21.3	21.3	21.9	21.8	21.8	28.3	28.3	28.3	81.3	81.2	81.2
BJ12	M	21.2	21.5	21.3	21.7	21.6	21.8	28.1	28.4	28.1	81.0	81.5	81.4
BJ13	M	20.5	20.4	20.4	20.6	20.6	20.8	28.0	28.0	28.1	81.5	81.5	81.5
BJ14	F	21.6	21.6	21.8	21.8	21.8	21.9	28.2	28.3	28.3	83.1	82.9	82.9
BJ15	F	20.7	20.5	20.8	21.0	20.8	20.9	27.6	27.6	27.5	82.5	82.5	82.6
BJ16	F	20.6	20.6	20.7	21.1	21.4	21.3	27.8	27.8	27.7	82.0	82.3	82.4
BJ17	F	22.5	23.8	23.7	23.9	24.0	23.8	27.5	27.8	27.7	83.2	83.2	83.3
BJ18	M	22.9	23.0	22.9	23.0	22.9	22.8	27.3	27.3	27.3	86.4	86.4	86.1
BJ19	M	21.3	20.9	21.0	21.4	21.6	21.3	27.5	27.5	27.4	85.3	85.3	85.4

BJ20	M	23.1	23.1	23.0	23.1	23.0	23.0	27.3	27.4	27.4	87.3	86.6	84.7
BJ21	M	23.0	23.1	23.0	23.0	23.0	23.0	27.1	27.1	27.1	86.3	86.3	86.3
BJ22	M	22.3	22.1	22.0	21.8	22.3	22.2	26.8	26.7	26.6	86.5	86.5	86.4
BJ23	M	22.5	22.2	22.2	22.0	22.0	22.0	26.5	26.5	26.5	85.2	85.2	85.2
BJ24	M	22.5	22.4	22.4	22.2	22.2	22.4	26.7	26.7	26.7	85.3	85.3	85.3
BJ25	F	22.9	22.8	23.0	23.1	23.2	23.2	27.2	27.2	27.2	85.2	85.2	85.2
BJ26	M	23.0	22.7	22.7	23.0	23.1	22.9	27.3	27.4	27.6	85.2	85.2	85.2
BJ27	M	22.4	22.3	22.3	22.4	22.4	22.4	27.1	27.1	27.1	83.6	83.6	83.6
BJ28	M	22.9	22.9	22.9	23.0	23.0	23.0	27.5	27.5	27.5	82.9	82.9	82.9
BJ29	M	24.0	24.0	24.0	24.3	24.3	24.3	26.3	26.3	26.3	87.0	87.0	87.0
BJ31	M	22.5	22.4	22.4	22.2	22.2	22.4	26.5	26.5	26.5	86.4	86.4	86.0
BJ32	F	22.7	22.7	22.7	23.0	23.0	23.0	26.5	26.5	26.3	86.5	86.5	86.5
BJ33	F	22.9	22.7	22.7	23.2	23.1	23.2	26.4	26.4	26.4	86.8	86.8	86.8
BJ34	F	23.2	23.2	23.3	23.0	22.9	23.1	27.0	26.9	27.2	85.9	86.2	86.2
BJ35	F	22.5	22.4	22.3	22.1	22.2	22.2	27.5	27.5	27.5	83.2	83.0	83.3
BJ36	F	22.3	22.1	22.1	21.9	21.8	22.1	26.9	26.8	26.8	85.6	85.4	85.5
BJ37	M	21.3	21.5	21.2	20.9	21.2	21.3	27.8	27.8	27.8	83.1	83.0	83.3
BJ38	M	20.5	20.5	20.4	20.4	20.4	20.6	27.3	27.3	27.3	84.9	84.9	84.9
BJ39	M	21.3	21.2	21.2	21.3	21.3	21.4	27.2	27.3	27.3	84.9	84.9	84.9
BJ40	F	23.6	23.6	23.5	23.3	23.4	23.4	27.7	27.7	27.7	82.4	82.4	82.4
BJ41	F	21.8	21.6	21.5	21.7	21.6	21.5	27.4	27.4	27.4	82.4	82.4	82.4
BJ42	M	23.5	23.4	23.5	24.1	23.9	23.0	26.5	26.5	26.5	87.7	87.7	87.7
BJ43	F	22.5	22.4	22.5	22.6	22.6	22.7	26.1	26.1	26.1	88.2	88.2	88.2
BJ44	M	21.8	21.9	21.8	21.8	21.8	21.7	28.6	28.6	28.6	80.5	80.5	80.5
BJ45	M	22.7	22.8	22.9	22.8	22.8	22.8	26.0	26.0	26.0	87.9	87.9	87.9
BJ46	M	21.7	21.6	21.6	21.5	21.4	21.4	28.4	28.4	28.4	79.4	79.4	79.4
BJ47	F	22.8	23.0	23.0	22.3	22.4	22.3	28.2	28.2	28.2	85.3	85.3	85.3

BJ48	F	21.6	21.6	21.6	21.6	21.5	21.5	26.1	26.1	26.1	87.1	87.1	87.1
BJ49	F	23.1	23.1	23.0	22.0	29.9	22.0	26.4	26.4	26.4	87.3	87.3	87.3
BJ50	F	21.0	20.8	20.8	20.7	20.8	20.8	27.3	27.4	27.3	86.2	86.2	86.3
BJ51	M	21.1	21.1	21.1	20.9	20.8	20.9	27.5	27.5	27.6	87.4	87.3	87.3
BJ52	M	21.2	21.1	21.0	21.1	21.0	21.2	26.9	26.9	26.8	86.9	86.9	86.9
BJ53	F	21.5	21.6	21.4	21.4	21.4	21.3	27.6	27.7	27.7	87.0	87.2	87.2
BJ54	F	21.4	21.4	21.3	21.3	21.3	21.3	27.8	27.8	27.8	87.2	87.2	87.3
BJ55	F	20.8	20.8	20.7	20.9	21.2	21.1	28.1	28.2	28.2	86.5	86.5	86.5
BJ56	F	21.0	21.0	21.1	21.2	21.2	21.1	27.6	27.6	27.6	86.4	86.4	86.4
BJ57	F	22.0	21.9	21.9	21.9	22.1	22.2	27.3	27.4	27.3	86.2	86.2	86.3
BJ58	F	21.3	21.4	21.5	21.5	21.5	21.4	27.8	27.8	27.8	87.2	87.2	87.3
BJ59	M	21.5	21.5	21.3	21.4	21.3	21.3	27.3	27.4	27.3	86.2	86.2	86.3
BJ60	F	22.2	22.3	22.2	22.0	22.1	22.1	28.1	28.2	28.2	86.5	86.5	86.5
BJ61	M	21.9	21.8	21.8	21.6	21.6	21.7	27.6	27.7	27.7	87.0	87.2	87.2
BJ62	F	22.3	22.4	22.3	22.5	22.4	22.3	27.3	27.4	27.3	86.2	86.2	86.3
BJ63	M	22.4	22.3	22.3	22.4	22.4	22.3	27.8	27.8	27.8	85.1	85.0	85.3
BJ64	M	22.6	22.6	22.4	22.6	22.5	22.5	27.8	27.8	27.7	85.0	85.3	85.4
BJ65	M	22.4	22.6	22.5	22.5	22.4	22.4	27.5	27.6	27.7	86.2	86.0	86.3
MWC 1558	M	20.8	21.1	21.2	20.7	20.8	20.8	28.4	28.5	28.5	77.3	76.4	76.0
MWC 1559	M	21.9	21.9	21.9	21.8	21.8	21.8	28.5	28.6	28.6	77.3	76.4	76.0
MWC 1560	M	21.5	21.4	21.6	20.5	20.6	20.5	28.4	28.4	28.5	77.3	76.4	76.0
MWC 1561	F	22.1	22.0	21.9	21.4	21.4	21.5	28.5	28.4	28.5	73.9	74.8	74.9
MWC 1562	F	21.6	21.6	21.7	21.2	21.2	21.3	28.5	28.4	28.5	73.9	74.8	74.9
MWC 1563	M	21.4	21.4	21.4	20.8	20.7	20.9	28.5	28.4	28.5	73.9	74.8	74.9
MWC 1564	M	21.6	21.5	21.5	21.5	21.4	21.5	28.5	28.4	28.5	73.9	74.8	74.9
MWC 1565	F	21.0	21.1	21.2	21.2	21.6	21.6	28.3	28.2	28.2	74.9	74.3	74.2
MWC 1566	M	21.8	21.7	21.8	21.7	21.7	21.8	28.3	28.2	28.2	74.9	74.3	74.2

MWC 1567	M	21.7	21.7	21.8	21.6	21.7	21.8	28.3	28.2	28.2	74.9	74.3	74.2
MWC 1568	F	22.1	22.2	22.3	22.1	22.2	21.9	28.3	28.2	28.2	74.9	74.3	74.2
MWC 1569	M	21.7	21.8	21.9	21.8	21.8	21.9	28.3	28.2	28.2	74.9	74.3	74.2
MWC 1570	M	21.6	21.6	21.5	21.4	21.4	21.4	28.3	28.2	28.2	74.9	74.3	74.2
MWC 1571	M	21.6	21.7	21.7	22.4	22.4	22.3	28.2	28.3	28.2	75.7	75.7	75.2
MWC 1572	M	22.3	22.2	22.4	21.1	21.2	21.1	28.2	28.3	28.2	75.7	75.7	75.7
MWC 1573	M	20.3	20.4	20.5	20.3	20.2	20.3	29.0	29.0	28.9	75.2	7.3	75.4
MWC 1574	M	20.3	20.3	20.2	20.3	20.4	20.3	28.5	28.6	28.6	75.4	75.4	75.7
MWC 1575	F	20.9	20.9	20.8	21.2	21.2	21.1	28.4	28.3	28.4	76.2	75.3	75.6
MWC 1576	F	23.5	23.5	23.4	23.4	23.4	23.4	28.4	28.3	28.4	76.2	75.3	75.6
MWC 1577	M	21.9	22.0	22.2	22.3	22.0	21.9	28.4	28.3	28.4	76.2	75.3	75.6
MWC 1578	F	21.5	21.7	21.6	22.2	22.2	22.1	28.3	28.3	28.4	75.5	74.9	75.1
MWC 1579	F	20.9	20.9	20.7	20.8	20.7	20.7	27.9	27.9	27.9	76.1	75.4	75.3
MWC 1580	F	22.1	22.2	22.2	22.1	22.1	22.1	27.9	27.9	27.9	76.1	75.4	75.3
MWC 1581	M	22.3	22.1	22.3	22.1	22.1	22.1	27.9	27.9	27.9	76.1	75.4	75.3
MWC 1582	M	23.0	22.9	22.8	22.8	22.8	22.7	27.9	27.9	27.9	76.1	75.4	75.3
MWC 1583	M	23.7	23.6	23.5	23.5	23.5	23.5	27.9	27.9	27.9	76.1	75.4	75.3
MWC 1584	F	23.8	23.8	23.8	23.4	23.1	23.0	27.9	27.9	27.9	76.1	75.4	75.3
MWC 1585	M	23.2	23.0	23.2	22.9	22.9	22.8	28.2	28.3	28.3	82.8	83.0	82.8
MWC 1586	F	23.4	23.4	23.3	23.2	23.3	23.2	28.2	28.3	28.3	82.8	83.0	82.8
MWC 1587	M	22.3	22.2	22.3	23.3	23.3	23.3	28.9	28.9	29.0	80.5	79.5	79.5
MWC 1588	M	22.4	22.5	22.5	22.4	22.3	22.2	28.9	28.9	29.0	80.5	79.5	79.5
MWC 1589	F	23.2	23.1	23.0	23.0	23.2	23.1	28.9	28.9	29.0	80.5	79.5	79.5
MWC 1590	F	22.8	22.7	22.7	22.7	22.6	22.5	28.9	28.9	29.0	80.5	79.5	79.5
MWC 1591	M	23.3	23.4	23.3	23.4	23.5	23.4	28.9	28.9	29.0	80.5	79.5	79.5
MWC 1592	F	23.5	23.4	23.3	28.8	28.8	28.9	28.9	28.9	29.0	80.5	79.5	79.5
MWC 1593	M	20.2	20.2	20.2	20.1	20.1	20.1	28.6	28.6	28.6	82.4	82.8	82.8

