



Faculty of Resource Science and Technology

Diversity of Aquatic and Marsh plants in Western Sarawak

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Diversity of Aquatic and Marsh plants in Western Sarawak

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DECLARATION

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



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ABSTRACT

Sarawak is a Malaysian state on the island of Borneo. Malaysia has an estimated 15,000 vascular plant species, with approximately 8,300 in Peninsular Malaysia and over 12,000 in Sabah and Sarawak, including aquatic and marsh plants that are critical to the biological balance of the wetlands there. These wetlands, which include mangrove forests and riverine systems, support a diverse range of plant species, and adapt to seasonal changes in rainfall. Aquatic plants are important components of waterbody systems, but Sarawak has had far fewer studies on them than Peninsular Malaysia. More research on the distribution and diversity of aquatic plants is essential to improve the management of waterbody systems and to add educational value to these plants. The study aims to document the aquatic and marsh plant species in western Sarawak, assessing their diversity through a comprehensive review of the plants' morphological and palynological characteristics. It reveals the data on diversity, distribution, ecology, morphology, micromorphology (stomata and trichomes), and palynology data from the western Sarawak region, with a focus on Samarahan, Kuching, and Serian divisions. Every collected species was mapped and recorded. Only fresh samples were used for micromorphological and palynological studies. A total of 23 families, 41 genera, and 50 taxa have been identified in western Sarawak. The Araceae family contains the most taxa which were a total of 10 taxa. Samarahan (32 taxa) has the most species among the two divisions, according to the location survey. The aquatic and marsh plants were divided into seven groups: emergent, floating-leaved, submerged, emergent free-floating, submerged free-floating, rheophyte, and marsh plant. The pH of water aquatic species identified in western Sarawak ranged from 3.87 to 9.44, with temperatures ranging from 26.0 to 33.0 °C. For micromorphological studies, a total of 27 species from various habitat types (aquatic-related plants) were collected. The species' micromorphology (stomata) was chosen

at random, but each habit type must be represented by at least one species. Among the species studied, anisocytic, diacytic, hemiparacytic, paracytic, pericytic, stephanocytic, and tetracytic stomata were identified. Palynology evaluated the size, shape, length and breadth, unit, ratio, aperture, and exine sculpturing of pollen from 14 species from seven genera and families. The checklist, distribution, micromorphology, and palynology of aquatic and marsh plants in western Sarawak were all covered in this study. This study has provided an identification key for the region's aquatic and marsh plant families, which will aid future research and conservation efforts, fostering a more understanding of local plant diversity and endorsing focused efforts to protect and uphold these vital ecosystems.

Keywords: Borneo, Freshwater, Biodiversity, Wetland

Kepelbagaian Tumbuhan Akuatik dan Rawa di Sarawak Barat

ABSTRAK

Sarawak ialah sebuah negeri di Malaysia dari pulau Borneo. Malaysia mempunyai lebih kurang 15,000 spesies tumbuhan vaskular, dengan kira-kira 8,300 spesies di Semenanjung Malaysia dan lebih daripada 12,000 spesies di Sabah dan Sarawak, termasuk tumbuhan akuatik dan paya yang penting untuk keseimbangan biologi di kawasan tanah lembap tersebut. Kawasan tanah lembap ini, termasuk hutan bakau dan sistem sungai mengekalkan pelbagai jenis spesies tumbuhan dan dapat menyesuaikan diri dengan perubahan musim hujan. Tumbuhan akuatik adalah komponen penting dalam sistem pengairan, tetapi Sarawak mempunyai kekurangan kajian tentang tumbuhan akuatik berbanding dengan Semenanjung Malaysia. Kajian lebih lanjut mengenai taburan dan kepelbagaian tumbuhan akuatik adalah penting untuk meningkatkan pengurusan sistem badan air dan mempertingkatkan nilai pendidikan kepada tumbuhan ini. Pengajian ini bertujuan untuk mendokumentasikan spesies tumbuhan akuatik dan paya di Sarawak Barat, menilai kepelbagaian mereka dengan melalui kajian menyeluruh terhadap ciri-ciri morfologi dan palinologi tumbuhan. Ia mendedahkan data kepelbagaian, taburan, ekologi, morfologi, mikromorfologi (stomata dan trikoma), dan data palinologi dari kawasan Sarawak Barat, dengan focus kepada bahagian Samarahan, Kuching, dan Serian. Setiap spesies yang dikumpulkan telah dipetakan dan direkodkan. Hanya sampel segar yang digunakan untuk kajian mikromorfologi dan palinologi. Sejumlah 23 keluarga, 41 genera, dan 50 taksa telah dikenal pasti di Sarawak Barat. Keluarga Araceae mengandungi taksa paling banyak yang berjumlah 10 taksa. Samarahan (32 taksa) mempunyai spesies paling banyak di antara kedua-dua bahagian menurut kajian lokasi. Tumbuhan akuatik dan paya dibahagikan kepada tujuh kumpulan: tumbuhan yang timbul, daun terapung, tenggelam, bebas terapung,

terendam bebas terapung, rheofit, dan tumbuhan rawa. Bagi pH air spesies akuatik yang dikenal pasti di Sarawak Barat adalah antara 3.87 hingga 9.44, dengan suhu antara 26.0 hingga 33.0 °C. Untuk kajian mikromorfologi, sejumlah 27 spesies dari pelbagai jenis habitat (tumbuhan berkaitan akuatik) telah dikumpulkan. Mikromorfologi (stomata) spesies dipilih secara rawak, tetapi setiap jenis habitat mesti diwakili oleh sekurang-kurangnya satu spesies. Di antara spesies yang dikaji, stomata Anisositik, Diacitik, Hemiparasitik, Parasitik, Perisitik, Stephanositik, dan Tetracitik stomata telah dikenal pasti. Palinologi menilai saiz, bentuk, panjang dan lebar, unit, nisbah, apertur, dan seni ukiran exine serbuk dari 14 spesies daripada tujuh genus dan keluarga. Senarai semak, pengedaran, mikromorfologi, dan palinologi tumbuhan akuatik dan rawa di Sarawak Barat kesemuanya dikaji dalam kajian ini. Kajian ini telah menyediakan satu kunci pengenalan bagi keluarga tumbuhan akuatik dan paya di kawasan ini, yang akan membantu penyelidikan dan usaha pemuliharaan masa depan, menggalakkan pemahaman yang lebih mendalam terhadap kepelbagaian tumbuhan tempatan, serta menyokong usaha yang difokuskan untuk melindungi dan mengekalkan ekosistem yang penting ini.

Kata kunci: *Borneo, Air Tawar, Biodiversiti, Tanah Lembap*

TABLE OF CONTENTS

	Page
DECLARATION	i
ACKNOWLEDGEMENT	ii
ABSTRACT	iii
ABSTRAK	v
TABLE OF CONTENTS	vii
LIST OF TABLES	x
LIST OF FIGURES	xi
LIST OF ABBREVIATIONS	xvi
CHAPTER 1 INTRODUCTION	1
1.1 General Introduction	1
1.2 Problem Statement	3
1.3 Objectives	4
CHAPTER 2 LITERATURE REVIEW	5
2.1 Aquatic and Marsh Plants in Sarawak	5
2.2 Importance of Aquatic and Marsh plants.	7
2.3 Overview of Aquatic and Marsh Plants	9
2.3.1 Definition of Aquatic and Marsh Plants	9
2.3.2 Diversity of Aquatic Plant	11

2.3.3	Habitat and Ecology of Aquatic and Marsh Plant	12
2.4	Systematics of Aquatic and Marsh Plants	22
2.4.1	Morphology of Aquatic and Marsh Plants	23
2.4.2	Micromorphology of Aquatic and Marsh Plants	24
2.4.3	Palynology of Aquatic and Marsh Plants	33
CHAPTER 3 MATERIALS AND METHODS		42
3.1	Field Sampling and Samples Collection	42
3.2	Ecology Studies	43
3.3	Taxonomic Identification	44
3.3.1	Morphology Characteristics	44
3.3.2	Micromorphology Characteristics (Preparation of Leaves for the Field Emission Scanning Electron Microscope (FESEM)	45
3.3.3	Sample Preparations Palynology	48
CHAPTER 4 RESULTS		50
4.1	Documentation of Aquatic and Marsh Plants in Kuching, Samarahan, and Serian divisions	50
4.1.1	Diversity Aquatic and Marsh Plant	50
4.1.2	Distribution of species according to group	58
4.2	Ecological characteristics and Habitat Aquatic and Marsh Plant	77
4.2.1	Habitat and Ecology of Aquatic and Marsh Plant	77
4.2.2	The Temperature and pH of Water for Aquatic and Marsh Environment	82

4.2.3	The moisture and pH of soil of aquatic and marsh plant	86
4.3	Morphological and Palynological Characteristics of Aquatic and Marsh Plants	88
4.3.1	Morphology	89
4.3.2	Micromorphology	134
4.3.3	Palynology	158
CHAPTER 5 DISCUSSIONS		167
5.1	Diversity and Distribution of Aquatic and Marsh Plant Western Sarawak	167
5.2	Morphological Characteristics of Aquatic and Marsh Plant in Western Sarawak	174
5.3	Stomata and Trichome Characteristics of Aquatic and Marsh Plant in Western Sarawak	177
5.4	Palynology Characteristics of Aquatic and Marsh Plant in Western Sarawak	180
CHAPTER 6 CONCLUSION AND RECOMMENDATIONS		183
5.1	Conclusion	183
5.2	Recommendations	184
REFERENCES		185
APPENDICES		208

LIST OF TABLES

	Page
Table 3.1: Parameter of plant observation.	44
Table 3.2: Parameters of the structures of the leaves	46
Table 4.1: The list of aquatic and marsh plant species found in the western of Sarawak	51
Table 4.2: The division, localities, latitude, longitude, elevation, and collector of 50 aquatic and marsh plant species in western Sarawak	66
Table 4.3: The Distribution Presence of Species According to Aquatic Lifeform in Three Divisions.	74
Table 4.4: Type of forest and and habitat of 50 aquatic and marsh plant in western Sarawak	80
Table 4.5: The pH of water and temperature for 50 aquatic plant species in western Sarawak	84
Table 4.6: The species characteristics of 50 taxa found in western Sarawak	93
Table 4.7: The leaf arrangement, apex, base and measurement of 50 taxa of aquatic and marsh plant in western Sarawak.	101
Table 4.8: Stomata characteristics for aquatic and marsh plant species in western Sarawak	137
Table 4.9: Average, size, and density of stomata for aquatic and marsh species stomata in western Sarawak.	142
Table 4.10: Pollen characteristics of 14 species of aquatic and marsh plant from western of Sarawak arranged by alphabetically species.	160

LIST OF FIGURES

	Page
Figure 1.1: Maps of Sarawak, Malaysia (Map of Sarawak, 2023)	2
Figure 2.1: The littoral zone occurs on the edges of rivers, lakes, and the sea (Rana & Maiti, 2020).	18
Figure 2.2: The Raunkiaer life form classification (Raunkiaer, 1934).	19
Figure 2.3: The five types of lifeforms of aquatic plant (Tanaka et al., 2019).	21
Figure 2.4: Stomatal complex types (Barclay, 2007).	29
Figure 2.5: A schematic image of pollen grains structure (Kawane, 2022)	36
Figure 3.1: Maps of Samarahan, Serian and Kuching Division in Western Sarawak, Malaysia.	43
Figure 4.1: Diversity of aquatic and marsh plants according to the families	50
Figure 4.2: Number of taxa, genera, and families in three division of western Sarawak.	55
Figure 4.3: Map distribution of 23 families throughout western Sarawak.	56
Figure 4.4: The percentage of lifeforms found throughout the three divisions (Kuching, Samarahan, and Serian).	58
Figure 4.5: Distribution of emergent plant species in western Sarawak.	59
Figure 4.6: Distribution of floating-leaved plant species in western Sarawak.	60
Figure 4.7: Distribution of emergent free-floating plant species in western Sarawak.	61
Figure 4.8: Distribution of submerged plant species in western Sarawak.	62
Figure 4.9: Distribution of submerged free-floating plant species in western Sarawak.	63
Figure 4.10: Distribution of aquatic marsh plant species in western Sarawak.	65
Figure 4.11: Distribution of rheophyte plant species in western Sarawak.	65
Figure 4.12: The lifeform of aquatic and marsh plants in western Sarawak	88