MWC 1594	JUV	21.2	21.3	21.2	21.0	21.2	21.1	28.6	28.6	28.6	82.4	82.8	82.8
MWC 1595	F	20.0	19.9	19.8	22.0	22.0	22.0	28.7	28.8	28.8	83.6	83.6	83.6
MWC 1596	M	22.0	22.0	22.1	22.0	22.0	22.1	28.7	28.8	28.8	83.6	83.6	83.6
MWC 1597	M	22.1	22.1	22.0	21.9	22.0	22.1	29.1	29.1	29.2	81.4	81.0	81.1
MWC 1598	M	21.9	21.8	22.0	21.8	21.8	21.9	29.1	29.1	29.2	81.4	81.0	81.1
MWC 1599	F	21.5	21.6	21.6	21.6	21.6	21.6	29.3	29.3	29.3	82.4	83.2	82.2
MWC 1600	M	21.6	21.6	21.7	21.5	21.5	21.6	29.3	29.3	29.3	82.4	83.2	82.2
MWC 1601	M	22.1	22.0	22.0	22.0	22.1	22.1	29.3	29.3	29.3	82.4	83.2	82.2
MWC 1602	F	21.7	21.8	21.8	21.8	21.9	21.9	28.9	29.0	29.0	82.4	82.3	80.9
MWC 1603	F	22.8	22.9	22.9	22.6	22.5	22.7	28.9	29.0	29.0	82.4	82.3	80.9
MWC 1604	F	21.7	21.8	21.8	21.6	21.5	21.7	28.9	29.0	29.0	82.4	82.3	80.9
MWC 1605	JUV	22.9	22.7	22.7	23.9	23.9	23.9	28.9	29.0	29.0	82.4	82.3	80.9
MWC 1606	JUV	22.5	22.6	22.7	22.4	22.5	22.6	28.9	29.0	29.0	82.4	82.3	80.9
MWC 1607	JUV	22.5	22.5	22.5	22.3	22.2	22.1	28.9	29.0	29.0	82.4	82.3	80.9
MWC 1608	M	22.4	22.5	22.7	22.3	22.4	22.5	28.9	29.0	29.0	82.4	82.3	80.9
MWC 1609	M	22.4	22.3	22.4	22.4	22.4	22.4	28.4	28.4	28.5	89.8	89.4	89.1
MWC 1610	M	22.4	22.3	22.4	22.4	22.4	22.4	28.4	28.4	28.5	89.8	89.4	89.1
MWC 1611	JUV	26.4	26.4	26.9	26.3	26.2	26.2	28.4	28.4	28.5	89.8	89.4	89.1
MWC 1612	F	24.2	24.2	24.1	24.1	24.0	24.0	28.4	28.4	28.5	89.8	89.4	89.1
MWC 1613	F	23.9	23.8	24.0	25.4	25.4	25.4	28.4	28.4	28.5	89.8	89.4	89.1
MWC 1614	F	23.4	23.5	23.4	23.1	23.2	23.3	28.4	28.4	28.5	89.8	89.4	89.1
MWC 1615	JUV	23.6	23.3	23.3	23.4	23.5	23.4	28.4	28.4	28.5	89.8	89.4	89.1
MWC 1616	M	23.4	23.5	23.6	23.2	23.2	23.3	28.4	28.4	28.5	89.8	89.4	89.1
MWC 1617	JUV	24.2	24.1	24.2	24.2	24.1	24.1	30.0	30.0	29.9	86.8	85.2	84.5
MWC 1618	M	24.9	24.8	24.9	24.8	24.8	24.8	29.5	29.4	29.3	82.9	82.9	82.3
MWC 1619	F	21.9	22.0	21.9	22.0	22.0	22.1	29.9	29.9	29.9	87.3	86.8	86.1
MWC 1620	F	24.4	24.5	24.6	24.6	24.5	24.7	29.9	29.9	29.9	87.3	86.8	86.1

MWC 1621	F	24.3	24.2	24.3	24.2	24.2	24.2	29.9	29.9	29.9	87.3	86.8	86.1
MWC 1622	F	23.2	22.9	22.9	22.6	22.5	22.5	29.9	29.9	29.9	87.3	86.8	86.1
MWC 1623	F	24.3	24.2	24.3	24.5	24.4	24.3	29.9	29.9	29.9	87.3	86.8	86.1
MWC 1624	M	22.8	22.8	22.8	22.7	22.6	22.6	29.9	29.9	29.9	87.3	86.8	86.1
MWC 1625	F	22.1	22.1	22.1	22.0	22.0	22.1	29.9	29.9	29.9	87.3	86.8	86.1
UW166	M	25.5	25.4	25.5	25.4	25.3	25.5	27.1	27.3	27.3	79.4	79.2	29.6
UW167	M	25.0	25.0	25.0	24.9	24.9	24.9	27.1	27.3	27.3	79.4	79.2	29.6
UW168	F	25.5	25.5	25.3	25.4	25.3	25.4	27.1	27.3	27.3	79.4	79.2	29.6
UW169	F	25.2	25.1	24.7	24.8	24.9	24.9	27.1	27.3	27.3	79.4	79.2	29.6
UW170	M	25.5	25.5	25.5	25.4	25.3	25.4	27.1	27.3	27.3	79.4	79.2	29.6
UW171	M	24.4	24.3	24.5	24.0	24.3	24.2	27.1	27.3	27.3	79.4	79.2	29.6
UW172	M	24.7	24.7	24.9	24.9	24.8	24.8	27.1	27.3	27.3	79.4	79.2	29.6
UW173	M	24.8	24.8	24.9	24.8	24.8	24.8	28.9	27.9	27.7	75.6	77.8	77.8
UW174	F	24.0	24.0	24.0	23.8	23.9	24.0	28.9	27.9	27.7	75.6	77.8	77.8
UW175	M	23.6	23.5	23.6	23.8	23.8	23.9	29.0	28.9	29.0	73.7	76.8	78.9
UW176	F	24.2	24.0	24.3	24.5	24.5	24.6	29.0	28.9	29.0	73.7	76.8	78.9
UW177	M	25.6	25.5	25.4	26.0	25.6	25.8	29.0	28.9	29.0	73.7	76.8	78.9
UW178	F	24.4	24.3	24.3	24.3	24.3	24.4	30.4	29.7	29.3	77.4	73.0	74.2
UW179	M	24.2	24.0	24.2	24.1	24.3	24.3	30.4	29.7	29.3	77.4	73.0	74.2
UW180	F	24.6	24.5	24.5	24.4	24.5	24.6	30.4	29.7	29.3	77.4	73.0	74.2
UW181	F	23.9	23.9	23.9	23.7	23.7	23.7	30.4	29.7	29.3	77.4	73.0	74.2
UW182	JUV	24.0	24.1	24.0	24.1	24.2	24.1	30.4	29.7	29.3	77.4	73.0	74.2
UW183	M	24.3	24.3	24.4	24.4	24.4	24.4	27.3	27.5	27.5	84.8	89.8	83.5
UW184	F	24.8	24.7	24.9	24.8	24.6	24.8	27.3	27.5	27.5	84.8	89.8	83.5
UW185	M	24.8	24.8	24.8	26.1	26.1	26.2	27.3	27.5	27.5	84.8	89.8	83.5
UW186	JUV	24.8	24.8	24.8	25.1	25.0	25.0	27.3	27.5	27.5	83.5	89.8	83.5
UW187	F	24.3	24.3	24.3	24.4	24.4	24.4	27.3	27.5	27.5	84.8	89.8	83.5

UW188	F	28.2	28.2	28.1	26.5	26.4	26.3	28.8	28.8	28.6	81.8	80.8	80.7
UW189	F	26.1	26.2	26.3	26.4	26.5	26.4	28.8	28.8	28.6	81.8	80.8	80.7
KTM1	M	24.4	25.5	25.4	25.3	25.4	25.3	28.0	28.0	28.0	80.3	80.7	80.8
KTM2	M	25.8	25.8	25.8	25.9	26.0	26.0	28.0	28.0	28.0	80.3	80.7	80.8
KTM3	M	26.0	26.4	26.4	26.4	26.3	26.3	28.0	28.0	28.0	80.3	80.7	80.8
KTM4	F	25.4	25.8	25.9	25.8	25.9	25.8	28.0	28.1	28.1	81.3	81.6	81.7
KTM5	F	26.0	26.0	25.9	26.0	25.9	25.8	28.0	28.1	28.1	81.3	81.6	81.7
KTM6	M	25.6	25.5	25.4	25.5	25.4	25.0	28.0	28.1	28.1	81.3	81.6	81.7
KTM7	M	24.3	24.3	24.3	24.3	24.3	24.1	25.6	25.6	25.7	87.2	87.3	87.4
KTM8	JUV/M	24.4	24.4	24.3	24.5	24.5	24.4	25.6	25.6	25.7	87.2	87.3	87.4
KTM9	JUV	24.6	24.6	24.6	24.7	24.7	24.7	25.6	25.6	25.7	87.2	87.3	87.4
KTM10	F	25.4	25.4	25.5	25.4	25.5	25.5	25.6	25.6	25.7	87.2	87.3	87.4
KTM11	JUV	25.1	25.2	25.3	25.0	25.1	25.1	25.6	25.6	25.7	87.2	87.3	87.4
KTM12	M	24.9	24.9	24.8	24.6	24.6	24.7	25.6	25.6	25.7	87.2	87.3	87.4
KTM13	JUV	24.8	24.7	24.7	24.6	24.5	24.6	25.6	25.6	25.7	87.2	87.3	87.4
KTM14	F	24.8	24.8	24.9	24.7	24.6	24.7	25.6	25.6	25.7	87.2	87.3	87.4
KTM15	M	25.1	25.2	25.2	25.1	25.1	25.2	25.6	25.6	25.7	87.2	87.3	87.4
KTM16	M	26.5	26.4	26.5	26.3	26.4	26.5	25.6	25.6	25.7	87.2	87.3	87.4
KTM17	M	25.6	25.7	25.8	25.3	25.3	25.4	25.6	25.6	25.7	87.2	87.3	87.4
KTM18	F	26.1	26.2	26.2	25.9	25.8	25.9	25.6	25.6	25.7	87.2	87.3	87.4
KTM19	F	26.7	26.7	26.6	26.5	26.6	26.4	25.6	25.6	25.7	87.2	87.3	87.4
KTM20	M	27.1	27.1	27.2	27.2	27.3	27.2	25.6	25.6	25.7	87.2	87.3	87.4
KTM21	F	26.9	26.9	26.8	26.6	26.6	26.6	25.6	25.6	25.7	87.2	87.3	87.4
KTM22	M	25.1	25.1	25.2	25.2	25.2	25.1	25.6	25.6	25.7	87.2	87.3	87.4
KTM23	M	25.4	25.5	25.6	25.5	25.3	25.2	25.6	25.6	25.7	87.2	87.3	87.4
KTM24	F	25.3	25.3	25.2	25.0	25.2	25.2	25.6	25.6	25.7	87.2	87.3	87.4
KTM25	F	26.7	26.7	26.7	26.8	26.8	26.8	25.6	25.6	25.7	87.2	87.3	87.4

KTM26	F	25.7	25.6	25.5	25.4	25.5	25.5	25.6	25.6	25.7	87.2	87.3	87.4
KTM27	M	26.1	26.2	26.3	26.2	26.2	26.3	25.6	25.6	25.7	87.2	87.3	87.4
KTM28	M	26.3	26.3	26.3	26.3	26.2	26.3	27.7	27.8	28.1	86.8	86.3	86.1
KTM29	F	26.7	26.7	26.6	26.6	26.6	26.6	27.7	27.8	28.1	86.8	86.3	86.1
KTM30	M	26.5	26.4	26.4	26.3	26.4	26.4	27.7	27.8	28.1	86.8	86.3	86.1
KTM31	M	26.1	26.2	26.1	26.0	26.0	26.0	27.7	27.8	28.1	86.8	86.3	86.1
MNP01	F	24.9	24.9	24.9	23.6	23.9	24.0	29.8	29.9	29.9	81.5	81.3	81.4
MNP02	JUV	24.4	24.4	24.5	24.3	24.3	24.4	29.8	29.9	29.9	81.5	81.3	81.4
MNP15	JUV/M	24.2	24.4	24.3	24.3	24.3	24.2	30.2	30.1	30.1	78.8	79.8	80.2
MNP16	JUV/M	26.2	26.1	26.1	26.4	26.4	26.5	30.2	30.1	30.1	78.8	79.8	80.2
MNP17	M	25.5	25.5	25.4	25.6	25.6	25.5	30.2	30.1	30.1	78.8	79.8	80.2
MNP18	M	26.5	26.5	26.8	26.3	26.3	26.4	30.2	30.1	30.1	78.8	79.8	80.2
MNP19	F	24.5	24.4	24.3	24.7	24.8	24.5	30.2	30.1	30.1	78.8	79.8	80.2
MNP20	JUV/M	24.6	24.9	24.8	24.6	24.9	24.8	30.2	30.1	30.1	78.8	79.8	80.2
MNP21	F	24.3	24.3	24.2	24.3	24.3	24.3	30.2	30.1	30.1	78.8	79.8	80.2
MNP22	M	25.4	25.4	25.3	25.3	25.4	25.5	30.2	30.1	30.1	78.8	79.8	80.2
MNP23	M	24.5	24.6	24.7	24.4	24.3	24.4	30.2	30.1	30.1	78.8	79.8	80.2
MNP24	F	24.3	24.2	24.2	24.2	24.2	24.2	30.2	30.1	30.1	78.8	79.8	80.2
MNP25	M	24.6	24.5	24.4	24.4	24.4	24.3	30.2	30.1	30.1	78.8	79.8	80.2
MNP26	F	24.5	24.5	24.4	24.4	24.3	24.3	30.2	30.1	30.1	78.8	79.8	80.2
MNP27	M	24.6	24.4	24.5	24.5	24.5	24.6	30.2	30.1	30.1	78.8	79.8	80.2
MNP28	JUV/F	24.3	24.3	24.4	24.3	24.2	24.2	30.2	30.1	30.1	78.8	79.8	80.2
MNP29	M	24.2	24.3	24.4	24.4	24.4	24.4	30.2	30.1	30.1	78.8	79.8	80.2
MNP30	JUV/M	24.1	24.2	24.1	24.3	24.2	24.3	30.2	30.1	30.1	78.8	79.8	80.2
MNP31	M	25.0	24.8	24.7	24.8	24.8	24.7	30.2	30.1	30.1	78.8	79.8	80.2
MNP32	F	23.8	23.9	23.8	23.8	23.8	23.8	30.2	30.1	30.1	78.8	79.8	80.2
MNP33	JUV/M	23.9	24.0	24.0	24.1	24.0	24.0	30.2	30.1	30.1	78.8	79.8	80.2