Figure 4.13: Lentibulariaceae, the species from genus <i>Utricularia</i> found in western Sarawak, species A and B were found in Bako NP, species C, D, F, and H were found in UNIMAS while species E was taken in Matang-Sempadi roadside while G was taken in jalan Atro-Gedong A. <i>Utricularia hirta</i> . B. <i>U. subulata</i> . C. <i>U. minutissima</i> . D. <i>U. bifida</i> . E and F. <i>U. caerulea</i> . G. <i>U. aurea</i> . H. <i>U. gibba</i> .	108
Figure 4.14: Convolvulaceae, from the genus <i>Ipomoea</i> . A. and B. <i>Ipomoea aquatica</i> found in Samarahan division.	111
Figure 4.15: Droseraceae, from the genus <i>Drosera</i> . A. <i>Drosera spatulata</i> var. <i>bakoensis</i> in the habit of Bako NP sandstone plateau. B. the inflorescence of <i>D. spatulata</i> var. <i>bakoensis</i> .	111
Figure 4.16: Menyanthaceae from the genus <i>Nymphoides</i> . A. Inflorescence, <i>Nymphoides</i> sp. B. <i>Nymphoides</i> sp. in its habit in Sungai Paon Gahat, Kampung Melaban	111
Figure 4.17: Onagraceae, from the genus <i>Ludwigia</i> , A, C, and E are the species found in its habit. A and B. <i>Ludwigia repens</i> . C and D. <i>L. leptocarpa</i> . E and F. <i>L. adscendens</i> .	113
Figure 4.18: Plantaginaceae, species found was from the genus <i>Limnophila</i> and <i>Bacopa</i> . A. inflorescence, <i>Limnophila</i> sp. B. Habit, <i>Limnophila</i> sp. C. leaves, <i>Bacopa</i> sp. D. habit, <i>Bacopa</i> sp.	114
Figure 4.19: Polygonaceae, from the genus <i>Persicaria</i> . A. inflorescence, <i>Persicaria attenuata</i> subsp. <i>pulchra</i> . B. leaves, <i>P. attenuata</i> subsp. <i>pulchra</i> .	117
Figure 4. 20: Rubiaceae, from the genus <i>Neonauclea</i> . A. habit, <i>Neonauclea</i> sp. B. leaves, <i>Neonauclea</i> sp.	117
Figure 4.21: Gesneriaceae, from the genus <i>Loxocarpus</i> . A. inflorescence, <i>Loxocarpus</i> sp. B. habit, <i>Loxocarpus</i> sp.	117
Figure 4.22: Linderniaceae, from the genus <i>Lindernia</i> found in UNIMAS. A. habit, <i>Lindernia</i> sp. B. inflorescence, <i>Lindernia</i> sp.	118
Figure 4.23: Alismataceae, from the genus <i>Limnocharis</i> . A. habit in UNIMAS, <i>Limnocharis flava</i> . B. inflorescence, <i>L. flava</i> .	119
Figure 4.24: Araceae, from the genera <i>Lasia</i> , <i>Bucephalandra</i> , <i>Rhynophyle</i> , <i>Lemna</i> , and <i>Cryptocoryne</i> found in western Sarawak. A. <i>Lasia spinosa</i> . B. <i>Cryptocoryne auriculata</i> . C. <i>Bucephalandra</i> sp. D. <i>Rhynophyle</i> sp. E. <i>Lemna minor</i> . F. inflorescence, <i>Cryptocoryne longicauda</i> .	121
Figure 4.25: Burmanniaceae, from the genus <i>Burmanniea</i> in Bako NP. A. inflorescence, <i>Burmanniea</i> sp. B. leaves, <i>Burmanniea</i> sp.	122

Figure 4.26: Cyperaceae, the genera found in western Sarawak are <i>Fimbristylis</i> , <i>Schoenoplectus</i> , <i>Cyperus</i> , and <i>Rhynchospora</i> . A. <i>Schoenoplectus</i> sp. B. <i>Rhynchospora asperula</i> . C. <i>Cyperus</i> sp. D. <i>Fimbristylis polytrichoides</i>	125
Figure 4.27: Eriocaulaceae, from the genus <i>Eriocaulon</i> . A. habit, <i>Eriocaulon</i> sp. B. inflorescence, <i>Eriocaulon</i> sp.	125
Figure 4.28: Hydrocharitaceae, from the genus <i>Hydrilla</i> . A. leaves, <i>Hydrilla verticillata</i> . B. habitat, <i>H. verticillata</i> .	125
Figure 4.29: Nymphaeaceae, found in western Sarawak, genera found are <i>Nymphaea</i> and <i>Barclaya</i> . A. <i>Nymphaea pubescens</i> . B. <i>Nymphaea lotus</i> . C. <i>Nymphaea nouchalli</i> . D. <i>Barclaya motleyi</i> .	131
Figure 4.30: Typhaceae, the genus found in this family was <i>Typha</i> . A. <i>Typha angustifolia</i> . B. habit, <i>T. angustifolia</i> .	131
Figure 4.31: Pandanaceae, genus found in western Sarawak was <i>Pandanus</i> . A. fruit and leaves, <i>Pandanus yvanii</i> . B. habit, <i>P. yvanii</i> . C. habit, <i>Pandanus helicopus</i> . D. fruit and leaves, <i>P. helicopus</i> .	132
Figure 4.32: Pontederiaceae, genera found in western Sarawak were <i>Pontederia</i> and <i>Monochoria</i> . A. inflorescence, <i>Pontederia crassipes</i> . B. inflorescence, <i>Monochoria hastata</i> . C. Habit, <i>P. crassipes</i> . D. Habit, <i>M. hastata</i> .	132
Figure 4.33: Xyridaceae, the genus that found in western Sarawak was <i>Xyris</i> . A. habit, <i>Xyris</i> sp. B. inflorescence, <i>Xyris</i> sp.	133
Figure 4.34: Salviniaceae, the genus found was <i>Salvinia</i> . A. leaves, <i>Salvinia molesta</i> . B. habit, <i>S. molesta</i> .	133
Figure 4.35: Parkeriaceae, the genus found for this aquatic fern was <i>Ceratopteris</i> . A. habitat, <i>Ceratopteris thalichoides</i> var. <i>thalichoides</i> . B. leaves, <i>C. thalichoides</i> var. <i>thalichoides</i>	133
Figure 4.36: Type of stomata found in aquatic and marsh plant in Western part of Sarawak.	136
Figure 4.37: The adaxial of I. <i>Bacopa</i> sp., II. <i>Pontederia crassipes</i> , III. <i>Limnocharis flava</i> , IV. <i>Hydrilla verticillata</i> , V. <i>Monochoria hastata</i> , VI. <i>Ludwigia repens</i> . Magnification: 150x-300x. Type of stomata paracytic (II),(III), and (V); diacytic (VI).	146
Figure 4.38: The adaxial of VII. <i>Nymphaea nouchalli</i> , VIII. <i>Barclaya motleyi</i> , IX. <i>Cryptocoryne auriculata</i> , X. <i>Cryptocoryne lingua</i> , XI. <i>Cryptocoryne longicauda</i> , XII. <i>Cryptocoryne striolata</i> . Magnification = 300x. Type of stomata stephanocytic (VIII); tetracytic (IX), (X), (XI), and (XII).	147

- Figure 4.39: The adaxial of XIII. *Fimbristylis polytrichoides*, XIV. *Ipomoea aquatica*, XV. *Lasia spinosa*, XVI. *Persicaria attenuata* subsp. *pulchra*, XVII. *Pandanus yvanii*, XVIII. *Xyris* sp. Magnifications = 100x-300x. Type of stomata hemiparacytic (XIII); paracytic (XIV), (XVI), and (XVIII). 148
- Figure 4.40: The adaxial of XIX. *Cryptocoryne zadiana*, XX. *Lemna minor*, XXI. *Salvinia molesta*, XXII. *Cyperus* sp., XXIII. *Drosera spatulata* var. *bakoensis*, XXIV. *Eriocaulon* sp. Magnification = 150x – 300x. Type of stomata tetracytic (XIX); anisocytic (XXI); paracytic (XXII) and (XXIV); pericytic (XXIII). 149
- Figure 4.41: The adaxial of XXIV. *Bucephalandra* sp., XXV. *Neonauclea* sp., XXVI. *Rhynchosytle* sp. Magnification = 300x-330x. Type of stomata paracytic (XXIV) and (XXV); tetracytic (XXVI). 150
- Figure 4.42: The abaxial of I. *Bacopa* sp., II. *Pontederia crassipes*, III. *Limncharis flava*, IV. *Rhynchosytle* sp., V. *Monochoria hastata*, VI. *Ludwigia repens*. Magnification = 150x – 300x. Type of stomata (II), (II), and (V); tetracytic (IV); diacytic (VI). 151
- Figure 4.43: The abaxial of VII. *Hydrilla verticillata*, VIII. *Nymphaea nouchalli*, IX. *Barclaya motleyi*, X. *Cryptocoryne auriculata*, XI. *Cryptocoryne lingua*, XII. *Cryptocoryne longicauda*. Magnification = 300x. Type of stomata stephanocytic (IX); tetracytic (X), (XI), and (XII). 152
- Figure 4.44: The abaxial of XIII. *Cryptocoryne striolata*, XIV. *Cryptocoryne zadiana*, XV. *Lemna minor*, XVI. *Cyperus* sp., XVII. *Drosera spatulata* var. *bakoensis*, XVIII. *Eriocaulon* sp. Magnification = 100x – 500x. Type of stomata tetracytic (XIII) and (XIV); paracytic (XVI) and (XVIII); pericytic (XVII). 153
- Figure 4.45: The abaxial of XIX. *Fimbristylis polytrichoides*, XX. *Pandanus yvanii*, XXI. *Xyris* sp., XXII. *Ipomoea aquatica*, XXIII. *Lasia spinosa*, XXIV. *Persicaria attenuata* subsp. *pulchra*. Magnification = 100x – 300x. Type of stomata hemiparacytic (XIX); paracytic (XXI), (XXII), and (XXIV). 154
- Figure 4.46: The abaxial of XXV. *Bucephalandra* sp., XXVI. *Neonauclea* sp., Magnification = 300x. Type of stomata paracytic (XXV) and (XXVI). 155
- Figure 4.47: Scanning Electron Microscope (SEM) trichome of A. and B. *Barclaya motleyi*, C. and D. *Cryptocoryne striolata*, E and F. *Drosera spatulata* var. *bakoensis*, G. *Ipomoea aquatica*, H. *Nymphaea nouchalli*, I. *Salvinia molesta*., J. *Ludwigia repens*, K. *Neonauclea* sp. Magnification = 100x – 3000x. Type of trichome unicellular (A), (H), (C), and (K); hydropotes (B); multicelled glandular (G), (J), and (F); multicellular uniseriate (I); glandular hair (E). 157

- Figure 4.48: Scanning Electron Microscope (SEM) A. Equatorial view, *Utricularia nivea*. B. Equatorial view, *Utricularia minutissima*. C. Polar view, *Ceratopteris thalichoides* var. *thalichoides*. D. Polar view, *Ipomoea aquatica*. E. Equatorial view, *Cryptocoryne longicauda*. F. Equatorial view, *Utricularia aurea*. G. Equatorial view, *Cryptocoryne auriculata*. H. Equatorial view, *Utricularia bifida*. I. Polar view, *Drosera spatulata* var. *bakoensis*. J. Equatorial view, *Monochoria hastata*. K. Equatorial view, *Utricularia hirta*. L. Polar view, *Utricularia gibba*. M. Polar view, *Utricularia subulata*. N. Equatorial view, *Limnocharis flava*. 159
- Figure 5.1: Invasive plant found in western Sarawak. A. habit of *Pontederia crassipes* dominating at Kota Samarahan roadside. B. *Salvinia molesta* and *Ludwigia leptocarpa* dominates the lake of UNIMAS. C. *Ludwigia leptocarpa* at UNIMAS lake. D. *Salvinia molesta* dominating UNIMAS lake and drainage system. 170
- Figure 5.2: The Sarawak topographic map, elevation, terrain. Note: The data for Sarawak topography are from “Sarawak topographic map”, by topographic-map.com, World topographic map. 172

LIST OF ABBREVIATIONS

a.s.l	Elevation above sea level
CGS	Centre for Graduate Studies
CO ₂	Carbon Dioxide
cm	Centimetres
CPD	Critical Point Drying
DOC	Dissolved Organic Carbon
E	Equatorial diameter
EM	Electron Microscope
FAA	Formalin-acetic acid-alcohol
FESEM	Field Emission Scanning Electron Microscope
FOV	Area of field of view
GPS	Global Positioning System
kV	Kilovolt
M	Molar
mA	Milliampere
mequiv. /L HCO ₃ ⁻	Milliequivalents per litre Bicarbonate
mm ²	Millimeter square
nm	Nanometre
NRE	Ministry of Natural Resources
P	Polar axis
PDU	Pollen dispersion unit
pH	Potential of Hydrogen

Psi	Pound per square inch
P/E	Pollen ratio
RECODA	The Regional Corridor Development Authority
REM	Reflection Electron Microscope
SD	Standard Density
SEM	Standard Electron Microscope
TEM	Transmission Electron Microscope
UITM	Universiti Teknologi MARA
UNIMAS	Universiti Malaysia Sarawak
μ	Micro
μm	Micrometre
°C	Degree Celsius

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Malaysia is home to a rich biodiversity, hosting approximately 15,000 vascular plant species (Saw & Chung, 2015). In Sarawak alone, there are over 8,000 species, constituting more than 50% of the country's vascular flora (Forest Department Sarawak, 2020). There are two primary ecosystems that these plants belong to: terrestrial and wetland, which include aquatic and marsh species and are essential to the ecological balance of wetlands. In Sarawak, the majority of research on vascular plants focuses on terrestrial habitats. Consequently, wetland habitats are considered understudied. Aquatic plants are those that adapted to survive in an aquatic environment, such as saltwater or freshwater. Marsh plants are plants that are found at the borders of lakes and streams. The marsh plants live between the aquatic and terrestrial ecosystems, acting as transitional forms between the two. Aquatic plant are the fundamental components contributing to the operation of aquatic ecosystems aiding in the provision of habitat, nutrient cycling, water quality management. Furthermore, it is essential to comprehend their biology and ecology to manage and conserve the ecosystem. Sarawak is well-known for its unique aquatic ecosystems, which include great river systems, lakes, and coastal areas Sarawak's wetlands are represented by a diverse range of habitats, including mangrove forests, peat swamps, and riverine systems, which support a diverse range of plant species (Figure 1.1).

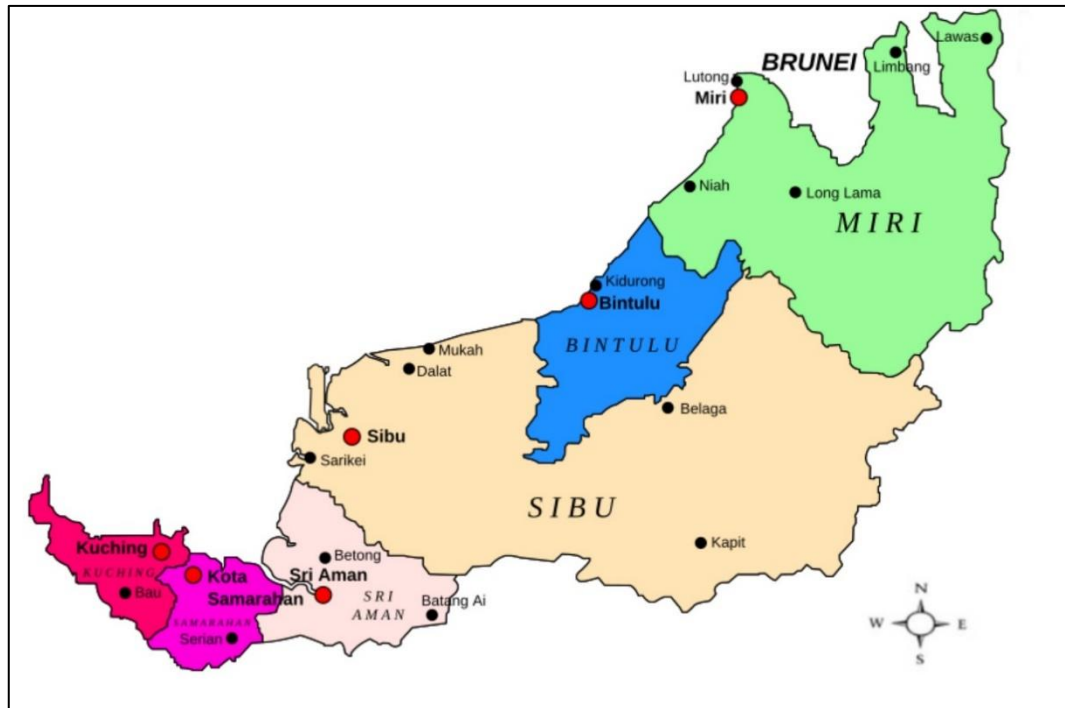


Figure 1.1: Maps of Sarawak, Malaysia (Map of Sarawak, 2023)

These diverse aquatic environments provide a unique opportunity for researchers to study a diverse of aquatic and marsh plant species as well as their interactions with local fauna and environmental circumstances. According to Parlan et al. (2021) the estimated area of wetlands in Sarawak in hectares (ha) are mangrove (139, 890), freshwater swamp (28,907), and peat swamp forest (112,000). Moreover, Sarawak is ecologically significant and often supports rare and endemic species, making aquatic and marsh plant discoveries particularly valuable for conservation efforts and making it more important to understand the potential impacts on aquatic and marsh plant communities and the broader ecosystem. To establish a comprehensive understanding of the biodiversity and ecological dynamics of Sarawak's wetlands, it is imperative to delve into the study of aquatic and marsh plant species. This research will bridge the gap highlighted in the literature regarding the limited

documentation of aquatic plants in Sarawak, particularly in western regions, and address the critical need for systematic documentation of their distribution.

1.2 Problem Statement

Aquatic plants are important elements of waterbody systems such as rivers, streams, lakes, and ponds, as well as drainages that can be beneficial or harmful to the environment. Mulhberg's book in 1982, covered global aquatic plant species but only documented those in Tasik Bera, Peninsular Malaysia. No documentation for Sarawak exists. It's crucial to systematically document aquatic plants in western Sarawak due to unique ecological factors. This missing information hampers understanding of aquatic plant dynamics in the region. The focus of botanical research in Sarawak has been predominantly on specific plant families or genera, such as Nymphaeaceae (water lily) and Araceae (water trumpet), as exemplified by research conducted by Natasha Arina (2014) and Simon et al. (2008).

Despite this, only a few studies that documented on aquatic plants have been conducted, as opposed to those in Peninsular Malaysia, which were fairly well documented. Earlier studies examined aquatic and marsh plant species in Sarawak, including the assessments of plant diversity and community ecology in the Sematan mangrove forest (Ashton & Macintosh, 2002), and investigation into freshwater macrophytes in Bintulu and Miri coastal areas (Awing, 2008). Given the limited existing research on the western Sarawak's aquatic and marsh plant species, it becomes imperative to undertake a comprehensive documentation of their distribution in this region. Thus, it is critical to research the diversity, distribution, and ecology of aquatic plants to understand their habits and habitat and to manage waterbody systems wisely. The lack of taxonomic information on aquatic plants will make it more difficult for scientists or researchers to investigate further

the various aspects of the study to add informative value to these plants in the future, resulting in few objectives for achieving this study.

1.3 Objectives

The main aim of this project was to conduct a comprehensive study and to obtain info of the current knowledge on systematic ecology of aquatic and marsh plants in the western of Sarawak, with the objective of this study are as follows:

- i. To document the aquatic and marsh plant species in Kuching, Samarahan, and Serian Divisions of Sarawak.
- ii. To assess the diversity of the documented species via morphological and palynological characteristics.

CHAPTER 2

LITERATURE REVIEW

2.1 Aquatic and Marsh Plants in Sarawak

Sarawak is a Malaysia state located on the island of Borneo, specifically between 0° 50' and 5°N and longitude 109°36' and 115° 40' E (The Official Portal of Sarawak Government, n.d.). The climate in Sarawak is equatorial climate type. This means temperatures in Sarawak are uniform throughout the year, with a mean of five hours' sunshine a day. Nearly every day we will see the temperature relatively rise from a 23 °C early in the morning to a warm 32°C around noon (The Regional Corridor Development Authority (RECODA), 2018). This region has a diverse and rich biodiversity, with many plant species found in its aquatic and marsh environments. Sarawak's aquatic and marsh plants are diverse and important in terms of ecology. These botanical treasures include a wide range of species that thrive in the region's diverse aquatic habitats, such as rivers, lakes, and swamps. The diverse aquatic plants play an important role maintaining the delicate balance of these ecosystems by providing essential habitat and nutrition for a wide range of aquatic organisms. Sarawak's wetlands encompass extensive areas, including mangrove, freshwater swamp, and peat swamp forest, as estimated by Parlan et al. (2021). However, despite these estimates, certain smaller wetland areas remain unexplored and undocumented in the study.

Helmut Muhlberg's book, *The Complete Guide to Water Plants*, listed all families and genera of aquatic plants in the world and included information on aquatic plant anatomy, physiology, and propagation (Muhlberg, 1982). While Muhlberg's work extensively documented global species, he only documented the aquatic and marsh plant species found

in Tasik Bera, Pahang, Peninsular Malaysia. Unfortunately, no documentation for Sarawak has been identified. Even though Muhlberg's book has already compiled a comprehensive list of aquatic plant species from around the world, it remains critical to systematically document the species present in a western Sarawak, as diverse topography and local environmental factors can lead to unique and region-specific aquatic and marsh plant distributions. Acknowledging the aquatic plant distribution is essential, but missing information required to understand the dynamics of the aquatic plant in western Sarawak ecosystem. Research efforts, like Awing's (2008) conducted studies on freshwater macrophytes in Sarawak, particularly in the Bintulu division and Miri district, investigating their distribution, habitat characteristics, and local uses. Ashton and Macintosh (2002) carried out a thorough investigation into the community ecology and preliminary assessment of plant diversity in the Sematan mangrove forest in Sarawak, Malaysia. These past research had shed light on specific areas, where only fragments of Sarawak's botanical landscape have been studied. Most research conducted in Sarawak focused on specific plant families or genera, such as Nymphaeaceae (water lily) and Araceae (water trumpet). For instance, studies included morphological and molecular characterization of water lilies (Arina, 2014) and examination of distribution patterns, growth, and biomass allocation of *Crptocoryne ciliata* (Simon et al., 2008).

In conclusion, the distribution and diversity of aquatic and marsh plants in western Sarawak, which includes the division of Kuching, Samarahan, and Serian, need to be studied in great detail. In the biologically diverse region of Borneo, Sarawak is home to a wide variety of plant species, many of which are thrive in its marsh and aquatic habitats. A large variety of aquatic life depends on these ecosystems, which include rivers, lakes, and wetlands, as important habitats and food supplies. Despite its ecological importance, past studies in

Sarawak frequently concentrated on particular plant families or genera, creating a significant void in our knowledge of the region's overall distribution and diversity of aquatic and marsh plants. There is still a need for thorough analyses covering all three of the aforementioned divisions, despite studies like Natasha Arina's research on water lilies and Awing's study on freshwater macrophytes have provided insightful information in specific areas. The thorough analysis of the Sematan mangrove forest by Ashton and Macintosh, which sheds light on the detailed ecological processes of pristine environments, is an example of how such research is useful. Therefore, a comprehensive analysis of the distribution of aquatic and marsh plants in western Sarawak is crucial for protecting this region's distinctive biodiversity as well as for informing effective conservation and management methods.

2.2 Importance of Aquatic and Marsh plants.

Aquatic and marsh plants play a crucial role in maintaining the health of aquatic ecosystems by providing habitat, oxygenation, and sustenance to a variety of organisms, highlighting their crucial significance in sustaining biodiversity and ecological balance. Studying aquatic plants thoroughly is essential due to their pivotal role in aquatic ecosystems and the numerous benefits they provide to humans. The primary supportive functions offered by these plants involve nutrient cycling and habitat provision, with macrophytes also playing a role in water circulation and gas generation. The presence and activities of aquatic plants contribute significantly to water purification and disease control, essential aspects of regulatory ecosystem services (Thomaz, 2023). According to Gross et al. (2007) in shallower lakes, these plants can curb algae proliferation and improve water clarity through various means, such as outcompeting for nutrients or releasing substances harmful to algae. As a result, lakes with abundant submerged vegetation are better equipped to withstand higher nutrient levels compared to those lacking such vegetation. Submerged macrophytes are

crucial to the structure and operation of aquatic freshwater systems. In nutrient-rich lakes, they are particularly crucial for maintaining a clear water state and for the in-lake cycling of nutrients. By releasing chemicals harmful to algae or competing with other plants for nutrients, submerged macrophytes in shallow lakes can inhibit the growth of algae and improve the clarity of the water. And hence, compared to lakes without or with restricted macrophyte cover, shallow lakes with macrophyte cover are more resilient to rising nutrient loads (Swe et al., 2021).

Studies on the overgrowth of aquatic plants and how to manage it have been a concern globally, including in Asia (Pieterse & Murphy, 1990). Although there's considerable research on how physical and chemical factors influence water quality and biological communities in temperate lakes, our understanding of these dynamics in tropical lakes is lacking. Nonetheless, various scattered studies indicate that physical and chemical conditions, along with biological interactions, vary between tropical and temperate lakes. This emphasizes the necessity for more research in tropical areas to address challenges such as excessive macrophyte growth, especially considering the extensive knowledge about temperate lakes and the existing gaps in understanding tropical lake ecosystems. Thus it is unclear whether the information and conclusions drawn from studies in temperate regions can be applied directly to tropical lakes. To sum up, the significance of aquatic and marsh plants in preserving the well-being of aquatic ecosystems is evident, underscoring their vital contribution to biodiversity and ecological harmony. Nevertheless, additional investigation, particularly in tropical areas, is necessary to tackle issues such as overgrowth of plants and to establish efficient management approaches for various water ecosystems globally.