MNP34	M	23.9	23.9	24.0	24.1	23.9	23.9	30.2	30.1	30.1	78.8	79.8	80.2
MNP35	M	24.0	24.0	24.0	24.0	24.0	23.9	30.2	30.1	30.1	78.8	79.8	80.2
MNP36	JUV/M	24.5	24.5	24.6	24.5	24.4	24.4	30.2	30.1	30.1	78.8	79.8	80.2
MNP37	F	25.7	25.7	25.7	25.9	25.9	25.9	28.7	29.0	29.0	83.2	84.1	84.9
MNP38	M	25.8	25.6	25.9	25.8	25.9	25.8	28.7	29.0	29.0	83.2	84.1	84.9
MNP39	F	25.7	25.6	25.5	25.8	25.7	25.7	28.7	29.0	29.0	83.2	84.1	84.9
MNP40	M	24.4	24.4	24.4	24.5	24.5	24.5	28.7	29.0	29.0	83.2	84.1	84.9
MNP41	M	25.3	25.2	25.3	25.4	25.3	25.3	28.7	29.0	29.0	83.2	84.1	84.9
MNP42	M	25.4	25.3	25.2	25.3	25.3	25.2	28.7	29.0	29.0	83.2	84.1	84.9
MNP43	JUV/M	25.3	25.2	25.3	25.2	25.3	25.4	28.7	29.0	29.0	83.2	84.1	84.9
MNP44	F	25.2	25.3	25.2	25.1	25.2	25.3	28.7	29.0	29.0	83.2	84.1	84.9
MNP45	M	26.2	26.1	26.1	25.8	26.1	26.1	28.7	29.0	29.0	83.2	84.1	84.9
MNP46	F	25.1	25.0	25.1	25.0	25.1	25.1	28.7	29.0	29.0	83.2	84.1	84.9
MNP47	M	25.2	25.2	25.1	25.1	25.1	25.1	28.7	29.0	29.0	83.2	84.1	84.9
MNP48	F	25.1	25.2	25.3	25.0	25.1	25.1	28.7	29.0	29.0	83.2	84.1	84.9
MNP49	M	25.2	25.1	25.2	25.1	25.2	25.2	28.7	29.0	29.0	83.2	84.1	84.9
MNP50	F	25.1	25.1	25.1	25.2	25.2	25.3	28.7	29.0	29.0	83.2	84.1	84.9
MNP51	M	25.3	25.3	25.2	25.3	25.3	25.3	28.7	29.0	29.0	83.2	84.1	84.9
MNP52	F	25.4	25.3	25.2	25.2	25.2	25.3	28.7	29.0	29.0	83.2	84.1	84.9
MNP53	M	24.7	24.6	24.5	24.7	24.7	24.6	28.5	28.6	28.7	85.3	85.2	84.8
MNP54	M	24.6	24.6	24.7	24.5	24.6	24.7	28.5	28.6	28.7	85.3	85.2	84.8
MNP55	M	24.8	24.9	24.9	24.7	24.7	24.8	28.5	28.6	28.7	85.3	85.2	84.8
MNP56	M	24.8	24.9	24.9	25.0	24.9	24.9	28.5	28.6	28.7	85.3	85.2	84.8
MNP57	M	24.8	24.8	24.8	24.8	24.7	24.6	28.5	28.6	28.7	85.3	85.2	84.8
MNP58	M	25.1	25.0	24.9	25.0	25.0	25.0	28.5	28.6	28.7	85.3	85.2	84.8
MNP59	F	24.9	24.9	24.8	24.8	24.9	25.0	28.5	28.6	28.7	85.3	85.2	84.8
MNP60	M	24.9	25.0	25.1	24.9	24.9	25.0	28.5	28.6	28.7	85.3	85.2	84.8

MNP61	M	25.0	25.0	25.1	24.9	25.0	25.0	28.5	28.6	28.7	85.3	85.2	84.8
MNP62	M	25.0	25.0	24.9	24.7	4.7	24.8	28.5	28.6	28.7	85.3	85.2	84.8
MNP63	M	24.9	25.0	25.1	25.0	25.0	25.0	28.5	28.6	28.7	85.3	85.2	84.8
MNP64	M	24.8	24.8	24.9	24.7	24.8	24.9	28.5	28.6	28.7	85.3	85.2	84.8
MNP65	M	24.9	24.8	24.8	24.7	24.8	24.9	28.5	28.6	28.7	85.3	85.2	84.8
MNP66	M	25.0	25.1	25.1	24.7	24.8	24.8	28.5	28.6	28.7	85.3	85.2	84.8
MNP67	M	25.0	25.1	25.1	25.1	25.3	25.2	28.5	28.6	28.7	85.3	85.2	84.8
MNP68	M	25.1	25.1	25.1	25.2	25.2	25.3	28.5	28.6	28.7	85.3	85.2	84.8
MNP87	F	26.9	26.8	26.7	26.8	26.8	26.8	28.4	28.5	28.5	87.9	84.8	84.5
MNP88	M	26.1	26.2	26.3	26.2	26.2	26.3	28.4	28.5	28.5	87.9	84.8	84.5
MNP89	M	26.4	26.4	26.3	26.3	26.4	26.3	28.4	28.5	28.5	87.9	84.8	84.5
MNP90	M	26.7	26.8	26.8	26.7	26.7	26.8	28.4	28.5	28.5	87.9	84.8	84.5
MNP91	M	25.1	25.0	25.2	25.2	25.3	25.2	28.4	28.5	28.5	87.9	84.8	84.5
MNP92	M	25.2	25.2	25.1	25.2	25.3	25.3	28.4	28.5	28.5	87.9	84.8	84.5
MNP93	M	25.3	25.3	25.2	25.1	25.1	25.2	28.4	28.5	28.5	87.9	84.8	84.5
MNP94	M	25.2	25.2	25.3	25.1	25.1	25.1	28.4	28.5	28.5	87.9	84.8	84.5
MNP95	M	25.1	25.2	25.3	25.2	25.2	25.1	28.4	28.5	28.5	87.9	84.8	84.5
MNP96	M	25.2	25.1	25.1	25.1	25.1	25.1	28.4	28.5	28.5	87.9	84.8	84.5
MNP97	M	25.3	25.2	25.2	25.3	25.2	25.2	28.4	28.5	28.5	87.9	84.8	84.5
MNP98	F	25.4	25.5	25.4	25.4	25.4	25.4	28.4	28.5	28.5	87.9	84.8	84.5
MNP99	M	24.9	25.2	25.2	25.1	25.1	25.1	28.4	28.5	28.5	87.9	84.8	84.5
MNP100	F	27.1	26.9	26.9	26.8	26.8	26.9	28.4	28.5	28.5	87.9	84.8	84.5
MNP101	M	26.1	26.2	26.1	26.2	26.1	26.1	28.4	28.5	28.5	87.9	84.8	84.5
MNP102	F	26.1	26.2	26.1	26.2	26.1	26.1	28.4	28.5	28.5	87.9	84.8	84.5
MNP103	M	26.0	26.6	26.5	26.8	26.5	26.5	28.4	28.5	28.5	87.9	84.8	84.5
MNP104	M	25.6	25.6	25.6	25.7	25.6	25.6	28.4	28.5	28.5	87.9	84.8	84.5

Appendix C: Continuation on data on body temperatures of Bornean frogs in different habitat types recorded from 2022 to 2023 in Sarawak.

Abbreviation: SVL, snout-vent-length: M, Male; F, Female; Juv, Juvenile; m, meter.

Field ID	Distance from water (m)	SUBSTRATE (aquatic/non-aquatic)	HABITAT TYPE (flowing water <1m, non-flowing water <1m, non-aquatic)
BJ01	distant	non-aquatic	non-aquatic
BJ02	distant	non-aquatic	non-aquatic
BJ03	distant	non-aquatic	non-aquatic
BJ04	distant	non-aquatic	non-aquatic
BJ05	1.0	non-aquatic	flowing water
BJ06	distant	non-aquatic	non-aquatic
BJ07	in puddle	aquatic	non-flowing water
BJ08	0.0	non-aquatic	non- flowing water
BJ09	0.1	aquatic	non-flowing water
BJ10	3.0	non-aquatic	non-aquatic
BJ11	distant	non-aquatic	non-aquatic
BJ12	distant	non-aquatic	non-aquatic
BJ13	0.1	aquatic	non-flowing water
BJ14	distant	non-aquatic	non-aquatic
BJ15	distant	non-aquatic	non-aquatic
BJ16	1.0	non-aquatic	flowing water
BJ17	distant	non-aquatic	non-aquatic
BJ18	1.9	non-aquatic	non-aquatic
BJ19	4.0	non-aquatic	non-aquatic

BJ20	distant	non-aquatic	non-aquatic
BJ21	2.0	non-aquatic	non-aquatic
BJ22	distant	non-aquatic	non-aquatic
BJ23	8.0	non-aquatic	non-aquatic
BJ24	distant	non-aquatic	non-aquatic
BJ25	3.0	non-aquatic	non-aquatic
BJ26	distant	non-aquatic	non-aquatic
BJ27	5.0	non-aquatic	non-aquatic
BJ28	2.0	non-aquatic	non-aquatic
BJ29	7.0	non-aquatic	non-aquatic
BJ31	distant	non-aquatic	non-aquatic
BJ32	0.3	aquatic	flowing water
BJ33	distant	non-aquatic	non-aquatic
BJ34	distant	non-aquatic	non-aquatic
BJ35	distant	non-aquatic	non-aquatic
BJ36	distant	non-aquatic	non-aquatic
BJ37	distant	non-aquatic	non-aquatic
BJ38	2.0	non-aquatic	non-aquatic
BJ39	3m	non-aquatic	non-aquatic
BJ40	0.1	non-aquatic	flowing water
BJ41	3.0	non-aquatic	non-aquatic
BJ42	distant	non-aquatic	non-aquatic
BJ43	distant	non-aquatic	non-aquatic
BJ44	2.0	non-aquatic	non-aquatic
BJ45	4.0	non-aquatic	non-aquatic
BJ46	1.0	non-aquatic	flowing water
BJ47	in water	aquatic	flowing water