2.3 Overview of Aquatic and Marsh Plants

According to Amaral et al. (2008), aquatic and marsh plants can withstand continuous or intermittent submersion in water, and these plants can live in environments that are at least periodically waterlogged. According to Aona et al. (2015) the terms “aquatic” and “marsh” plant are rather broad concepts that are not specifically defined, so transitional forms are always present. Aquatic plants, according to Cook (1996), can be divided into a few life forms that are influenced by their position, which also correlates to the water surface and degree of adaptation to the environment. Many tropical and subtropical marsh plants living in temporary waters or flood zones of stagnant or flowing waters exhibit symptoms of aquatic and marsh plant adaptation to the periodic shift in rain-intensive and rain-deficient seasons (Kasselmann, 2003).

2.3.1 Definition of Aquatic and Marsh Plants

Researchers use a variety of terms to describe aquatic plants or hydrophytes, but the patterns of the terms are all quite similar, and they are all related to the ability to adapt and grow in waterlogged habitats. These plants can be found in deep water, bogs, and marshes, as well as seasonally and permanently flooded areas. Aquatic plants have been physiologically and morphologically modified to survive, adapt, and thrive in aquatic environments, whereas other plants would die. There are numerous aquatic plant families found all over the world. Aquatic plants fascinate many biologists due to their evolutionary antiquity, extremely plastic phenotypes, and reduced vegetative and reproductive structures, which make them biologically perplexing and evolutionary fascinating (Philbrick & Les, 1993). According to Knight et al. (2014) three things must be learned in order to comprehend aquatic plant ecology (1) the biological factors that affect where and how plants develop,

such as competition, light, and nutrition; (2) how plant life may be impacted by inadvertently changing these parameters due to human activities like pollution and the introduction of invasive species; (3) the effects of intentional aquaculture plant management techniques.

Aquatic plants are plants that can adapt to living in aquatic environments and known as macrophytes (hydrophytes), can adapt and modifying themselves in environment to live in waterbodies such as freshwater or saltwater. Marshes have herbaceous (non-woody) vegetation that is accustomed to moist soil conditions and are characterised by periodic water saturation, flooding, or wetlands while tidal marshes and non-tidal marshes are further classifications for marshes (United States Environmental Protection Agency (EPA), 2001). Marsh plants are plants found near the edges of lakes and streams. Marsh plants exist between the aquatic and terrestrial ecosystems, acting as transitional forms between the two. Aquatic plants, as defined by Chambers et al. (2008), are aquatic photosynthetic organisms large enough to be seen with the naked eye, such as those that actively grow submerged below, floating on, or growing up through the water surface. These are aquatic macrophytes found in freshwater or brackish bodies of water. This definition also includes aquatic plants that live in permanent, temporary, and ephemeral inland bodies of water and watercourses. Lakes, rivers, canals, reservoirs, and other inland waters that rarely, if ever, dry up provide obvious potential macrophyte habitats; however, short-term, and ephemeral waterbodies are also open to debate regarding their status as macrophyte habitats where ephemeral waterbodies can go years between filling, are less predictable in their occurrence, and are frequently dependent on the amount of rainfall in a given year while temporary waterbodies are those that dry up and re-fill after a reasonably predictable (often annual) temporal precipitation cycle. Although the macrophytes of temporary and ephemeral systems can endure brief periods of drought, they often need partial or complete flooding at some point

in their life cycle for example, to begin propagule production or germination (Murphy et al., 2019).

According to Amaral et al. (2008), aquatic and marsh plants can withstand continuous or intermittent submersion in water, and these plants can live in environments that are at least periodically waterlogged. According to Aona et al. (2015), Weaver and Clements first used the term “aquatic macrophytes” in 1938 to describe water-growing plants, while Raunkiaer in 1934 called them hydrophytes if they were submerged or had floating leaves, and Iversen in 1936 introduced “limnophytes” for higher freshwater plants, but Aona et al. noted that because these terms are broad and not specific, there are always transitional forms.

2.3.2 Diversity of Aquatic Plant

According to Raja et al. (2015), there are approximately more than 100 families of vascular plants worldwide, with approximately 7.5% being dicotyledonous and 11% being monocotyledonous. There are 11 vs 22.7 species per genus respectively, are the average number of species found in aquatic genera as compared to the terrestrial genera, according to Meseguer et al., (2022) calculations (4467 aquatic species/ 407 genera; 292015 terrestrial species/ 12840 genera). Freshwater habitats often experience more consistent temperatures than terrestrial ones, though particular water temperature fluctuations may differ dependent on a number of variables (Bornette & Puijalon, 2011). These plants serve as the primary producers and serve as the foundation of many organisms' food webs. No previous global scale study had evaluated the global distribution of the total world pool of aquatic macrophyte species, or the global scale drivers of macrophyte diversity, assemblage, and

endemism patterns Murphy et al. (2019) and there are 1292 species in the world macrophytes dataset (or 37.5% of the total) whose conservation status was determined to be Data Deficient (DD) and 954 to be of Least Concern (LC) are included in the dataset. The remaining 244 species, which make up 7.2% all macrophyte species assessed by the IUCN up to 2018, are deemed to be in danger (classified by the IUCN as Near Threatened NT, Vulnerable VU, Endangered EN, or Critically Endangered CR).

2.3.3 Habitat and Ecology of Aquatic and Marsh Plant

The goal of ecology research is to comprehend all effective, active factors, as well as their specific functions and tasks within natural biotopes and living environments (Kasselman, 2003). According to Carvalho et al. (2009), the goal of macroecology research is to understand the component that controls large-scale patterns of species distribution and diversity. However, there has been little application of these macroecology principles in practical ecological research and management. Macroecology, the study of ecological patterns observed on large spatial scales (from continents and oceans to the entire planet), has recently become a recognized discipline in ecological science (Whittaker et al., 2001). Endo- and ectozoochory vectors of macrophyte propagule movement, such as migratory birds, are one of the main factors influencing the macroecology of aquatic plants. This factor is increasingly recognized, and examples exist for the factors that play a role in explaining the macrophyte global distributions (Lovas-Kiss et al., 2019).

According to Lacoul and Freedman (2006), changes in environmental conditions influence the distribution and abundance of aquatic plants, as they do for all species. Aquatic organisms, including those associated with physical characteristics such as geomorphology (geology and topography), sediment, climate, and hydrology, are primarily influenced by

factors inherent in water body limnology, and these variables are impacted by the in-situ properties of water bodies as well as the terrestrial components of their watersheds. As a result, it is critical to observe and analyse data for aquatic plant ecology, such as latitude, altitude, temperature, and pH value of water.

2.3.3.1 Spatial Environment (Latitude and Altitude)

Latitude and altitude (elevation above sea level: a.s.l.) are great examples of spatial-environment technologies to provide insight into the patterns of variation in macrophyte species richness and community composition (species presence/absence across site) (Murphy et al., 2019). According to Virola et al. (2001) high-latitude limit aquatic plant species diversity. In this case, latitude should be considered a biogeographical overview of both the historical and current impact of the variety of interacting individual spatial-bio-environmental variables that collectively form the structure, range size, abundance distribution, and diversity of freshwater species in inland water bodies around the world for both macrophytes and another freshwater biota (Grimaldo et al., 2016).

Ferna'ndez-Ala'ez et al. (2018) theory that the richness will decline as altitude rises. Altitude, according to Jones et al. (2003), was the strongest indicator of species richness among the environmental variables studied. Similarly, Lacoul and Freedman (2006) identified that water temperature (which correlated strongly and linearly with altitude) was the best predictor of macrophyte richness, followed by clarity, pH, alkalinity, and conductivity. They added that aquatic plants at high altitudes live in extreme environments where physical stressors associated, and harsh climatic conditions limit the factors that determine aquatic plant distribution. In general, as elevation increases, so does species diversity, a trend that can be attributed to climate change.

2.3.3.2 Water

The aquatic and marsh plant can be found in both stagnant and flowing waterways; additionally, the distinct characteristics of this living environment are primarily defined by the flow of water and the currents to which the plants are subjected. Water is an important ecological element for the survival of aquatic and marsh plants. Water flow, currents, hardness, pH value, and nutrient composition, in particular, have a significant impact on plant growth (Kasselman, 2003). Kasselman also mentioned that the power of the current affects the consistency of the soil. Water movement is critical for many physiological metabolic processes. It speeds up nutrient delivery and wastewater elimination by enabling exchange processes.

According to Rhazi and Grillas (2010), the presence of aquatic plants is primarily determined by the depth and rate of water flow, and some species prefer stagnant or at least calm waters, such as lakes, rivers, marshes, and bogs. Kasselman (2003) concluded that there are three classifications of water: white water rivers, clear water, and black water. Further explanation of water classification on their characteristics by Kasselman (2003) are:

1. Typical white-water rivers: Loamy-yellow, turbid water and, in contrast to clear and black water river, contain a large amount of inorganic floating matter which deposits on the riverbanks and forms an especially fertile soil
2. Clear water rivers: Poor sediments and contain very clear, yellow green to dark olive-green water with high visibility. White sandy beaches often form on the riverbanks.
3. Black water rivers: Characterized by clear, transparent but dark, brown-coloured water. The typical deep, brown-coloured water is a result of the regular flooding of

the surrounding forest which leads to the inflow of humic matter. As a results black water is exceptionally acid and very poor in dissolved minerals.

2.3.3.3 Temperature

The ambient temperature of water and sediment also affects the distribution of aquatic plants by influencing their physiology, including seed germination, seasonal growth initiation and rate, and dormancy onset (Spencer et al., 2000). Due to their climate's higher mean and maximum temperatures, tropical species demonstrated maximal net photosynthesis at a higher growth temperature than temperate species (Cunningham & Read, 2002).

Hiscock (2003) also stated that heat influences all biological processes in an organism, provided the temperature change is within the organism's tolerance; thus, an increase in temperature commonly causes an increase in metabolism. Temperature is one of the most important considerations in an aquatic world. Changes in the global climate can affect temperature availability, which is an important environmental variable, both locally and regionally. Climate zones, geographical areas, incident light, height, geology, and season are some of the factors that affect its variance on various spatial and temporal scales (Riis, et al., 2012). It was also revealed that plants have adapted to differences in temperature between night and day in their natural environment (Kasselmann, 2003).

2.3.3.4 The pH value

Water temperatures are well known to affect aquatic plants and their ecosystems (Spencer et al., 2000). Most tropical and subtropical waters containing aquatic plants display very salt-deficient, soft water with a pH value in the weak acid to a neutral range (around

pH 6.0-7.0) due to mineral deficiency (Kasselman, 2003). In his work, the author also mentioned how rare it is to find rivers in tropical and subtropical regions that have medium-to-hard water with a pH that is alkaline. The pH and associated factors (such as alkalinity) have been shown in lentic, lotic, and wetland studies to have a significant impact on aquatic plants and their populations (Riis et al., 2000). According to Lacoul and Freedman (2006) aquatic plants can be divided into the following major classes with their preference for conditions associated with alkalinity, pH and associated causes which are:

1. Softwater habitats (<0.2 mequiv. /L HCO_3^-), with low concentrations of dissolved ions, compromising nutrients, and clear water, there are two types (i) circumneutral, with pH ca. 6.0-7.5 and low alkalinity and (ii) acidic, with pH < 5.5 and zero alkalinity.
2. Hardwater habitats (> 0.4 mequiv. /L HCO_3^-) with high concentrations of carbonates and pH >7
3. Brown water habitats, with high concentrations of dissolved humic substances (or dissolved organic carbon, DOC), poor visibility, zero alkalinity, and pH <5.5
4. Saline waterbodies, with high concentrations sodium, chloride, and sometimes other ions, and with extremely high alkalinity and pH.

2.3.3.5 Habit and habitat of aquatic and marsh plants

According to Krahmer (2016) the definitions, wetlands are “lands that transition between terrestrial and aquatic systems and typically have a water table at or near the surface, or are covered in shallow water.” Deepwater habitats, on the other hand, are areas of land that are permanently flooded and located below wetlands’ deepwater border. True aquatic or hydrophytes are permanently found in wet areas while amphibious plants, known as

emerging aquatics or seasonal, can tolerate seasonal drying. These aquatic plants are typically herbaceous and often shrubby, and they tend to grow rapidly, often due to their association with human activities Naskar (1990 cited in Raja et al., 2015).

Littoral zone

The lifeforms of aquatic plant are ususally at the littoral zone (near shore) which are the part of the lakes, sea or river that is near to the shore. The littoral zone usually includes the intertidal zone, this terms are often interchangeable and this zone can be expanded more than the intertidal zone. Three types of plants are known to thrive in littoral zones, according to Gettys et al. (2014). Shallow water is home to emergent plants, whixh have leaves that float above the water's surface and are rooted in the silt. The cattail, arrowhead, and bulrush are examples of representative emergent plant species. Deep roots support the growth of floating-leaf plants. Certain species that flaot have their roots anchored in the sediment, whereas others float freely and have roots that dangle freely in the water column. In the water's surface, the leaves of plants with floating leaves float near flatly. The littoral zone can be divided it several sub-regions, and each sub-region varies in different contexts because lakes and rivers have their definitions. As for freshwater ecosystems, the littoral zones are usually shallow areas in the water bodies. The littoral zone occurs on the edges of rivers, lakes, and the sea. Figure 2.1 shows the different types of macrophytes in the littoral zone of wetlands.