BJ48	distant	non-aquatic	non-aquatic
BJ49	distant	non-aquatic	non-aquatic
BJ50	1.0	non-aquatic	non-flowing water
BJ51	1.0	non-aquatic	non-flowing water
BJ52	1.0	non-aquatic	non-flowing water
BJ53	1.0	non-aquatic	non-flowing water
BJ54	1.0	non-aquatic	non-flowing water
BJ55	1.0	non-aquatic	non-flowing water
BJ56	1.0	non-aquatic	non-flowing water
BJ57	1.0	non-aquatic	non-flowing water
BJ58	1.0	non-aquatic	non-flowing water
BJ59	1.0	non-aquatic	non-flowing water
BJ60	1.0	non-aquatic	non-flowing water
BJ61	1.0	non-aquatic	non-flowing water
BJ62	1.0	non-aquatic	non-flowing water
BJ63	1.0	non-aquatic	non-flowing water
BJ64	1.0	non-aquatic	non-flowing water
BJ65	1.0	non-aquatic	non-flowing water
MWC 1558	distant	non-aquatic	non-aquatic
MWC 1559	1.5	non-aquatic	non-aquatic
MWC 1560	0.7	non-aquatic	non-flowing water
MWC 1561	distant	non-aquatic	non-aquatic
MWC 1562	1.0	non-aquatic	non-flowing water
MWC 1563	1.0	non-aquatic	non-flowing water
MWC 1564	1.5	non-aquatic	non-aquatic
MWC 1565	5.0	non-aquatic	non-aquatic
MWC 1566	1.0	non-aquatic	non-flowing water

MWC 1567	3.0	non-aquatic	non-aquatic
MWC 1568	in water	aquatic	flowing water
MWC 1569	1.0	non-aquatic	non-flowing water
MWC 1570	10.0	non-aquatic	non-aquatic
MWC 1571	2.5	non-aquatic	non-aquatic
MWC 1572	2.5	non-aquatic	non-aquatic
MWC 1573	1.5	non-aquatic	non-aquatic
MWC 1574	1.0	non-aquatic	non-flowing water
MWC 1575	1.0	non-aquatic	flowing water
MWC 1576	distant	non-aquatic	non-aquatic
MWC 1577	1.0	non-aquatic	flowing water
MWC 1578	1.5	non-aquatic	non-aquatic
MWC 1579	distant	non-aquatic	non-aquatic
MWC 1580	20.0	non-aquatic	non-aquatic
MWC 1581	1.0	non-aquatic	non-flowing water
MWC 1582	1.0	non-aquatic	flowing water
MWC 1583	1.5	non-aquatic	non-aquatic
MWC 1584	1.0	non-aquatic	flowing water
MWC 1585	25.0	non-aquatic	non-aquatic
MWC 1586	10.0	non-aquatic	non-aquatic
MWC 1587	distant	non-aquatic	non-aquatic
MWC 1588	distant	non-aquatic	non-aquatic
MWC 1589	distant	non-aquatic	non-aquatic
MWC 1590	distant	non-aquatic	non-aquatic
MWC 1591	distant	non-aquatic	non-aquatic
MWC 1592	5.0	non-aquatic	non-aquatic
MWC 1593	1.0	non-aquatic	flowing water

MWC 1594	2.0	non-aquatic	non-aquatic
MWC 1595	5.0	non-aquatic	non-aquatic
MWC 1596	1.5	non-aquatic	non-aquatic
MWC 1597	5.0	non-aquatic	non-aquatic
MWC 1598	10.0	non-aquatic	non-aquatic
MWC 1599	distant	non-aquatic	non-aquatic
MWC 1600	distant	non-aquatic	non-aquatic
MWC 1601	distant	non-aquatic	non-aquatic
MWC 1602	distant	non-aquatic	non-aquatic
MWC 1603	distant	non-aquatic	non-aquatic
MWC 1604	1.0	non-aquatic	non-flowing water
MWC 1605	distant	non-aquatic	non-aquatic
MWC 1606	distant	non-aquatic	non-aquatic
MWC 1607	distant	non-aquatic	non-aquatic
MWC 1608	distant	non-aquatic	non-aquatic
MWC 1609	in puddle	aquatic	non-flowing water
MWC 1610	in puddle	aquatic	non-flowing water
MWC 1611	distant	non-aquatic	non-aquatic
MWC 1612	1.0	non-aquatic	non-flowing water
MWC 1613	distant	non-aquatic	non-aquatic
MWC 1614	distant	non-aquatic	non-aquatic
MWC 1615	1.0	non-aquatic	non-flowing water
MWC 1616	1.0	non-aquatic	non-flowing water
MWC 1617	1.5	non-aquatic	non-aquatic
MWC 1618	distant	non-aquatic	non-aquatic
MWC 1619	distant	non-aquatic	non-aquatic
MWC 1620	distant	non-aquatic	non-aquatic

MWC 1621	distant	non-aquatic	non-aquatic
MWC 1622	distant	non-aquatic	non-aquatic
MWC 1623	distant	non-aquatic	non-aquatic
MWC 1624	1.0	non-aquatic	non-flowing water
MWC 1625	in water	aquatic	non-flowing water
UW166	in water	aquatic	non-flowing water
UW167	in water	aquatic	non-flowing water
UW168	in water	aquatic	non-flowing water
UW169	in water	aquatic	non-flowing water
UW170	in water	aquatic	non-flowing water
UW171	in water	aquatic	non-flowing water
UW172	in water	aquatic	non-flowing water
UW173	distant	non-aquatic	non-aquatic
UW174	distant	non-aquatic	non-aquatic
UW175	distant	non-aquatic	non-aquatic
UW176	distant	non-aquatic	non-aquatic
UW177	2.0	non-aquatic	non-aquatic
UW178	distant	non-aquatic	non-aquatic
UW179	1.0	aquatic	flowing water
UW180	distant	non-aquatic	non-aquatic
UW181	1.0	aquatic	non-flowing water
UW182	distant	non-aquatic	non-aquatic
UW183	1.0	aquatic	non-flowing water
UW184	1.0	aquatic	non-flowing water
UW185	in water	aquatic	non-flowing water
UW186	6.0	non-aquatic	non-aquatic
UW187	distant	non-aquatic	non-aquatic

UW188	in water	aquatic	non-flowing water
UW189	in water	aquatic	non-flowing water
KTM1	distant	non-aquatic	non-aquatic
KTM2	distant	non-aquatic	non-aquatic
KTM3	3.0	non-aquatic	non-flowing water
KTM4	5.0	non-aquatic	non-flowing water
KTM5	1.5	non-aquatic	non-flowing water
KTM6	0.5	non-aquatic	flowing water
KTM7	distant	non-aquatic	non-aquatic
KTM8	distant	non-aquatic	non-aquatic
KTM9	distant	non-aquatic	non-aquatic
KTM10	distant	non-aquatic	non-aquatic
KTM11	distant	non-aquatic	non-aquatic
KTM12	distant	non-aquatic	non-aquatic
KTM13	in water	aquatic	flowing water
KTM14	in water	aquatic	flowing water
KTM15	0.4	non-aquatic	flowing water
KTM16	Distant	non-aquatic	non-aquatic
KTM17	Distant	non-aquatic	non-aquatic
KTM18	Distant	non-aquatic	non-aquatic
KTM19	in water	aquatic	flowing water
KTM20	in water	aquatic	flowing water
KTM21	distant	non-aquatic	non-aquatic
KTM22	0.1	non-aquatic	flowing water
KTM23	0.7	non-aquatic	non-flowing water
KTM24	0.5	non-aquatic	non-flowing water
KTM25	4.0	non-aquatic	non-flowing water

KTM26	0.5	non-aquatic	non-flowing water
KTM27	0.5	non-aquatic	non-flowing water
KTM28	0.2	non-aquatic	flowing water
KTM29	0.4	non-aquatic	flowing water
KTM30	0.6	non-aquatic	flowing water
KTM31	0.6	non-aquatic	flowing water
MNP01	distant	non-aquatic	non-aquatic
MNP02	distant	non-aquatic	non-aquatic
MNP15	distant	non-aquatic	non-aquatic
MNP16	distant	non-aquatic	non-aquatic
MNP17	distant	non-aquatic	non-aquatic
MNP18	distant	non-aquatic	non-aquatic
MNP19	distant	non-aquatic	non-aquatic
MNP20	distant	non-aquatic	non-aquatic
MNP21	0.3	aquatic	flowing water
MNP22	0.5	non-aquatic	flowing water
MNP23	0.5	non-aquatic	non-aquatic
MNP24	0.5	aquatic	flowing water
MNP25	0.5	aquatic	flowing water
MNP26	distant	non-aquatic	non-aquatic
MNP27	0.6	non-aquatic	flowing water
MNP28	0.6	non-aquatic	flowing water
MNP29	0.5	non-aquatic	flowing water
MNP30	0.3	non-aquatic	flowing water
MNP31	0.8	non-aquatic	flowing water
MNP32	in water	aquatic	flowing water
MNP33	1.0	non-aquatic	flowing water

MNP34	in water	aquatic	flowing water
MNP35	in water	aquatic	flowing water
MNP36	0.4	non-aquatic	non-flowing water
MNP37	distant	non-aquatic	non-aquatic
MNP38	distant	non-aquatic	non-aquatic
MNP39	distant	non-aquatic	non-aquatic
MNP40	distant	non-aquatic	non-aquatic
MNP41	distant	non-aquatic	non-aquatic
MNP42	distant	non-aquatic	non-aquatic
MNP43	distant	non-aquatic	non-aquatic
MNP44	distant	non-aquatic	non-aquatic
MNP45	distant	non-aquatic	non-aquatic
MNP46	distant	non-aquatic	non-aquatic
MNP47	distant	non-aquatic	non-aquatic
MNP48	distant	non-aquatic	non-aquatic
MNP49	distant	non-aquatic	non-aquatic
MNP50	distant	non-aquatic	non-aquatic
MNP51	distant	non-aquatic	non-aquatic
MNP52	distant	non-aquatic	non-aquatic
MNP53	distant	non-aquatic	non-aquatic
MNP54	distant	non-aquatic	non-aquatic
MNP55	distant	non-aquatic	non-aquatic
MNP56	1.0	non-aquatic	non-flowing water
MNP57	distant	non-aquatic	non-aquatic
MNP58	distant	non-aquatic	non-aquatic
MNP59	distant	non-aquatic	non-aquatic
MNP60	in water	aquatic	non-flowing water

MNP61	in water	aquatic	non-flowing water
MNP62	0.8	non-aquatic	non-flowing water
MNP63	in water	aquatic	non-flowing water
MNP64	in water	aquatic	non-flowing water
MNP65	0.2	non-aquatic	non-flowing water
MNP66	distant	non-aquatic	non-aquatic
MNP67	distant	non-aquatic	non-aquatic
MNP68	0.1	non-aquatic	non-flowing water
MNP87	10.0	non-aquatic	non-aquatic
MNP88	8.0	non-aquatic	non-aquatic
MNP89	0.2	non-aquatic	non-flowing water
MNP90	distant	non-aquatic	non-aquatic
MNP91	1.0	non-aquatic	non-flowing water
MNP92	distant	non-aquatic	non-aquatic
MNP93	10.0	non-aquatic	non-aquatic
MNP94	distant	non-aquatic	non-aquatic
MNP95	5.0	non-aquatic	non-aquatic
MNP96	distant	non-aquatic	non-aquatic
MNP97	distant	non-aquatic	non-aquatic
MNP98	distant	non-aquatic	non-aquatic
MNP99	0.5	non-aquatic	non-flowing water
MNP100	5.0	non-aquatic	non-aquatic
MNP101	0.1	non-aquatic	non-flowing water
MNP102	distant	non-aquatic	non-aquatic
MNP103	distant	non-aquatic	non-aquatic
MNP104	10.0	non-aquatic	non-aquatic

Appendix D: Data on microhabitat preferences by Bornean frogs recorded from 2022 to 2023 in Sarawak.

Abbreviation: SVL, Snout-Vent-Length; TL, Tibia Length; W, Weight M, Male; F, Female; Juv, Juvenile; m, meter.

Field ID	Species Name	Locality		Coordinate in Decimal		Date
				Latitude	Longitude	
BJ01	<i>Duttaphrynus melanostictus</i>	Bung Jagoi, Bau	Side Stream, Sigon Duyoh	1.3516	110.3829	5/11/2022
BJ02	<i>Duttaphrynus melanostictus</i>		Side Stream, Sigon Duyoh	1.3406	110.0345	
BJ03	<i>Chalcorana megalonesa</i>		Side Stream, Sigon Duyoh	1.3406	110.0345	
BJ04	<i>Phrynoidis asper</i>		Side Stream, Sigon Duyoh	1.3390	110.0331	
BJ05	<i>Nyctixalus pictus</i>		Side Stream, Sigon Duyoh	1.3391	110.0331	
BJ06	<i>Fejervarya limnocharis</i>		Side Stream, Sigon Duyoh	1.3390	110.0333	
BJ07	<i>Ingerophrynus divergens</i>		Kebun Kelapa Sawit, Sigon Duyoh	1.3389	110.0331	
BJ08	<i>Chalcorana megalonesa</i>		Kebun Kelapa Sawit, Sigon Duyoh	1.3389	110.0331	
BJ09	<i>Polypedates leucomystax</i>		Kebun Kelapa Sawit, Sigon Duyoh	1.3389	110.0333	
BJ10	<i>Polypedates leucomystax</i>		Kebun Kelapa Sawit, Sigon Duyoh	1.3477	110.0393	
BJ11	<i>Polypedates leucomystax</i>		Kebun Kelapa Sawit, Sigon Duyoh	1.3477	110.0393	
BJ12	<i>Polypedates leucomystax</i>		Kebun Kelapa Sawit, Sigon Duyoh	1.3477	110.0393	
BJ13	<i>Polypedates leucomystax</i>		Kebun Kelapa Sawit, Sigon Duyoh	1.3389	110.0331	

BJ14	<i>Phrynoidis asper</i>		Kebun Kelapa Sawit, Sigon Duyoh	1.3477	110.0393	
BJ15	<i>Chalcorana megalonesa</i>		Kebun Kelapa Sawit, Sigon Duyoh	1.3478	110.0393	
BJ16	<i>Duttaphrynus melanostictus</i>		Kebun Kelapa Sawit, Sigon Duyoh	1.3479	110.0392	
BJ17	<i>Ingerophrynus divergens</i>		Kebun Kelapa Sawit, Sigon Duyoh	1.3479	110.0394	
BJ18	<i>Ansonia spinulifer</i>		Upstream, Bung Jagoi	1.3485	110.0396	6/11/2022
BJ19	<i>Limnonectes kuhlii</i>		Upstream, Bung Jagoi	1.3470	110.0394	
BJ20	<i>Staurois guttatus</i>		Upstream, Bung Jagoi	1.3569	110.0332	
BJ21	<i>Meristogenys jerboa</i>		Upstream, Bung Jagoi	1.3570	110.0331	
BJ22	<i>Staurois guttatus</i>		Upstream, Bung Jagoi	1.3570	110.0331	
BJ23	<i>Ansonia spinulifer</i>		Upstream, Bung Jagoi	1.3567	110.0330	
BJ24	<i>Ansonia spinulifer</i>		Upstream, Bung Jagoi	2.3567	111.0330	
BJ25	<i>Staurois guttatus</i>		Upstream, Bung Jagoi	3.3567	112.0330	
BJ26	<i>Limnonectes kuhlii</i>		Upstream, Bung Jagoi	4.3567	113.0330	
BJ27	<i>Ansonia spinulifer</i>		Upstream, Bung Jagoi	4.3567	113.0330	
BJ28	<i>Meristogenys jerboa</i>		Upstream, Bung Jagoi	4.3567	113.0330	
BJ29	<i>Ansonia spinulifer</i>		Upstream, Bung Jagoi	2.3567	111.0330	

BJ31	<i>Meristogenys jerboa</i>		Upstream, Bung Jagoi	1.3570	110.0331	
BJ32	<i>Limnonectes kuhlii</i>		Upstream, Bung Jagoi	1.3570	110.0331	
BJ33	<i>Leptolalax gracilis</i>		Upstream, Bung Jagoi	1.3570	110.0331	
BJ34	<i>Chalcorana megalonesa</i>		Upstream, Bung Jagoi	1.3570	110.0331	
BJ35	<i>Philautus tectus</i>		Bung Jagoi Trail, Bau	1.3567	110.0331	7/11/2022
BJ36	<i>Chalcorana raniceps</i>		Bung Jagoi Trail, Bau	1.3567	110.0331	
BJ37	<i>Duttaphrynus melanostictus</i>		Bung Jagoi Trail, Bau	1.3567	110.0331	
BJ38	<i>Chalcorana megalonesa</i>		Bung Jagoi Trail, Bau	1.3560	110.0328	
BJ39	<i>Chalcorana megalonesa</i>		Bung Jagoi Trail, Bau	1.3560	110.0326	
BJ40	<i>Limnonectes kuhlii</i>		Bung Jagoi Trail, Bau	1.3560	110.0326	
BJ41	<i>Chalcorana raniceps</i>		Bung Jagoi Trail, Bau	1.3475	110.0385	
BJ42	<i>Leptolalax gracilis</i>		Bung Jagoi Trail, Bau	1.3475	110.0385	
BJ43	<i>Leptolalax gracilis</i>		Bung Jagoi Trail, Bau	1.3475	110.0385	
BJ44	<i>Limnonectes kuhlii</i>		Bung Jagoi Trail, Bau	1.3475	110.0385	
BJ45	<i>Ansonia spinulifer</i>		Bung Jagoi Trail, Bau	1.3475	110.0385	
BJ46	<i>Ansonia spinulifer</i>		Bung Jagoi Trail, Bau	1.3475	110.0385	

BJ47	<i>Limnonectes kuhlii</i>		Bung Jagoi Trail, Bau	1.3475	110.0385	
BJ48	<i>Megophrys nasuta</i>		Bung Jagoi Trail, Bau	1.3475	110.0385	
BJ49	<i>Phrynoidis juxtasper</i>		Bung Jagoi Trail, Bau	1.3475	110.0385	
BJ50	<i>Hylarana erythraea</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	8/11/2022
BJ51	<i>Hylarana erythraea</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	
BJ52	<i>Hylarana erythraea</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	
BJ53	<i>Fejervarya cancrivora</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	
BJ54	<i>Hylarana erythraea</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	
BJ55	<i>Limnonectes kuhlii</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	
BJ56	<i>Hylarana erythraea</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	
BJ57	<i>Duttaphrynus melanostictus</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	
BJ58	<i>Hylarana erythraea</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	
BJ59	<i>Hylarana erythraea</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	
BJ60	<i>Duttaphrynus melanostictus</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	
BJ61	<i>Polypedates leucomystax</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	
BJ62	<i>Duttaphrynus melanostictus</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	

BJ63	<i>Duttaphrynus melanostictus</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	
BJ64	<i>Duttaphrynus melanostictus</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	
BJ65	<i>Megophrys nasuta</i>		Kolam Ikan Homestay Sigon Duyoh	1.3459	110.0439	
MWC 1558	<i>Limnonectes paramacrodon</i>	Matang Wildlife Centre, Lundu	Picnic Trail	2.2276	112.2141	12/12/2022
MWC 1559	<i>Kurixalus appendiculatus</i>		Picnic Trail	2.2276	112.2141	
MWC 1560	<i>Leptobrachum abbotti</i>		Picnic Trail	2.2276	112.2141	
MWC 1561	<i>Phrynoidis asper</i>		Picnic Trail	2.2276	112.2141	
MWC 1562	<i>Polypedates macrotis</i>		Picnic Trail	2.2276	112.2141	
MWC 1563	<i>Polypedates macrotis</i>		Picnic Trail	2.2276	112.2141	
MWC 1564	<i>Polypedates macrotis</i>		Picnic Trail	2.2276	112.2141	
MWC 1565	<i>Kalophrynus meizon</i>		Picnic Trail	1.6119	110.1565	
MWC 1566	<i>Polypedates macrotis</i>		Picnic Trail	1.6119	110.1565	
MWC 1567	<i>Polypedates macrotis</i>		Picnic Trail	1.6119	110.1565	
MWC 1568	<i>Oocidozyga baluensis</i>		Picnic Trail	1.6119	110.1565	
MWC 1569	<i>Polypedates macrotis</i>		Picnic Trail	1.6119	110.1565	
MWC 1570	<i>Ingerophrynus divergens</i>		Picnic Trail	1.6119	110.1565	

MWC 1571	<i>Rhacophorus pardalis</i>		Picnic Trail	1.6119	110.1565	
MWC 1572	<i>Polypedates macrotis</i>		Picnic Trail	1.6119	110.1565	
MWC 1573	<i>Kurixalus appendiculatus</i>		Picnic Trail	1.6119	110.1565	
MWC 1574	<i>Kurixalus appendiculatus</i>		Picnic Trail	1.6119	110.1565	
MWC 1575	<i>Ingerophrynus divergens</i>		Picnic Trail	1.6119	110.1565	
MWC 1576	<i>Fejervarya limnocharis</i>		Picnic Trail	1.6119	110.1565	
MWC 1577	<i>Limnonectes leporinus</i>		Picnic Trail	1.6119	110.1565	
MWC 1578	<i>Polypedates macrotis</i>		Picnic Trail	1.6119	110.1565	
MWC 1579	<i>Fejervarya limnocharis</i>		Picnic Trail	1.6119	110.1565	
MWC 1580	<i>Polypedates colletti</i>		Trail to parking lot	1.6108	110.1564	13/12/2022
MWC 1581	<i>Kurixalis appendiculatus</i>		Trail to parking lot	1.6108	110.1564	
MWC 1582	<i>Ingerophrynus divergens</i>		Trail to parking lot	1.6108	110.1564	
MWC 1583	<i>Kurixalus appendiculatus</i>		Trail to parking lot	1.6108	110.1564	
MWC 1584	<i>Ingerophrynus divergens</i>		Trail to parking lot	1.6109	110.1563	
MWC 1585	<i>Kalophrynus meizon</i>		Trail to parking lot	1.6109	110.1563	
MWC 1586	<i>Pulchrana baramica</i>		Trail to parking lot	1.6109	110.1563	

MWC 1587	<i>Limnonectes leporinus</i>		Campsite	1.6103	110.1554	
MWC 1588	<i>Pulchrana signata</i>		Campsite	1.6103	110.1554	
MWC 1589	<i>Pulchrana baramica</i>		Campsite	1.6102	110.1552	
MWC 1590	<i>Limnonectes leporinus</i>		Campsite	1.6102	110.1552	
MWC 1591	<i>Limnonectes leporinus</i>		Campsite	1.6102	110.1552	
MWC 1592	<i>Odorrana hosii</i>		Campsite	1.6105	110.1549	
MWC 1593	<i>Odorrana hosii</i>		Campsite	1.6105	110.1549	
MWC 1594	<i>Megophrys nasuta</i>		Campsite	1.6105	110.1549	
MWC 1595	<i>Chaperina fusca</i>		Campsite	1.6105	110.1547	
MWC 1596	<i>Odorrana hosii</i>		Campsite	1.6106	110.1549	
MWC 1597	<i>Ingerophrynus divergens</i>		Campsite	1.6106	110.1549	
MWC 1598	<i>Pulchrana signata</i>		Campsite	1.6106	110.1549	
MWC 1599	<i>Pulchrana baramica</i>		Campsite	1.6102	110.1554	
MWC 1600	<i>Pulchrana signata</i>		Campsite	1.6102	110.1554	
MWC 1601	<i>Ingerophrynus divergens</i>		Campsite	1.6102	110.1554	
MWC 1602	<i>Limnonectes leporinus</i>		Campsite	1.6113	110.1566	

MWC 1603	<i>Ingerophrynus divergens</i>		Campsite	1.6113	110.1566	
MWC 1604	<i>Kalophrynus meizon</i>		Campsite	1.6113	110.1566	
MWC 1605	<i>Limnonectes malesianus</i>		Campsite	1.6122	110.1566	
MWC 1606	<i>Limnonectes leporinus</i>		Campsite	1.6122	110.1566	
MWC 1607	<i>Limnonectes leporinus</i>		Campsite	1.6122	110.1566	
MWC 1608	<i>Pulchrana signata</i>		Campsite	1.6122	110.1566	
MWC 1609	<i>Ingerophrynus divergens</i>		HQ	1.6095	110.1566	14/12/2022
MWC 1610	<i>Ingerophrynus divergens</i>		HQ	1.6095	110.1566	
MWC 1611	<i>Limnonectes malesianus</i>		HQ	1.6095	110.1566	
MWC 1612	<i>Pulchrana baramica</i>		HQ	1.6095	110.1566	
MWC 1613	<i>Polypedates macrotis</i>		HQ	1.6095	110.1566	
MWC 1614	<i>Polypedates colletti</i>		HQ	1.6112	110.1564	
MWC 1615	<i>Limnonectes malesianus</i>		HQ	1.6112	110.1564	
MWC 1616	<i>Kurixalus appendiculatus</i>		HQ	1.6108	110.1566	
MWC 1617	<i>Limnonectes malesianus</i>		HQ	1.6108	110.1567	
MWC 1618	<i>Fejervarya limnocharis</i>		HQ	1.6108	110.1567	