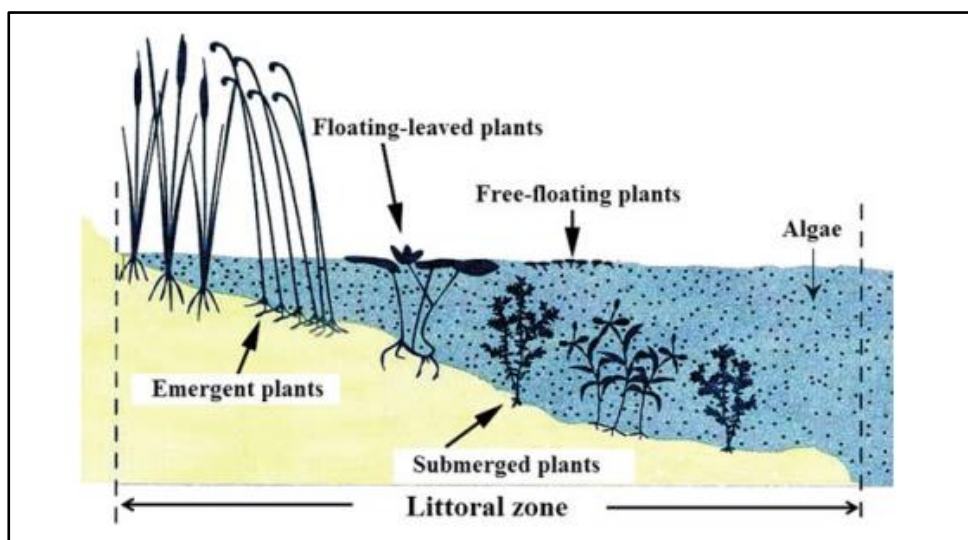


Figure 2.1: The littoral zone occurs on the edges of rivers, lakes, and the sea (Rana & Maiti, 2020).

Raunkiaer Lifeform System

Raunkiaer's system is used in this study to categorise as plant habit, height, and length of growth-cycle and life forms classes. Raunkiaer's life forms were based on the degree to which a plant adapted to a critical season, mostly on the levels of protection that dormant buds provided. According to Vymazal and Kropfelova (2008) in these systems, the two types of cryptophytes (plants with dormant parts below ground) whereas hydrophytes (plant with perennating rhizomes or winter buds) and helophytes (plants with buds at the bottom of the water or in the underlying soil), while other wetland plants were included in other life-forms, such as phanerophytes (tree and shrubs). They differentiated between terrestrial plants primarily exposed to air and aquatic plants that live submerged or with floating leaves. Based on the soil characteristics, they categorized vegetation into 'oecological classes,' with the first category covering extremely moist soil, including hydrophytes in water and helophytes in marshes. In order to facilitate the renewal of the aerial plant body following an unfavourable season, Raunkiaer (1934) developed a classification system based on the

location and level of protection of the renewing buds. The five primary classes of plant species are thus: hemicryptophytes, chamaephytes, cryptophytes, phanerophytes, and therophytes (Kargar Chigani et al., 2017). Because determining life forms is a broad concept with many ideas and opinions, the focus of this research is on Raunkiaer's life form system mainly on hydrophytes and helophytes, as shown in Figure 2.2.

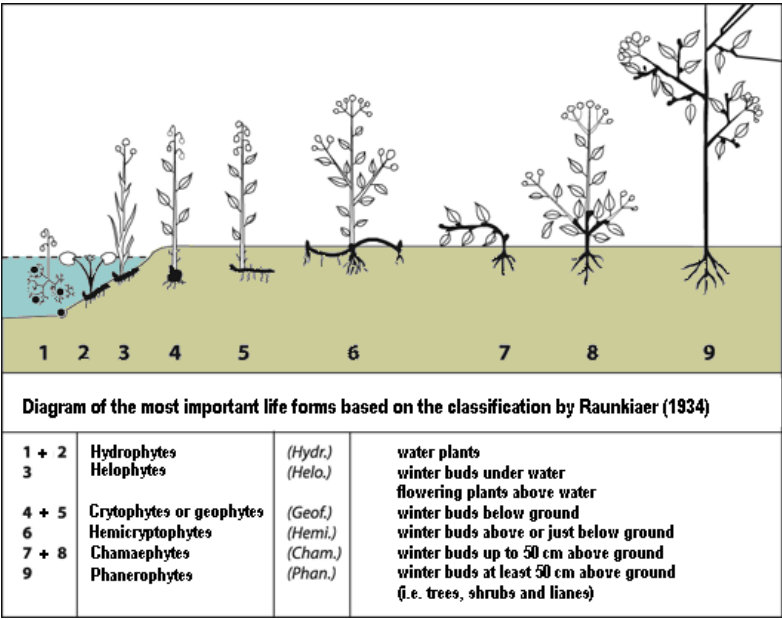


Figure 2.2: The Raunkiaer life form classification (Raunkiaer, 1934).

Lifeforms of Aquatic plants

Aquatic plants according to Cook (1996), can be divided into a few life forms that are influenced by their position, which also correlates to the water surface and degree of adaptation to the environment. In nature, aquatic plants are classified into two types: hydrophytes and helophytes. These plants can be found in either perennial or annual wet environments. Aquatic plants are distributed in an organised manner around the perimeter of the waterbody, forming a division zone from the waterbody's border to its interior; for example, aquatic plant life forms range from emergent plants to fixed submerged ones

(Cook, 1996; Ferreira et al., 2015). Aquatic plants have a variety of life forms, but most of them are fixed within species, making it easy to identify their characteristics. Certain aquatic plant species, on the other hand, can change their life forms in response to the diverse and fluctuating conditions in their habitat. According to Tanaka et al. (2019), it is critical to observe and record aquatic plant lifeforms for taxonomic identification and understanding of their ecological traits. In general, aquatic plants are classified into four major life forms: emergent, floating-leaved, submerged, and free-floating. The free-floating can be divided into two sub-life forms: emergent free-floating and submerged free-floating, but for this study, we included the marsh plant or amphibian plant. According to Cook (1996), aquatic plants are classified as free-floating, fixed-floating, free-submerged, fixed-submerged, and emergent, or helophytes, based on their position, which also correlates to the water surface and degree of adaptation to the environment. Free-floating hydrophytes were separated into two categories (emerging free-floating hydrophytes and submerged free-floating hydrophytes) in Tanaka et al.'s (2019) diagram of the five different types of lifeforms.

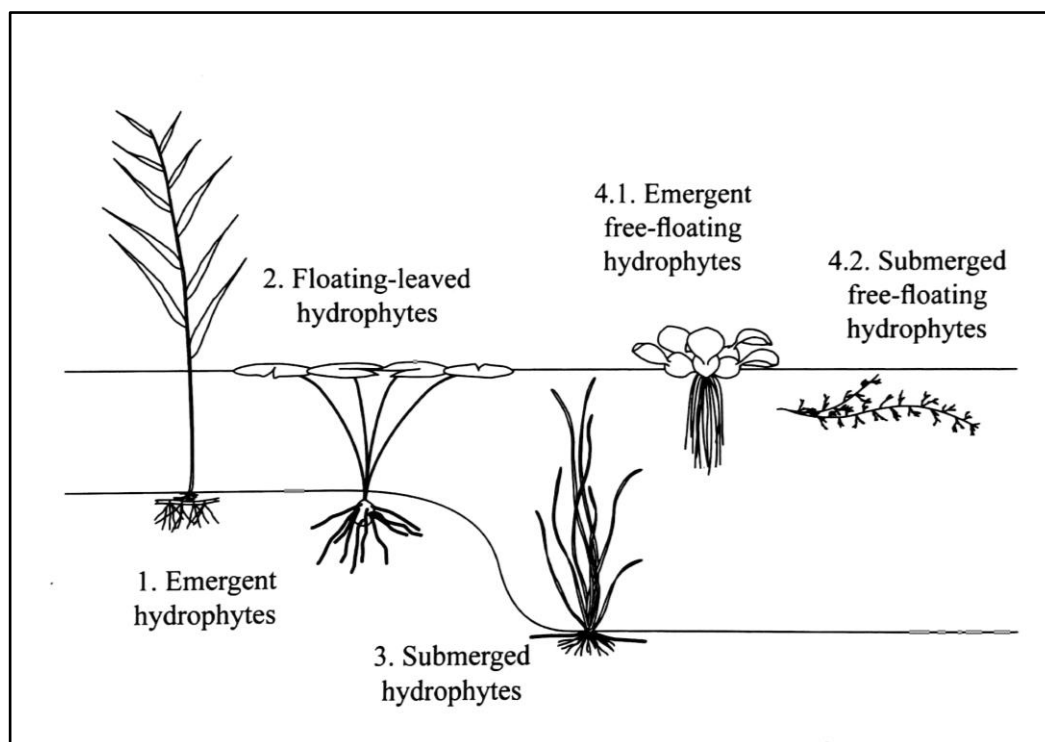


Figure 2.3: The five types of lifeforms of aquatic plant (Tanaka et al., 2019).

The aquatic plant can be divided into four major functional groups (Lacoul & Freedman, 2006). In this research, the lifeforms of aquatic plants are categorised based mostly on Sculthorpe (1967), Cook (1996) and Tanaka et al. (2019) opinions in Figure 2.3:

1. **Emergent hydrophytes** are plants where the root and/or are anchored to the substrate but the other parts of the plant emerge above the water surface. These plants mostly take place in shallow water and often include species from sedges and bulrush. (Cyperaceae), rushes (Juncaceae), grasses (Poaceae), dwarf pipewort (Eriocaulaceae) and cattails (Typhaceae).
2. **Floating leave hydrophytes** are plants where the root and/or stems are anchored to the substrate though some of the leaves are floating on the water surface, while the flowers are above or on the water. These plants can typically occur at moderate

depths and may be prominent in water with low visibility. For instance, lotus and waterlily (Nymphaeaceae).

3. **Submerged hydrophytes** are plants where the root and/or stem are anchored to the substrate. The vegetative organ normally underwater, however they occur at various depths and include species such as water-starwort (Plantaginaceae), watermilfoil (Haloragaceae), pond weed (Potamogetonaceae), and elodea, wild celery, and frogbit (Hydrocharitaceae).
4. **Free-floating hydrophytes** the vegetative organs usually float hence they do not have roots that is embedded in substrate, they are more freely move with wind and water currents. The free-floating hydrophytes are divided into 2 types of categories which are emergent free-floating and submerged free-floating hydrophyte.

4.1 Emergent free-floating hydrophytes is where all or part of leaves are floating on the water. The roots are freely hanging down in the water. For instance, water lettuce (Araceae), water hyacinth (Pontederiaceae), and kariba weed (Salviniaceae).

4.2 Submerged free-floating hydrophytes the vegetative organs are all under the water and flower above or under the water. These types of plant mostly do not have roots examples hornwort (Ceratophyllaceae) and bladderworts (some Lentibulariaceae species).

2.4 Systematics of Aquatic and Marsh Plants

Plants are the world's most significant community of living beings. Morphology is the Greek word for shape analysis, and plant morphology is the study of the shapes and types of external plants (Nakano, 2020). The author also mentioned in the book "characterization

or description of plants and their component parts is the initial and primary process in systematics”. Plant morphology is a biological discipline that based on its structural appearance, aims to understand the biology of plant species, so it generally consists of scientific research into the types and/or structures of plants (Salmeri, 2019).

2.4.1 Morphology of Aquatic and Marsh Plants

According to Preston and Croft (2022) it difficult to identify aquatic vascular plants because they're par tof an ecological category, not a taxonomic one. The boundary between land and water changes day by day, season by season, and year by year. Many species have adapted to this fluctuating zone to reduce competition from larger, specialized plants, making it even harder to define. The physical features of aquatic habitats can affect the populations of aquatic habitats more directly when appropriate structures are available, as a result of the ecosystems' combined evolutionary and environmental characteristics. Accordingly, problems related to habitat complexity in aquatic systems are expected to be easier to identify, which means that further study may uncoer insightful data on the connections between habitat complexity and population functioning and species (Tokeshi & Arakaki, 2012).

A working understanding of plant identification morphological descriptors allows the use of dichotomous keys as well as samples of herbariums and digital databases (Nakano, 2020). Macromorphology are studies on gross morphology were performed on living plants collected where the qualitative and quantitative morphological features were examined and recorded such as the type, length, width, lifeform, appearance, colour, arrangement, and etc that could be observe with the naked eye. The identification of plants relies on taxonomy knowledge and comprehension of the morphology of the stem, leaf, bud, flower, and fruit.