MWC 1619	<i>Rhacophorus pardalis</i>		HQ	1.6113	110.1562	
MWC 1620	<i>Fejervarya limnocharis</i>		HQ	1.6113	110.1562	
MWC 1621	<i>Ingerophrynus divergens</i>		HQ	1.6099	110.1569	
MWC 1622	<i>Ingerophrynus divergens</i>		HQ	1.6099	110.1569	
MWC 1623	<i>Fejervarya limnocharis</i>		HQ	1.6099	110.1569	
MWC 1624	<i>Limnonectes malesianus</i>		HQ	1.6099	110.1569	
MWC 1625	<i>Oocidozyga baluensis</i>		HQ	1.6099	110.1569	
UW166	<i>Duttaphrynus melanostictus</i>	West Campus, UNIMAS, Saramahan	Allamanda, UNIMAS	1.4677	110.4319	3/1/2023
UW167	<i>Duttaphrynus melanostictus</i>		Allamanda, UNIMAS	1.4677	110.4319	
UW168	<i>Duttaphrynus melanostictus</i>		Allamanda, UNIMAS	1.4677	110.4319	
UW169	<i>Duttaphrynus melanostictus</i>		Allamanda, UNIMAS	1.4677	110.4319	
UW170	<i>Limnonectes paramacrodon</i>		Allamanda, UNIMAS	1.4677	110.4319	
UW171	<i>Duttaphrynus melanostictus</i>		Allamanda, UNIMAS	1.4677	110.4319	
UW172	<i>Fejervarya limnocharis</i>		Allamanda, UNIMAS	1.4677	110.4319	
UW173	<i>Fejervarya limnocharis</i>		Arena Sukan, UNIMAS	1.4677	110.4319	4/1/2023
UW174	<i>Duttaphrynus melanostictus</i>		Arena Sukan, UNIMAS	1.4677	110.4319	

UW175	<i>Pulcharana baramica</i>		Arena Sukan, UNIMAS	1.4677	110.4319	
UW176	<i>Duttaphyrinus melanostictus</i>		Arena Sukan, UNIMAS	1.4677	110.4319	
UW177	<i>Fejervarya limnocharis</i>		Arena Sukan, UNIMAS	1.4677	110.4319	
UW178	<i>Fejervarya limnocharis</i>		Arena Sukan, UNIMAS	1.4677	110.4319	
UW179	<i>Polypedates leucomystax</i>		Arena Sukan, UNIMAS	1.4677	110.4319	
UW180	<i>Fejervarya limnocharis</i>		Arena Sukan, UNIMAS	1.4677	110.4319	
UW181	<i>Hylarana erythraea</i>		Arena Sukan, UNIMAS	1.4677	110.4319	
UW182	<i>Duttaphyrinus melanostictus</i>		Arena Sukan, UNIMAS	1.4677	110.4319	
UW183	<i>Pulcharana baramica</i>		Allamanda, UNIMAS	1.4677	110.4319	5/1/2023
UW184	<i>Duttaphyrinus melanostictus</i>		Allamanda, UNIMAS	1.4677	110.4319	
UW185	<i>Duttaphyrinus melanostictus</i>		Allamanda, UNIMAS	1.4677	110.4319	
UW186	<i>Duttaphyrinus melanostictus</i>		Allamanda, UNIMAS	1.4677	110.4319	
UW187	<i>Duttaphyrinus melanostictus</i>		Allamanda, UNIMAS	1.4677	110.4319	
UW188	<i>Hylarana erythraea</i>		Jalan Merbau, UNIMAS	1.4677	110.4319	
UW189	<i>Fejervarya limnocharis</i>		Jalan Merbau, UNIMAS	1.4677	110.4319	
KTM1	<i>Duttaphyrinus melanostictus</i>	Kampong	Kampung Telok Melano	2.007	109.6461	27/2/2023

KTM2	<i>Duttaphyrinus melanostictus</i>	Telok Melano, Sematan	Kampung Telok Melano	2.007	109.6461	
KTM3	<i>Duttaphyrinus melanostictus</i>		Kampung Telok Melano	2.007	109.6461	
KTM4	<i>Duttaphyrinus melanostictus</i>		Kampung Telok Melano	2.007	109.6461	
KTM5	<i>Duttaphyrinus melanostictus</i>		Kampung Telok Melano	2.007	109.6461	
KTM6	<i>Fejervarya limnocharis</i>		Kampung Telok Melano	2.007	109.6461	
KTM7	<i>Philautus sp.</i>		Kampung Telok Melano	2.007	109.6461	1/3/2023
KTM8	<i>Kaloula pulchra</i>		Kampung Telok Melano	2.007	109.6461	
KTM9	<i>Megophrys nasuta (Juvenile)</i>		Kampung Telok Melano	2.007	109.6461	
KTM10	<i>Fejervarya cancrivora</i>		Kampung Telok Melano	2.007	109.6461	
KTM11	<i>Kaloula pulchra</i>		Kampung Telok Melano	2.007	109.6461	
KTM12	<i>Fejervarya limnocharis</i>		Kampung Telok Melano	2.007	109.6461	
KTM13	<i>Fejervarya cancrivora</i>		Kampung Telok Melano	2.007	109.6461	
KTM14	<i>Fejervarya cancrivora</i>		Kampung Telok Melano	2.007	109.6461	
KTM15	<i>Fejervarya cancrivora</i>		Kampung Telok Melano	2.007	109.6461	
KTM16	<i>Fejervarya limnocharis</i>		Kampung Telok Melano	2.007	109.6461	
KTM17	<i>Kaloula pulchra</i>		Kampung Telok Melano	2.007	109.6461	

KTM18	<i>Fejervarya cancrivora</i>		Kampung Telok Melano	2.007	109.6461	2/3/2023
KTM19	<i>Fejervarya limnocharis</i>		Kampung Telok Melano	2.007	109.6461	
KTM20	<i>Hylarana erythraea</i>		Kampung Telok Melano	2.007	109.6461	
KTM21	<i>Fejervarya cancrivora</i>		Kampung Telok Melano	2.007	109.6461	
KTM22	<i>Fejervarya cancrivora</i>		Kampung Telok Melano	2.007	109.6461	
KTM23	<i>Kaloula pulchra</i>		Kampung Telok Melano	2.007	109.6461	
KTM24	<i>Fejervarya limnocharis</i>		Kampung Telok Melano	2.007	109.6461	
KTM25	<i>Kaloula pulchra</i>		Kampung Telok Melano	2.007	109.6461	
KTM26	<i>Kaloula pulchra</i>		Kampung Telok Melano	2.007	109.6461	
KTM27	<i>Kaloula pulchra</i>		Kampung Telok Melano	2.007	109.6461	
KTM28	<i>Fejervarya limnocharis</i>		Kampung Telok Melano	2.007	109.6461	
KTM29	<i>Fejervarya limnocharis</i>		Kampung Telok Melano	2.007	109.6461	
KTM30	<i>Fejervarya cancrivora</i>		Kampung Telok Melano	2.007	109.6461	
KTM31	<i>Fejervarya cancrivora</i>		Kampung Telok Melano	2.007	109.6461	
MNP01	<i>Pulchrana baramica</i>	Mulu National Park, Long Lama Miri	Forbidden Nighttrail, HQ	4.1313	114.9099	9/5/2023
MNP02	<i>Pulchrana baramica</i>		Forbidden Nighttrail, HQ	4.1313	114.9099	

MNP15	<i>Leptolalax fritinni</i>		Camp 1	4.0508	114.8546	10/5/2023
MNP16	<i>Leptolalax gracilis</i>		Camp 1	4.0508	114.8546	
MNP17	<i>Leptolalax gracilis</i>		Camp 1	4.0508	114.8546	
MNP18	<i>Leptobranchium abbotti</i>		Camp 1	4.0508	114.8546	
MNP19	<i>Pulchrana signata</i>		Camp 1	4.0508	114.8546	
MNP20	<i>Leptobranchium abbotti</i>		Camp 1	4.0508	114.8546	
MNP21	<i>Limnonectes kuhlii</i>		Camp 1	4.0508	114.8546	
MNP22	<i>Pulchrana signata</i>		Camp 1	4.0508	114.8546	
MNP23	<i>Phrynomantis juxtasper</i>		Camp 1; Stream Area	4.0508	114.8546	11/5/2023
MNP24	<i>Pulchrana signata</i>		Camp 1; Stream Area	4.0508	114.8546	
MNP25	<i>Huia cavitympanum</i>		Camp 1; Stream Area	4.0508	114.8546	
MNP26	<i>Megophrys nasuta</i>		Camp 1; Stream Area	4.0508	114.8546	
MNP27	<i>Huia cavitympanum</i>		Camp 1; Stream Area	4.0508	114.8546	
MNP28	<i>Limnonectes leporinus</i>		Camp 1; Stream Area	4.0508	114.8546	
MNP29	<i>Limnonectes leporinus</i>		Camp 1; Stream Area	4.0508	114.8546	
MNP30	<i>Limnonectes leporinus</i>		Camp 1; Stream Area	4.0508	114.8546	

MNP31	<i>Huia cavitympanum</i>		Camp 1; Stream Area	4.0508	114.8546	
MNP32	<i>Staurois latopalmatus</i>		Camp 1; Stream Area	4.0508	114.8546	
MNP33	<i>Limnonectes ibanorum</i>		Camp 1; Stream Area	4.0508	114.8546	
MNP34	<i>Staurois latopalmatus</i>		Camp 1; Stream Area	4.0508	114.8546	
MNP35	<i>Staurois latopalmatus</i>		Camp 1; Stream Area	4.0508	114.8546	
MNP36	<i>Phrynoidis juxtasper</i>		Camp 1; Stream Area	4.0508	114.8546	
MNP37	<i>Pulchrana baramica</i>		Botanical Garden Trail, HQ	4.1313	114.9099	12/5/2023
MNP38	<i>Pulchrana glandulosa</i>		Botanical Garden Trail, HQ	4.1313	114.9099	
MNP39	<i>Pulchrana glandulosa</i>		Botanical Garden Trail, HQ	4.1313	114.9099	
MNP40	<i>Pulchrana glandulosa</i>		Botanical Garden Trail, HQ	4.1313	114.9099	
MNP41	<i>Pulchrana glandulosa</i>		Botanical Garden Trail, HQ	4.1313	114.9099	
MNP42	<i>Limnonectes malesianus</i>		Botanical Garden Trail, HQ	4.1313	114.9099	
MNP43	<i>Limnonectes ingeri</i>		Botanical Garden Trail, HQ	4.1313	114.9099	
MNP44	<i>Limnonectes ingeri</i>		Botanical Garden Trail, HQ	4.1313	114.9099	
MNP45	<i>Kurixalus appendiculatus</i>		Botanical Garden Trail, HQ	4.1313	114.9099	
MNP46	<i>Microhyla borneensis</i>		Botanical Garden Trail, HQ	4.1313	114.9099	

MNP47	<i>Kurixalus appendiculatus</i>		Botanical Garden Trail, HQ	4.1313	114.9099	
MNP48	<i>Ingerophrynus divergens</i>		Botanical Garden Trail, HQ	4.1313	114.9099	
MNP49	<i>Pulchrana glandulosa</i>		Botanical Garden Trail, HQ	4.1313	114.9099	
MNP50	<i>Ingerophrynus divergens</i>		Botanical Garden Trail, HQ	4.1313	114.9099	
MNP51	<i>Phrynoidis juxtasper</i>		Botanical Garden Trail, HQ	4.1313	114.9099	
MNP52	<i>Pulchrana baramica</i>		Botanical Garden Trail, HQ	4.1313	114.9099	
MNP53	<i>Polypedates leucomystax</i>		Kampung Mulu	4.0330	114.7948	13/5/2023
MNP54	<i>Polypedates leucomystax</i>		Kampung Mulu	4.0330	114.7948	
MNP55	<i>Fejervarya limnocharis</i>		Kampung Mulu	4.0330	114.7948	
MNP56	<i>Rhacophorus pardalis</i>		Kampung Mulu	4.0330	114.7948	
MNP57	<i>Polypedates leucomystax</i>		Kampung Mulu	4.0330	114.7948	
MNP58	<i>Polypedates leucomystax</i>		Kampung Mulu	4.0330	114.7948	
MNP59	<i>Polypedates leucomystax</i>		Kampung Mulu	4.0330	114.7948	
MNP60	<i>Fejervarya limnocharis</i>		Kampung Mulu	4.0330	114.7948	
MNP61	<i>Fejervarya limnocharis</i>		Kampung Mulu	4.0330	114.7948	
MNP62	<i>Pulchrana baramica</i>		Kampung Mulu	4.0330	114.7948	