In the science of taxonomy, the definition of character is central, and characters provide the basic classification information; characters are the characteristics used in the identification process; characters are used to establish relationships; and character complexes associated with various species provide the basis for the taxa to be named (Radford et al., 1974).

2.4.2 Micromorphology of Aquatic and Marsh Plants

Micromorphology is studies that are done with the aid of a microscope such as the light and electron microscope on the characteristics of the plant. Usually, the measurements are done using image analysis software. The statistical analyses were computed on both quantitative and qualitative. According to Salmeri (2019), many studies have shown how vegetative and reproductive characters and their anatomical and/or micromorphological structures can be informative for phylogenetic studies and helpful at different levels in solving systematic problems this is because most phenotypic characteristics show adaptive variation and different ranges of plasticity that have proven to be of great ecological and physiological significance and useful. For example, in reconstructing plant adaptation to past climatic conditions or developing defensive mechanisms and structural changes in response to stress, climate changes and plant invasions, all of which are fundamental knowledge. The sizes, lengths, distribution, orientation, and frequency of the epidermal cells, stomata, and trichomes are ultra-structure that are considered as important in taxonomy and phylogeny (Albert & Sharma, 2013).

2.4.2.1 Stomata characteristics

Stomata are important micromorphological characteristics. They are tiny pores on the surfaces of leaves and stems, which are surrounded by two guard cells that govern the

movement of exchange of gases, most notably water vapour and carbon dioxide, between the leaf's interior and the atmosphere (Hetherington & Woodward, 2003). Stomata are essential for plant function by regulating gas exchange between the plant and its environment (Shtein et al., 2017). According to Franks and Beeling (2009), stomata are vital for regulating transpirational water loss from leaves during simultaneous CO₂ uptake for photosynthesis. The stomata vary in size and shape, allowing them to adapt to diverse environmental circumstances and ensure optimal photosynthetic conditions. Stomata play an essential function in plant development by managing gas exchange with the atmosphere and transpiration. In general, stomatal and epidermal cell frequency per unit leaf area drops as irradiance declines and guard-cell length or width increases (Pompelli et al., 2010). Various factors can alter the form and size of a plant's organs by successfully managing water intake, transport, and the distribution of nutrients and hormonal signals, hence controlling plant growth. Managing a plant's absence of stress is vital for preventing output losses, which may be a direct result of stomatal conditions (Caballero & Roca, 2018). Therefore, stomata are essential for the productivity and survival of plants.

2.4.2.1.1 Stomata occurrence

Stomata are found on the leaf blades of vascular plants, where they are frequently numerous; they can also be found on the petiole, stem, and in flower sections (Van Cotthem, 1970). Stomata are absent from roots and submerged vegetation. Stomata occur in three types and positions: hypostomatic, epistomatic, and amphistomatic. Amphistomatous refers to the presence of stomata on both the adaxial and abaxial surfaces of a leaf. The abaxial surface contains more stomas than the adaxial surface. Hypostomatous stomata are only found on the abaxial surface, whereas epistomatous stomata are only found on the adaxial surface (Richardson et al., 2020). Stomata are only found on the lower surface of

hypostomatic leaves, whereas amphistomatic leaves have stomata on both sides; however, the number of stomata on one surface may be greater than the number on the other.

Both hypostomatic and amphistomatic leaves are prevalent on a worldwide scale, although leaves with stomata limited to the upper surface ('hyper' or 'epistomatic') are uncommon. Fast-growing herbaceous annuals and slow-growing perennial shrubs and trees are the main places where amphistomaty occurs. While stomatal distributions between leaf surfaces have related to several environmental parameters, the exact functional implications of the costs and advantages of amphistomaty remain unclear but are crucial for comprehending general evolutionary trends (Drake et al., 2019). Most floating aquatic plants have continuously open stomata on their upper leaf surfaces (Shtein et al., 2017).

2.4.2.1.2 Stomata appearance

The position of the stomata concerning the epidermis varies between plant species. These stomata are referred to as phaneropore and are seen in the majority of guard cells. Many xerophytes have stomata that are deeply recessed below the epidermis; these are cryptopores (Van Cotthem, 1970). There are three types of stomata which were sunken, rise or semi-rise. As opposed to being on the surface of a plant's leaf or stem, sunken stomata are positioned beneath the surface. In arid or semi-arid settings, plants with sunken stomata help to prevent water loss by minimising the amount of leaf surface exposed to the air. Sunken stomata also protect the plant from damage caused by excessive sunshine or harsh temperatures (Gorane, 2023).

2.4.2.1.3 Type of stomata

A stoma is composed of the stomatal aperture and the guard cells that surround it. In other instances, however, this distribution changes from species to species, depending on whether the plant is xerophytic or mesophytic. They may be shallow or depressed.

Sometimes, stomata are encompassed by subsidiary cells, which are specialised epidermal cells. These subsidiary are distinct from unmodified epidermal cells in terms of shape, size, and staining qualities (Aldhebiani & Jury, 2013). A stoma is composed of two guard cells with a stomatal opening between them. It is surrounded by epidermal cells that are either typical or altered. Neighboring cells are non-differentiated epidermal cells that are next to the guard cells and do not form a barrier.

Subsidiary cells are cells adjacent to and surrounding the guard cells that clearly differ from the other epidermal cells in size, shape, and structure (Baranova, 1992). The epidermal cells that comprise the complex are referred to as subsidiary or auxiliary cells. They differ in size, shape, and arrangement from other epidermal cells surrounding the stoma. Subsidiary cells and guard cells are mechanically linked in that, when one cell type is damaged, the other cell type bulges into the vacant space (Croxdale, 2001). According to Gray et al. (2020) they generally describe subsidiary cells as cells, that are near to guard cells but are not necessarily in contact with them and distinct from other epidermal cells. The “different” is most readily distinguished by its unusual morphology, but it can also be distinguished by its unique chemical signature.

Being part of the stomatal complex, subsidiary cells may support the function of guard cells; however, the biochemical, mechanical, or anatomical mechanisms by which they do so are likely to be diverse (Gray et al., 2020). In many instances, the description is taxonomic, but without a comprehensive understanding of the physiological contributions subsidiary cells make to guard cells, it is impossible to provide a clear definition. The number, organisation, and potential function of subsidiary cells vary greatly. The diversity of stomatal apparatus morphology is mostly attributable to the variability of subsidiary cell characteristics, which has led to accepted classifications of subsidiary cell configurations.

Stomatal terminology was initially associated with certain taxonomic groups; hence, stomatal subtype terminology is complex. It can be ambiguous at best and contradictory at times. Figure 2.4 displays the stomata complex type as previously elucidated by Barclay (2007).

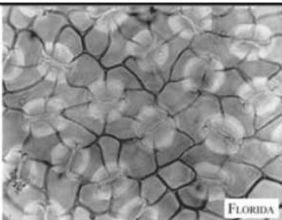
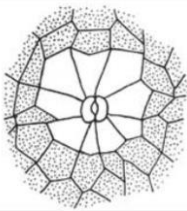
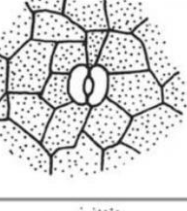
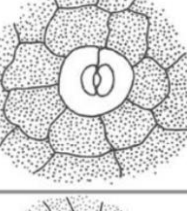
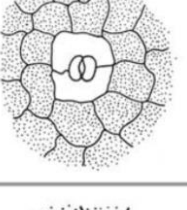
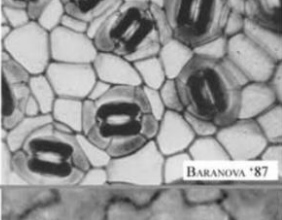
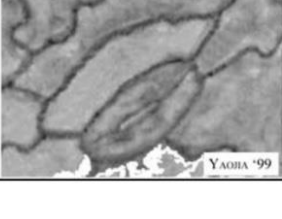
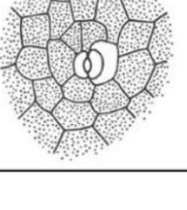
Stomatal Type		Description	
Actinocytic METCALFE & CHALK, 1950 <i>Toulicia crassifolia</i> RADLK. FLORIDA			Single ring of 5 or more somewhat enlarged or elongated cells enclosing the guard cells.
Anisocytic METCALFE & CHALK, 1950 <i>Peperomia maculosa</i> (L.) HOOK BARANOVA '87			3 cells, may be unequal in size, enclosing the guard cell 1 of 4 original types of VESQUE (1889); Cruciferous (METCALFE & CHALK, 1950)
Anomocytic METCALFE & CHALK, 1950 <i>Canacomyrica monticola</i> GUILLAUMIN BARANOVA '87			5 or more cells enclosing the guard cells, cells adjacent to the guard cells not differentiated in any way from the normal epidermal cells. 1 of 4 original types of VESQUE (1889); Ranunculaceous (METCALFE & CHALK, 1950)
Desmocytic VAN COTTHEM, 1970 Polypodiaceae YAOHA '99			1 cell enclosing both guard cells with one anticlinal wall extending from one of the poles cutting the cell once.
Diacytic METCALFE & CHALK, 1950 <i>Stachys officinalis</i> (L.) TREVISAN BARANOVA '87			2 cells enclosing the guard cells at right angles to the long axis of guard cells 1 of 4 original types of VESQUE (1889); Caryophyllaceous (MET. & CHALK, 1950)
(En)cyclocytic STROMBERG, 1956 STACE, 1965 <i>Gonystylus bancanus</i> (MIQ.) GILG BARANOVA '87			Single ring of 5 or more small cells enclosing the guard cells
Hemiparacytic VAN COTTHEM, 1970 <i>Paraleptochilus decurrens</i> (BLUME) COPEL. YAOHA '99			1 of the cells adjacent to the guard cell enclosing it and parallel to its long axis, the other guard cell having three or more normal epidermal cells surrounding it.

Figure 2.4: Stomatal complex types (Barclay, 2007).

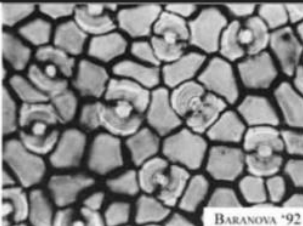
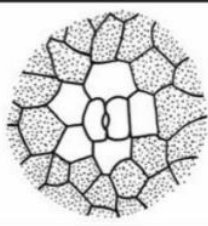
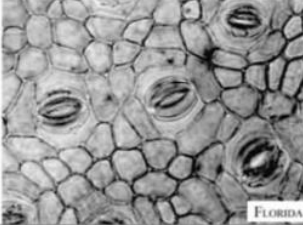
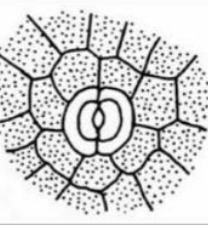
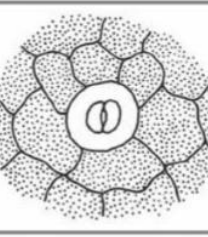
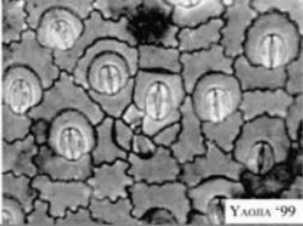
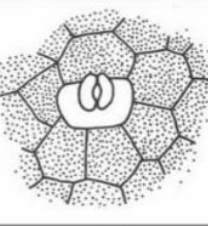
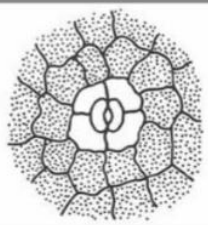
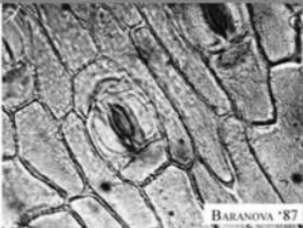
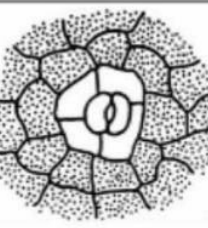
Stomatal Type			Description
Laterocytic DEN HARTOG & BAAS, 1978 <i>Buxus muelleriana</i> Urb.			Stomata flanked by 3 or more subsidiary cells all bordering on the lateral sides of the guard cell pair
Paracytic METCALFE & CHALK, 1950 <i>Chrysobalanus icaco</i> L.			1 or 2 cells adjacent to the guard cells with their long axis parallel to the long axis of the guard cells 1 of 4 original types of VESQUE (1889); Rubiaceae (METCALFE & CHALK, 1950)
Pericytic VAN COTTHEM, 1970 Polypodiaceae			1 cell encloses both guard cells
Polocytic VAN COTTHEM, 1970 Polypodiaceae			1 cell nearly but not completely enclosing the two guard cells.
Staurocytic VAN COTTHEM, 1970 <i>Polypodium vulgare</i> L.			4 cells, more or less equal in size, with the anticlinal walls of the subsidiary cells extending at right angles from the poles and middle of the guard cells
Stephanocytic BARANOVA, 1987 <i>Hedyosmum brasiliense</i> MARTIUS			Stomata surrounded by 4 or more (usually 5-7) weakly differentiated subsidiary cells forming a more or less distinct rosette. Intermediate between encycl. and actino. types. Subsid. cells form more broad & less clear ring, and less elongated.
Tetracytic METCALFE, 1961 <i>Hanguana malayana</i> (JACK) MERRILL			4 cells adjacent to and enclosing the guard cell

Figure 2.4: Stomatal complex types continued (Barclay, 2007).

2.4.2.1.4 Stomata size

The stomatal size was determined by the stoma's length and width (Adedejio & Jewoola, 2008). One study has revealed that stomatal size plays a crucial part in this regulation, and for six forest species, there is a definite inverse link between stomatal pore length and drought sensitivity. Larger stomata (in kidney-shaped species) were slower to close and had a greater risk for hydraulic dysfunction under drought conditions (Hetherington & Woodward, 2003). Zhang et al. (2022) asserts that a plant's size has an impact on its metabolism, nutrient absorption, and build-up of organic matter. Size is also intimately linked to physiological processes in plants, such as transpiration and photosynthesis. Consequently, stomata are crucial to plants' ability to regulate their natural environment.

2.4.2.1.5 Stomata Density

Stomatal density (SD) is a function of both the number of stomata and epidermal cell size. Hence, both the beginning of stomata and the extension of epidermal cells influence SD. Its expansion is a consequence of numerous variables (e.g., light, temperature, hydration status, leaf crown position, and intra-leaf position) and can overrun the signal indicative of stomatal initiation (Royer, 2001). However, how the change in stomatal density (SD), defined as the number of stomata per unit leaf area, impacts photosynthetic and growth properties in plants has been the subject of debate (Sakoda et al., 2020). Sakoda also mentioned that stomatal density is an important ecophysiological characteristic that influences gas exchange and photosynthesis, since the initial studies of Woodward in 1987 and others, the responsiveness of SD to environmental variables has been an intriguing and ongoing subjects. Plant metabolism, nutrient absorption, and organic matter accumulation are all impacted by density, which is strongly correlated with physiological processes like

transpiration and photosynthesis (Zhang., 2022). Although it is unclear how stomatal density is regulated during leaf development (Bergmann, 2003).

2.4.2.2 Trichome

To determine the taxonomic affinity of fossil plant cuticles, stomatal complex type and other epidermal characteristics such as presence or absence of trichomes, trichome type, epidermal physiognomy, and micromorphology must be identified (Barclay et al., 2007). Trichomes are part of the micromorphology of plant species, and Adedejio and Jewoola (2008) discovered that trichomes can be used successfully to delimit the genera within a family. One of the characteristics is the trichome, which can cover either a reproductive or vegetative structure. Trichomes can be found on all plant parts, both vegetative and reproductive (roots a short distance above their apical meristem) (sepals, petals, stamens, gynoecium, seeds, and fruits) (Werker, 2000). According to Levin (1973), a trichome is a hair-like protrusion that extends from the epidermis of aerial tissues. Frequently, the walls of trichomes are comparable to or thicker than the walls of the surrounding epidermis. Some mature trichomes lack cytoplasm, whereas others contain it. Trichomes exist in a variety of morphologies that are either unicellular or multicellular, glandular, or eglandular, linear, spiral, hooked, tortuous, simple, peltate, or stellate. They might vary in density and shape from one organ to another. While most plants produce trichomes constitutively, certain species increase trichome density in new leaves in response to injury. The form and quantity of leaf trichomes vary significantly between plant species, communities, and even individual plants. Trichome density influences interactions with insect herbivores but may also influence the abundance and efficiency of predators and parasitoids feeding on herbivores, as well as the tolerance to abiotic stress (Dalin et al., 2008).

2.4.3 Palynology of Aquatic and Marsh Plants

Pollen is an important reproductive structure of plants that plays an important role in plant survival and evolution. Pollen morphology and characteristics differ greatly between plant groups and habitats. According to Moore et al. (1991), palynology comes from a combination of two Greek words: *paluno*," which refers to sprinkle, and *pale*," which means dust, and it is an interdisciplinary subject and a geological and botanical branch of both. Palynology requires research into different structures of microorganisms called palynomorphs, and most analysis of palynomorphs is about spores and pollen plants. Halbritter et al. (2018) define palynology as the study of palynomorphs, which are organisms found in palynological preparations such as pollen, spores, cysts, and diatoms. The author also stated that a palynomorph is a dominant object in the palynomorph continuum. According to Meltsov et al. (2013) to study ancient plant ecosystems, fossil pollen is essential. Analyzing how current pollen diversity connects to surrounding plants and landscapes can help researchers comprehend it and the diversity in floristic richness and landscape structure within a single floristic or climatic region can be reliably estimated using paleontological richness. Nevertheless, care must be used when comparing the estimated vegetation diversities from various places using pollen or when interpreting prehistoric pollen records from periods with drastically different floral relationships.

Aquatic and marsh plants are distinct groups of plants that have evolved to thrive in wetlands. These plants play an important role in the maintenance of aquatic habitats by providing food and shelter to a wide variety of aquatic organisms. Understanding these plants' ecology, evolution, and reproductive biology requires pollen analysis. According to Ashman et al. (2004) there are ecological and evolutionary reasons and effects associated

with pollen limitation. For example, pollen limitation probability or the strength may be influenced by or connected with the ecological environment, plant life history, reproductive system, and phylogenetic history. Pollen limitation may be mitigated in the future by reproductive characteristics evolving in response to pollen or pollinator limitation (i.e., plants could establish systems or reproductive assurance. If the amount of seeds produced by a species limits its population size.

Lately, there has been a rise in curiosity about the pollen of these plants, as it can provide important information about their reproductive biology and ecological relationships. Aquatic and marsh plant pollen grains have distinct morphological characteristics that are adapted to their aquatic environments. Botanists and ecologists have used pollen to reconstruct past plant assemblages and identify periods of environmental change (Nolan, 2015). In plant taxonomy studies, morphological features of pollen grains may also be useful characteristics since many pollen characteristics are affected by the strong selective forces involved in various reproductive processes, including pollination, dispersal, and germination (Stuessy, 2009). Image-based, image analysis-based automated pollen analysis is an alternative to visual inspection. Image analysis converts visual data to numerical descriptions (Pospiech et al., 2021).

The role that the propagule bank plays in the regeneration of hydrophyte communities varies depending on whether riverine aquatic ecosystems experience periodic flooding or drying out (Combroux & Bornette, 2004). These plant groups are composed of those plants that have been able to spread to local ecosystems and then thrive there (Johansson & Nilsson, 1993; Henry & Amoros, 1996). As for aquatic plants, according to Soons et al. (2017), water, wind, and animals are the three significant dispersal vectors for pollen dispersal. According to Davidson et al. (2005) pollen and sedimentary macro-remains

of aquatic plants, such as fruits, seeds, spores and vegetative fragments, can be analysed to shed light on past communities, monitor changes over time, and assess the degree of any recovery following disturbance. The distribution of aquatic plant species is related to their ability to spread sexual or vegetative propagules on a large scale and to their ecological tolerance (Hutchinson, 1975). Pollen patterns and the sedimentary environment are connected. Interpreting grain-size distribution and associated characteristics statistically can aid in understanding spore and pollen dispersal in marine environments (Yang et al., 2021).

2.4.3.1 Pollen Structure

The structure of pollen grains varies among different plant species. According to Cutler (1985) when sufficient reference material is available, pollen grains are sometimes readily recognised at the level of the genus and often at the level of the species. In the absence of proper training and reference materials, it might be difficult for novice researchers to acquire the level of ability necessary for quick and precise pollen identification. The accessibility of existing pollen reference collections is limited since they are frequently maintained as collections of slides at academic institutions or private collections. The individual researchers and institutions frequently compile and produce their own reference collections, which are frequently forgotten, never shared, or stored. As a result, they are referred to as “dark data,” this problem is widespread only in palynology but in other taxonomic domains as well, such as collections housed in public and private establishment (Martin & Harvey, 2017). Depending on the plant species, pollen grains differ in size, shape, and surface features. Pollen grains are diverse in terms of diameter from 5 μm to more than 200 μm and there are two important kinds of pollen grains found in the angiosperms which are monosulcate and tricolpate (Twell, 2001). The author stated that the monosulcate pollen type

primitively the characteristics of dicotyledon and majority of monocotyledon, the cycads and the pteridosperms, while the tricolpate grains are globose symmetrical, which commonly have three germinal apertures and are characteristic of the advanced dicotyledon. According to Erdtman (1943), most pollen grains have two coats which are the outer (the exine) and inner (the intine). Pollen characteristics include pollen units, polarity, shape, size, aperture type, and surface pattern, among others (Linn et al., 2020). Figure 2.6 an illustration of pollen grains structure by Kawane (2022).

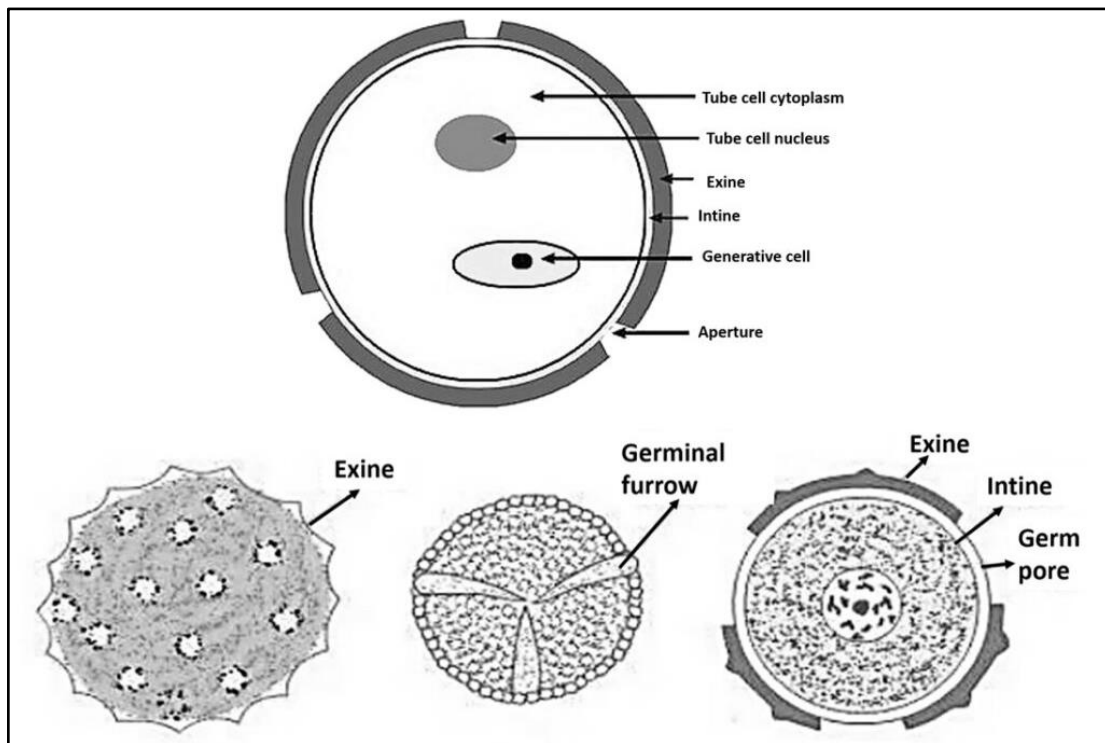


Figure 2.5: A schematic image of pollen grains structure (Kawane, 2022)

2.4.3.1.1 Pollen size

The size of pollen is an important factor in plant reproduction because it influences pollination efficiency and the likelihood of pollination. The size range of paleomorphs is between 5 and 500 microns. A light microscope is necessary for determining the particular, generic, or higher taxonomic rank (Kneller & Fowell, 2009). The range of pollen grain sizes

does not completely correspond to the range of floating and clinging it may stretch a little beyond at the top but fall short at the bottom, as there are spores that are much smaller than pollen grains but nevertheless freely float through the air. The largest pollen grains, such as those of the pumpkin, which are approximately 200 μ in diameter, are so huge that they can cling to insects with the aid of a small amount of oily adhesive. Only pollen grains of intermediate size are the best floaters, a finding that is quite intriguing. Its grains are barely thirteen microns in diameter, which is significantly smaller than the majority of airborne pollen. However, it is expelled from the anthers in a pretty spectacular fashion (Wodehouse, 1935).