MNP63	<i>Fejervarya limnocharis</i>		Kampung Mulu	4.0330	114.7948	
MNP64	<i>Fejervarya limnocharis</i>		Kampung Mulu	4.0330	114.7948	
MNP65	<i>Pulchrana baramica</i>		Kampung Mulu	4.0330	114.7948	
MNP66	<i>Polypedates leucomystax</i>		Kampung Mulu	4.0330	114.7948	
MNP67	<i>Polypedates leucomystax</i>		Kampung Mulu	4.0330	114.7948	
MNP68	<i>Fejervarya limnocharis</i>		Kampung Mulu	4.0330	114.7948	
MNP87	<i>Polypedates leucomystax</i>		Kpg Long Iman	4.4447	114.0109	14/5/2023
MNP88	<i>Polypedates leucomystax</i>		Kpg Long Iman	4.4447	114.0109	
MNP89	<i>Polypedates leucomystax</i>		Kpg Long Iman	4.4447	114.0109	
MNP90	<i>Polypedates leucomystax</i>		Kpg Long Iman	4.4447	114.0109	
MNP91	<i>Polypedates leucomystax</i>		Kpg Long Iman	4.4447	114.0109	
MNP92	<i>Polypedates leucomystax</i>		Kpg Long Iman	4.4447	114.0109	
MNP93	<i>Polypedates leucomystax</i>		Kpg Long Iman	4.4447	114.0109	
MNP94	<i>Polypedates leucomystax</i>		Kpg Long Iman	4.4447	114.0109	
MNP95	<i>Polypedates leucomystax</i>		Kpg Long Iman	4.4447	114.0109	
MNP96	<i>Polypedates leucomystax</i>		Kpg Long Iman	4.4447	114.0109	

MNP97	<i>Polypedates leucomystax</i>		Kpg Long Iman	4.4447	114.0109	
MNP98	<i>Fejervarya limnocharis</i>		Kpg Long Iman	4.4447	114.0109	
MNP99	<i>Polypedates leucomystax</i>		Kpg Long Iman	4.4447	114.0109	
MNP100	<i>Fejervarya limnocharis</i>		Kpg Long Iman	4.4447	114.0109	
MNP101	<i>Polypedates leucomystax</i>		Kpg Long Iman	4.4447	114.0109	
MNP102	<i>Fejervarya limnocharis</i>		Kpg Long Iman	4.4447	114.0109	
MNP103	<i>Fejervarya limnocharis</i>		Kpg Long Iman	4.4447	114.0109	
MNP104	<i>Fejervarya limnocharis</i>		Kpg Long Iman	4.4447	114.0109	

Appendix E: Data on microhabitat preferences by Bornean frogs recorded from 2022 to 2023 in Sarawak.

Abbreviation: SVL, Snout-Vent-Length; TL, Tibia Length; W, Weight M, Male; F, Female; Juv, Juvenile; m, meter.

Microhabitat								
Field ID	SVL (mm)	TL (mm)	W (g)	Sex (M/F/Juv)	Vegetation Type	Horizontal Position	Vertical Position	Substrate Type
BJ01	84.58	24.87	57.00	F	VG	HPL	VPC	SJ
BJ02	95.25	30.55	49.00	F	VG	HPG	VPC	SJ
BJ03	51.91	29.42	3.80	F	VG	HPH	VPK	SB
BJ04	74.52	36.51	34.00	M	VG	HPL	VPC	SJ
BJ05	34.06	18.27	1.70	F	VG	HPD	VPG	SH
BJ06	47.95	26.70	5.40	M	VG	HPD	VPG	SH
BJ07	45.09	20.16	7.40	F	VR	HPG	VPK	SA
BJ08	37.95	21.80	2.70	M	VR	HPL	VPQ	SH
BJ09	46.21	24.50	4.40	M	VR	HPL	VPQ	SH
BJ10	37.64	23.51	3.90	M	VR	HPL	VPD	SF
BJ11	45.76	25.06	4.20	M	VR	HPL	VPK	SA
BJ12	41.99	21.70	3.90	M	VR	HPL	VPK	SA
BJ13	48.92	24.57	4.20	M	VR	HPL	VPA	SH
BJ14	95.60	43.25	57.90	F	VR	HPL	VPA	SH
BJ15	46.91	24.34	5.40	F	VR	HPL	VPC	SJ
BJ16	83.86	29.38	44.00	F	VR	HPG	VPD	SF
BJ17	45.19	20.25	8.90	F	VR	HPG	VPD	SH
BJ18	33.30	17.78	2.60	M	VF	HPC	VPH	SJ

BJ19	56.85	27.88	21.00	M	VF	HPB	VPH	SJ
BJ20	31.03	18.62	2.00	M	VF	HPB	VPH	SJ
BJ21	37.39	25.87	4.00	M	VF	HPC	VPK	SA
BJ22	32.70	20.31	2.10	M	VF	HPB	VPK	SA
BJ23	34.67	17.52	2.40	M	VF	HPB	VPK	SA
BJ24	35.55	18.39	2.70	M	VF	HPC	VPH	SJ
BJ25	48.21	29.53	6.20	F	VF	HPB	VPK	SA
BJ26	34.07	16.15	3.80	M	VF	HPC	VPG	SH
BJ27	33.64	18.39	2.50	M	VF	HPC	VPK	SA
BJ28	40.43	29.48	5.00	M	VF	HPB	VPH	SJ
BJ29	38.83	18.33	3.10	M	VF	HPC	VPK	SA
BJ31	39.38	27.49	3.60	M	VF	HPB	VPH	SJ
BJ32	65.35	30.69	25.00	F	VF	HPB	VPH	SJ
BJ33	42.82	19.11	2.65	F	VF	HPB	VPH	SJ
BJ34	55.68	32.69	9.00	F	VF	HPC	VPA	SH
BJ35	24.71	13.65	0.90	F	VE	HPF	VPK	SA
BJ36	41.04	23.94	4.60	F	VE	HPF	VPK	SA
BJ37	81.30	30.44	42.00	M	VE	HPD	VPA	SH
BJ38	46.58	28.83	4.10	M	VE	HPF	VPL	SC
BJ39	38.26	22.09	2.90	M	VE	HPE	VPK	SA
BJ40	66.74	29.85	26.50	F	VE	HPG	VPG	SH
BJ41	39.30	22.95	3.10	F	VE	HPE	VPK	SA
BJ42	34.57	20.31	2.50	M	VE	HPE	VPG	SH
BJ43	50.26	27.75	7.00	F	VE	HPG	VPG	SF
BJ44	34.57	20.31	2.50	M	VE	HPG	VPG	SH
BJ45	37.50	20.44	4.00	M	VE	HPF	VPK	SA
BJ46	34.23	18.27	3.00	M	VE	HPE	VPJ	SH

BJ47	60.45	33.35	22.00	F	VE	HPE	VPA	SJ
BJ48	119.09	41.31	110.00	F	VE	HPG	VPG	SH
BJ49	921.40	59.04	250.00	F	VE	HPG	VPG	SH
BJ50	70.00	35.00	21.59	F	VAgr	HPV	VPA	SH
BJ51	45.00	22.00	6.00	M	VAgr	HPV	VPL	SA
BJ52	50.00	25.00	7.60	M	VAgr	HPV	VPK	SA
BJ53	60.00	25.00	13.00	F	VAgr	HPV	VPK	SA
BJ54	70.00	35.00	20.00	F	VAgr	HPV	VPA	SH
BJ55	57.00	25.00	16.00	F	VAgr	HPV	VPK	SA
BJ56	65.00	35.00	21.50	F	VAgr	HPV	VPA	SH
BJ57	85.00	25.00	41.00	F	VAgr	HPV	VPA	SH
BJ58	67.00	34.00	19.00	F	VAgr	HPV	VPL	SA
BJ59	45.00	21.00	3.30	M	VAgr	HPV	VPL	SA
BJ60	84.00	27.00	45.00	F	VAgr	HPG	VPH	SJ
BJ61	45.00	22.00	4.50	M	VAgr	HPV	VPK	SA
BJ62	85.00	30.00	47.00	F	VAgr	HPG	VPK	SJ
BJ63	40.00	30.00	55.00	M	VAgr	HPG	VPK	SJ
BJ64	80.00	28.00	44.00	M	VAgr	HPG	VPH	SJ
BJ65	73.00	24.00	23.00	M	VAgr	HPV	VPA	SH
MWC 1558	40.00	22.00	4.90	M	VG	HPG	VPG	SB
MWC 1559	36.00	19.00	1.80	M	VG	HPG	VPK	SA
MWC 1560	54.00	20.00	11.00	M	VG	HPG	VPG	SC
MWC 1561	145.00	63.00	340.00	F	VG	HPG	VPA	SH
MWC 1562	60.00	31.00	11.00	F	VG	HPG	VPG	SB
MWC 1563	58.00	28.00	8.00	M	VG	HPG	VPK	SB
MWC 1564	60.00	30.00	10.00	M	VG	HPG	VPK	SB
MWC 1565	50.00	16.00	13.00	F	VG	HPG	VPF	SF

MWC 1566	56.00	32.00	11.00	M	VG	HPG	VPK	SC
MWC 1567	55.00	33.00	8.00	M	VG	HPJ	VPG	SF
MWC 1568	30.00	15.00	2.80	F	VG	HPJ	VPG	SH
MWC 1569	55.00	33.00	9.00	M	VG	HPG	VPK	SB
MWC 1570	33.00	14.00	2.50	M	VG	HPG	VPK	SB
MWC 1571	55.00	28.00	5.00	M	VG	HPG	VPK	SA
MWC 1572	57.00	30.00	9.00	M	VG	HPG	VPG	SC
MWC 1573	36.00	19.00	2.00	M	VG	HPG	VPK	SA
MWC 1574	33.00	17.00	1.60	M	VG	HPG	VPK	SA
MWC 1575	35.00	19.00	2.80	F	VG	HPG	VPL	SA
MWC 1576	85.00	29.71	18.00	F	VG	HPG	VPP	SH
MWC 1577	52.00	28.35	9.00	M	VG	HPG	VPP	SH
MWC 1578	55.00	25.00	9.00	F	VG	HPG	VPM	SD
MWC 1579	50.00	27.00	12.00	F	VG	HPG	VPP	SH
MWC 1580	70.00	42.00	19.00	F	VG	HPG	VPK	SC
MWC 1581	28.00	14.00	1.00	M	VG	HPG	VPK	SA
MWC 1582	30.00	14.00	1.30	M	VG	HPG	VPK	SA
MWC 1583	30.00	16.00	1.50	M	VG	HPG	VPK	SA
MWC 1584	45.00	20.00	6.00	F	VG	HPG	VPF	SH
MWC 1585	42.00	19.00	9.00	M	VG	HPG	VPF	SH
MWC 1586	65.00	31.00	20.00	F	VG	HPG	VPF	SH
MWC 1587	60.00	29.00	20.00	M	VG	HPG	VPF	SH
MWC 1588	38.00	20.00	2.90	M	VG	HPG	VPN	SH
MWC 1589	70.00	35.00	27.00	F	VG	HPG	VPN	SH
MWC 1590	119.00	64.00	110.00	F	VG	HPG	VPF	SH
MWC 1591	90.00	55.00	20.00	M	VG	HPG	VPK	SA
MWC 1592	97.00	57.00	40.00	F	VG	HPG	VPN	SH

MWC 1593	60.00	39.00	10.10	M	VG	HPG	VPO	SF
MWC 1594	25.00	6.00	0.50	JUV	VG	HPG	VPG	SH
MWC 1595	20.00	10.00	0.50	F	VG	HPC	VPO	SC
MWC 1596	50.00	35.00	12.00	M	VG	HPG	VPA	SH
MWC 1597	30.00	14.00	1.70	M	VG	HPG	VPF	SH
MWC 1598	36.00	21.00	4.00	M	VG	HPG	VPG	SF
MWC 1599	57.00	32.00	10.40	F	VG	HPG	VPN	SH
MWC 1600	39.00	22.00	4.00	M	VG	HPG	VPN	SH
MWC 1601	33.00	15.00	2.30	M	VG	HPG	VPG	SH
MWC 1602	85.00	50.00	60.00	F	VG	HPG	VPF	SH
MWC 1603	46.00	20.00	7.00	F	VG	HPG	VPK	SA
MWC 1604	50.00	19.00	6.00	F	VG	HPG	VPF	SH
MWC 1605	60.00	30.00	23.00	JUV	VG	HPG	VPF	SH
MWC 1606	76.00	45.00	45.00	JUV	VG	HPG	VPF	SH
MWC 1607	70.00	40.00	25.00	JUV	VG	HPG	VPF	SH
MWC 1608	39.00	20.00	3.10	M	VG	HPG	VPG	SH
MWC 1609	35.00	15.00	2.70	M	VG	HPG	VPG	SH
MWC 1610	35.00	15.00	2.40	M	VG	HPG	VPG	SH
MWC 1611	50.00	26.00	6.00	JUV	VG	HPG	VPG	SF
MWC 1612	55.00	23.00	8.00	F	VG	HPG	VPN	SF
MWC 1613	59.00	30.00	8.20	F	VG	HPG	VPM	SD
MWC 1614	80.00	45.00	22.00	F	VG	HPG	VPM	SD
MWC 1615	50.00	30.00	10.00	JUV	VG	HPG	VPK	SA
MWC 1616	35.00	17.00	0.80	M	VG	HPG	VPK	SA
MWC 1617	54.00	26.00	8.70	JUV	VG	HPG	VPG	SH
MWC 1618	48.00	22.00	6.30	M	VG	HPG	VPP	SH
MWC 1619	58.00	35.70	4.30	F	VG	HPG	VPM	SA

MWC 1620	57.00	32.00	11.00	F	VG	HPG	VPP	SH
MWC 1621	55.00	26.00	9.60	F	VG	HPG	VPP	SH
MWC 1622	47.00	21.00	7.00	F	VG	HPG	VPQ	SH
MWC 1623	60.00	30.00	20.00	F	VG	HPG	VPQ	SH
MWC 1624	70.00	40.00	21.00	M	VG	HPG	VPP	SH
MWC 1625	50.00	25.00	7.00	F	VG	HPC	VPN	SG
UW166	63.00	24.00	28.00	M	VS	HPS	VPH	SG
UW167	61.00	21.00	27.00	M	VS	HPS	VPH	SG
UW168	65.00	24.00	27.00	F	VS	HPS	VPH	SG
UW169	74.00	27.00	42.00	F	VS	HPS	VPH	SG
UW170	74.00	27.00	14.00	M	VS	HPS	VPQ	SG
UW171	67.00	24.00	32.00	M	VS	HPS	VPH	SG
UW172	41.00	20.00	7.20	M	VS	HPS	VPH	SG
UW173	45.00	20.00	13.00	M	VF	HPL	VPP	SA
UW174	90.00	35.00	51.00	F	VF	HPV	VPP	SA
UW175	40.00	17.00	2.70	M	VF	HPV	VPP	SA
UW176	90.00	35.00	67.00	F	VF	HPV	VPP	SA
UW177	40.00	20.00	4.30	M	VF	HPL	VPC	SA
UW178	60.00	20.00	10.50	F	VF	HPQ	VPH	SA
UW179	45.00	25.00	5.00	M	VF	HPM	VPP	SA
UW180	57.00	21.00	12.00	F	VF	HPL	VPP	SA
UW181	80.00	33.00	19.00	F	VF	HPL	VPP	SA
UW182	48.00	20.00	9.00	JUV	VF	HPL	VPP	SA
UW183	33.00	18.00	23.00	M	VS	HPJ	VPP	SA
UW184	80.00	29.00	45.50	F	VS	HPJ	VPP	SA
UW185	75.00	25.00	31.00	M	VS	HPJ	VPP	SA
UW186	55.00	20.00	17.00	JUV	VS	HPJ	VPP	SA

UW187	68.00	26.00	27.00	F	VF	HPG	VPG	SA
UW188	70.00	40.00	27.00	F	VF	HPJ	VPK	SA
UW189	55.00	28.00	18.00	F	VF	HPJ	VPK	SA
KTM1	59.00	23.00	22.00	M	Vagr	HPG	VPH	SJ
KTM2	56.00	27.00	30.00	M	Vagr	HPL	VPF	SH
KTM3	64.00	25.00	29.00	M	Vagr	HPL	VPF	SH
KTM4	66.00	25.00	26.00	F	Vagr	HPL	VPF	SH
KTM5	70.00	29.00	36.00	F	Vagr	HPL	VPF	SH
KTM6	40.00	24.00	4.40	M	VAgr	HPG	VPG	SA
KTM7	20.00	10.00	0.20	M	VA	HPG	VPK	SA
KTM8	50.00	18.00	14.00	JUV/M	VA	HPG	VPQ	SG
KTM9	44.00	19.00	6.00	JUV	VA	HPG	VPG	SF
KTM10	68.00	34.00	29.00	F	VA	HPG	VPA	SG
KTM11	51.00	16.00	15.20	JUV	VA	HPG	VPQ	SG
KTM12	40.00	22.00	5.20	M	VA	HPG	VPF	SG
KTM13	45.00	22.00	3.90	JUV	VA	HPV	VPQ	SG
KTM14	75.00	34.00	30.00	F	VA	HPV	VPQ	SG
KTM15	70.00	35.00	30.00	M	VA	HPg	VPP	SG
KTM16	45.00	26.00	5.50	M	VA	HPG	VPL	SA
KTM17	60.00	20.00	24.00	M	VA	HPG	VPQ	SG
KTM18	65.00	34.00	20.00	F	VA	HPG	VPQ	SG
KTM19	58.00	30.00	15.00	F	VA	HPV	VPQ	SG
KTM20	73.00	39.00	33.00	M	VAgr	HPV	VPA	SG
KTM21	71.00	30.00	22.00	F	VAgr	HPG	VPQ	SG
KTM22	69.00	25.00	32.00	M	VAgr	HPG	VPQ	SG
KTM23	61.00	17.00	27.00	M	VAgr	HPG	VPF	SG
KTM24	54.00	26.00	12.00	F	VAgr	HPG	VPF	SG

KTM25	71.00	20.00	42.00	F	VAgr	HPG	VPF	SG
KTM26	69.00	21.00	40.50	F	VAgr	HPG	VPF	SG
KTM27	52.00	19.00	21.00	M	VAgr	HPG	VPF	SG
KTM28	46.00	25.00	10.00	M	VAgr	HPG	VPQ	SA
KTM29	49.00	21.00	14.00	F	VAgr	HPG	VPF	SG
KTM30	40.00	17.00	4.00	M	VAgr	HPG	VPQ	SH
KTM31	50.00	24.00	11.00	M	VAgr	HPG	VPQ	SH
MNP01	52.00	2.50	7.20	F	VE	HPG	VPK	SA
MNP02	14.00	3.00	14.00	JUV	VE	HPG	VPK	SA
MNP15	28.00	19.00	0.90	JUV/M	VE	HPG	VPK	SA
MNP16	28.00	20.00	1.10	JUV/M	VE	HPG	VPK	SF
MNP17	39.00	20.00	2.90	M	VE	HPG	VPK	SF
MNP18	55.00	22.00	7.70	M	VE	HPG	VPK	SH
MNP19	49.00	28.00	7.00	F	VE	HPB	VPO	SH
MNP20	40.00	18.00	3.60	JUV/M	VE	HPG	VPE	SF
MNP21	61.00	32.00	17.00	F	VE	HPA	VPC	SH
MNP22	45.00	22.00	6.00	M	VE	HPB	VPO	SH
MNP23	120.00	53.00	150.00	M	VE	HPV	VPK	SB
MNP24	48.00	23.00	7.00	F	VE	HPV	VPH	SJ
MNP25	45.00	32.00	9.20	M	VE	HPV	VPH	SJ
MNP26	100.00	41.00	51.00	F	VE	HPV	VPE	SF
MNP27	44.00	30.00	11.00	M	VE	HPV	VPH	SJ
MNP28	61.00	35.00	26.00	JUV/F	VE	HPV	VPH	SJ
MNP29	103.00	54.00	106.00	M	VE	HPV	VPH	SJ
MNP30	64.00	34.00	20.00	JUV/M	VE	HPV	VPH	SJ
MNP31	47.00	33.00	12.00	M	VE	HPV	VPH	SJ
MNP32	71.00	49.00	28.00	F	VE	HPV	VPH	SJ

MNP33	67.00	32.00	24.00	JUV/M	VE	HPV	VPH	SJ
MNP34	53.00	34.00	15.00	M	VE	HPV	VPH	SJ
MNP35	55.00	47.00	16.00	M	VE	HPV	VPH	SJ
MNP36	70.00	36.00	34.00	JUV/M	VE	HPV	VPK	SB
MNP37	68.00	29.00	16.50	F	VE	HPG	VPK	SA
MNP38	93.00	40.00	37.00	M	VE	HPG	VPG	SH
MNP39	72.00	34.00	21.00	F	VE	HPG	VPM	SD
MNP40	60.00	26.00	11.00	M	VE	HPG	VPG	SH
MNP41	92.00	40.00	50.00	M	VE	HPG	VPM	SB
MNP42	78.00	42.00	36.00	M	VE	HPG	VPG	SH
MNP43	43.00	21.00	5.30	JUV/M	VE	HPG	VPG	SH
MNP44	101.00	45.00	84.00	F	VE	HPG	VPG	SH
MNP45	31.00	16.00	0.10	M	VE	HPG	VPK	SA
MNP46	15.00	6.00	0.10	F	VE	HPG	VPK	SA
MNP47	36.00	16.00	0.20	M	VE	HPG	VPK	SA
MNP48	39.00	20.00	2.60	F	VE	HPG	VPE	SH
MNP49	85.00	34.00	42.00	M	VE	HPG	VPG	SH
MNP50	39.00	17.00	4.00	F	SE	HPG	VPG	SH
MNP51	110.00	53.00	180.00	M	VE	HPG	VPG	SA
MNP52	67.00	27.00	5.00	F	VE	HPG	VPK	SA
MNP53	46.00	26.00	5.00	M	VR	HPG	VPM	SG
MNP54	45.00	27.00	3.00	M	VR	HPG	VPA	SA
MNP55	46.00	24.00	7.90	M	VR	HPG	VPL	SA
MNP56	45.00	23.00	3.50	M	VK	HPE	VP	SG
MNP57	46.00	25.00	4.50	M	VR	HPG	VPL	SA
MNP58	48.00	24.00	5.00	M	VR	HPG	VPL	SA
MNP59	65.00	31.00	22.00	F	VR	HPG	VPL	SB

MNP60	48.00	27.00	16.50	M	VR	HPG	VPL	SA
MNP61	46.00	24.00	8.90	M	VR	HPG	VPL	SA
MNP62	36.00	18.00	3.30	M	VR	HPG	VPL	SA
MNP63	46.00	20.00	7.60	M	VR	HPG	VPA	SG
MNP64	46.00	19.00	7.50	M	VR	HPG	VPA	SG
MNP65	45.00	20.00	6.20	M	VR	HPG	VPA	SG
MNP66	48.00	27.00	5.00	M	VK	HPG	VPL	SB
MNP67	48.00	25.00	4.50	M	VR	HPG	VPL	SB
MNP68	45.00	17.00	7.50	M	VR	HPG	VPL	SG
MNP87	68.00	36.00	16.00	F	Vagr	HPG	VPF	SG
MNP88	50.00	25.00	5.10	M	VAgr	HPG	VPJ	SG
MNP89	50.00	27.00	5.30	M	VAgr	HPG	VPK	SA
MNP90	50.00	25.00	4.80	M	VAgr	HPG	VPJ	SG
MNP91	50.00	25.00	5.40	M	VAgr	HPG	VPK	SA
MNP92	51.00	27.00	5.70	M	VAgr	HPG	VPK	SB
MNP93	52.00	27.00	5.40	M	VAgr	HPG	VPJ	SG
MNP94	51.00	26.00	5.40	M	VAgr	HPG	VPK	SA
MNP95	52.00	26.00	5.80	M	VAgr	HPG	VPK	SB
MNP96	49.00	25.00	4.80	M	VAgr	HPG	VPK	SB
MNP97	51.00	26.00	5.70	M	VAgr	HPG	VPF	SG
MNP98	56.00	25.00	21.00	F	VAgr	HPG	VPF	SA
MNP99	48.00	25.00	4.60	M	VAgr	HPG	VPK	SA
MNP100	59.00	26.00	18.00	F	VAgr	HPG	VPF	SA
MNP101	48.00	26.00	5.10	M	VAgr	HPG	VPF	SA
MNP102	54.00	23.00	12.00	F	VAgr	HPG	VPF	SA
MNP103	44.00	22.00	9.10	M	VAgr	HPG	VPF	SA
MNP104	45.10	19.00	7.10	M	VAgr	HPG	VPF	SA

Appendix F: Coordinates for presence of *Fejervarya limnocharis* recorded from 2011 to 2023 in Sarawak.

Location	Coordinates in Decimal		
	Latitude	Longitude	Total
Bahagian Miri (Long Lama)	4.033	114.7948	6
	4.4447	114.0109	5
Bau	1.3390	110.0333	1
	1.3328	110.1061	3
	1.3802	110.1632	1
Kapit	1.9954	112.9325	1
Kuching	1.6128	110.1965	3
Lundu	1.6091	110.1599	10
Maludam	1.5364	111.1693	14
Padawan	1.1281	110.2185	1
Samarahan	1.4653	110.4473	2
	1.4612	110.4541	12
	1.4655	110.4213	1
	1.4677	110.4319	13
Sematan	2.0070	109.6460	7
Serian	1.0459	110.5988	1
Sibu	2.4519	111.8620	3