2.4.3.1.2 Pollen shape

The shape of pollen is an important characteristic that helps identify plant species. Pollen shapes vary among aquatic and marsh plants, reflecting their adaptation to the aquatic environment. According to Ge et al. (2018) most aquatic plants require adequate resources and energy to properly flower and pollinate, as well as a reasonably stable water environment. Aquatic pollen development is dependent on a number of parameters, including water depth, pH, temperature, daylight duration, and nutrient status. The pollen in these plants can be prolate, elliptical, triangular, or oblate in shape. Apertures exhibit a wide range of shapes, including extended furrows, circular pores, and mixtures of furrows and pores. In pollen analysis, the scientist examines dispersed pollen grains that have accumulated as sediment rather than germinating. As pollen is magnified, its shape and surface texture, known as morphology, become extremely distinct (Hunt, 2009). The pollen's form, aperture number and position, and exine sculpturing are distinctive taxonomic characteristics that enable identification of the species, genus, or family (Twell, 2001). A palynogram is the diagrammatic representation of the primary morphological features of

pollen grains or spores. It contains parameters of symmetry, shape, and size; number and location of apertures; ornamentation; and stratification (Halbritter et al., 2018).

2.4.3.1.3 Pollen unit

The pollen unit is the fundamental component of the pollen grain, comprising the male gametophyte and protective structures. The pollen units' size, shape, and surface ornamentation are important characteristics that influence pollen dispersal and reproductive success. The pollen unit in aquatic and marsh plants has specific adaptations to ensure successful pollination in their specific environments. Pollen may be distributed as single grains, as is the case with many plants that rely on wind dispersal, or in groups, as is the case with species that are nearly zoophilic. The word pollen dispersal unit is used to describe the manner in which pollen is provided for dispersal, i.e., as single or clustered grains. The reason pollen grains may be held together by shared walls, as in tetrads; threads on the pollen surface or produced from the anther; and viscous fluids, as a last resort (Pacini, 2008). Pollen characteristics such as pollen units are used to distinguish species or species groupings from various botanical families (Dutra et al., 2020). Pacini (1997) coined the term "pollen despersion unit" (PDU) to describe the many ways in which pollen is offered to dispersal agents and whether it travels individually or collectively as 'compound pollen' (Knox & McConchie, 1986). Complex pollen may be connected by (1) viscous fluids, which are typically formed by tapetal activation or degeneration; (2) filaments of diverse origin and composition, but normally continuous with the exine, and commonly known as viscin threads if they consist of sporopollenin; and (3) shared walls (Pacini & Franchi, 1999; Hesse et al., 2000). Pollen can be distributed individually, in pairs, or in cluster of up to a million grains (Schill et al., 1992). A pollen class is an artificial classification of pollen grains that share a particular distinguishing characteristic. Pollen classes refer to pollen units, aperture

form and placement, or a very distinguishable ornamental quality. The terms polyads, tetrads, dyads, saccate, inaperturate, sulcate, ulcerate, colpate, colporate, porate, synaperturate, spiraperturate, lophate, clypeate, and plicate are included in classes (Halbritter et al., 2018).

2.4.3.1.4 Pollen ratio

The ratio of fertile to sterile pollen grains in a plant species is called its pollen ratio. The shape was established by calculating the means of P and E and the ratio P/E (Beretta et al., 2014). The P/E ratio is the ratio between the length of the polar axis (P) and the equatorial diameter (E). The polar axis of spheroidal (or isodiametric) pollen grains is ($\pm$) equal to the equatorial diameter. Pollen grains whose polar axis is longer than their equatorial diameter are referred to as prolate, whereas grains whose polar axis is shorter than their equatorial diameter are referred to as oblate (Halbritter et al., 2018). Pollen grains are formed within the flower's anthers. Pollen mother cells come from the sporogenous tissue of the anther and divide meiotically to produce four pollen grains known as tetrads. Upon maturity, the pollen grains separate into a single pollen grain known as a monad. Occasionally, uncommon varieties such as dyads (two pollen grains), octads (eight pollen grains), and polyads (many pollen grains) are observed (Sugandha, n.d.).

2.4.3.1.5 Aperture

Most plant species cover pollen grains with a non-uniform layer of wall exine, leaving a fixed number of holes on the pollen surface. These gaps, known as apertures, have a distinct shape and form at certain locations (Dobritsa & Reeder, 2017). On the female (stigma) surface, pollen grains germinate by creating a pollen tube, which emerges from one of the pollen grain wall openings. Some sections do not develop exine; these regions specify the placements of germination apertures. Moreover, apertures exhibit a wide range of variety, including elongated furrows, circular pores, and mixtures of the two. Aperture number, position, and exine ornamentation are significant taxonomic features that, thanks to the fossil record, have enabled the reconstitution of the species composition of previous vegetation (Borg & Twell, 2011). A section of the pollen wall that differs considerably from the rest of the wall in morphology and/or anatomy and is considered to serve as the location of germination and play a role in harmomegathy is referred to as an aperture. Pollen grains without an aperture are referred to as inaperturate. The aperture definition applies to both angiosperm and gymnosperm pollen, but the type of aperture in gymnosperms typically differs from that in angiosperms, as a leptoma is frequently present (Halbritter et al., 2018).

2.4.3.1.6 Exine sculpting

Exine sculpturing is the process of changing the outer layer of pollen grains to make different patterns and structures. The internal construction of pollen is referred to as its structure, ornamental components on the pollen surface (ornaments) are characterized by the terms sculpture or sculpting. Yet, it is not always possible to discern structure from sculpture (e.g., free-standing columellae). Sculpture consists of ornamental motifs on the surface of pollen. The importance of SEM in displaying exine sculpture and ornamentation cannot be

overestimated (Harley et al., 1990). High SEM magnifications reveal the presence of additional granules (structure or sculpture elements of different size and shape; smaller than 1 micrometer) (Halbritter et al., 2018). According to Kaltenrieder et al. (2003), within the pollen-morphological main groups or classes, changes in the structure and sculpturing of pollen grains' exine are crucial identification criteria. The exine's interior structure might be either tectate or intectate. The sculpturing of the pollen grain is the surface ornamentation, which can be psilate, foveolate, areolate (frustillate), gemmate, clavate, verrucate, baculate, echinate, rugulate, striate, or reticulate.

CHAPTER 3

MATERIALS AND METHODS

3.1 Field Sampling and Samples Collection

The study area was conducted around the Western Sarawak which specifies on three division which are Samarahan (1° 28' 0" N, 110° 28' 55" E), Kuching (1° 31' 58" N, 110° 2' 44"), Serian (1° 9' 42" N, 110° 33' 38" E) division, and its proximate environs. Figure 3.1 showed the maps for the three division. The field sampling methodology adopted in this study is convenience sampling, as stipulated by Speak et al. (2018). This research was mainly dedicated through field and laboratory work on the selected fresh samples collected, the species of aquatic plants were mainly focusing on vascular plants. The number of fresh samples collected during fieldwork ranged about three per species, varying based on sample availability within the environment; some species were scarce, while others were abundant. Fresh samples were obtained and processed in accordance with Bridson and Forman's (1992) standard herbarium protocols for herbarium specimens and deposited in the Herbarium of Universiti Malaysia Sarawak (HUMS). To preserve aquatic and marsh species with high sensitivity, which may rapidly shrink upon removal from water, samples were cut into 5 mm² small pieces for micromorphology analysis preservation, the samples were put immediately in the Formalin-acetic acid- alcohol or 70% ethanol in McCartney bottles. Figure 3.1 showed the illustration studied location map of western Sarawak.

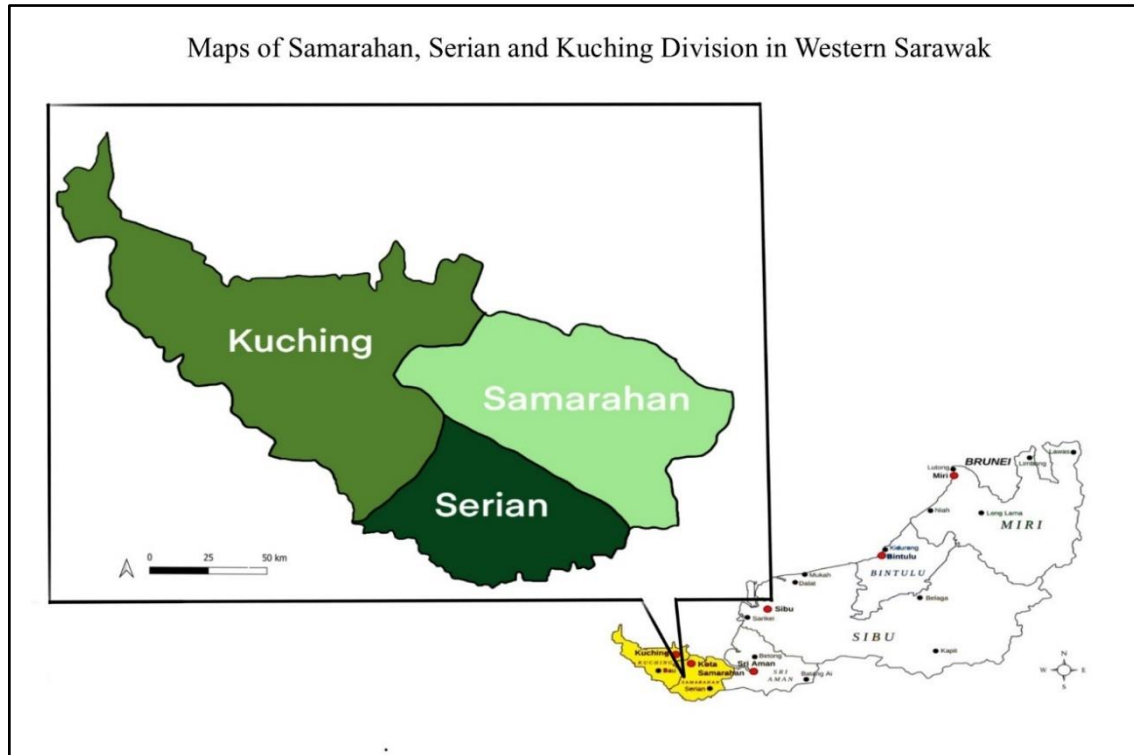


Figure 3.1: Maps of Samarahan, Serian and Kuching Division in Western Sarawak, Malaysia.

3.2 Ecology Studies

The ecology data taken from this research are the coordinates of the location (type of surroundings, latitude, longitude, and altitude), pH of water, temperature of the water, soil pH, and moisture of the soil. Data was collected after observing the habitat around the plant and its associated plants. For soil moisture and soil pH, the data was taken using a Takemura DM-15 soil pH and moisture metre. The data was taken at least three times within the same location to get an average reading, and the results were recorded. As for water quality, the data was taken by using the Yieryi water quality tester pen for the pH and temperature metres. The data was taken at least three times within the same location to get an average reading, and the data was recorded after. The GPS (Global Positioning System) co-ordinate

of the samples collected was presented using the QGIS software for the mapping distribution.

3.3 Taxonomic Identification

3.3.1 Morphology Characteristics

The leaf and petiole measures of the species found were recorded. For the measurement of data such as large parts (whole plant, leaf, shoots, and fruits) were measured with measuring tape and ruler. While the smaller parts (flowers, bracts, bracteoles, and style) were measured using the digital clipper. The part for vegetative and reproductive measurement found were recorded Plant structure and shapes were based on Smith et al. (1935) and determined by the ratio of the length the width of the leaf. Smith et al.'s plant observation parameters are shown in table 3.1. The colour of the parts observed was determined based on the common colour charts (Beentje, 2010).

Table 3.1: Parameter of plant observation.

Structure	Parameters
Whole plant	Plant lifeform Plant length Habit *Any special characteristic
Roots	Root system type Root and stem
Stems / Shoots	Appearance: colour, division and branching and shapes/type Measurement: length, width
Buds	Measurement: length, width Appearance: arrangement, type, scales, stipule type (present/ absent)
Leaves	Measurement: length, width Appearance: shape, apex, bases, venation, margin, surface, attachment, arrangement type, colour
Petiole	Measurement: length, width

Flower	Measurement: length (the whole inflorescence), peduncle (length), Inflorescence head (length) Type of inflorescence, bract (colour, size) Flower form, types Petals: Measurement: number of petals, shape, length, width, colour Sepals: Measurement: number of sepals, shape, length, width, colour Androecium and gynoecium: Measurement: filament, style, stigma (length) Appearance: Position and arrangement, structure type, thecal, anthers type and attachment, number of stamens, shape of stigma, colour Gynoecial type, carpel type, stigma type, style type Ovary: Measurement: length, diameter Appearance: colour, surface
Fruit and seed	Type, size, measurement, colour, surface. Seed: size, shape, surface

3.3.2 Micromorphology Characteristics (Preparation of Leaves for the Field Emission Scanning Electron Microscope (FESEM))

A matured, clean, and free of disease leave with the size of 5 mm² was cut and fixed into Formalin-acetic acid-alcohol (FAA) at the time of location according to Ickert-Bond et al. (2018) midvein, secondary veins, leaf margin and apex were observed for investigations and examined both the adaxial and abaxial leaf surfaces. The specimens were dehydrated according to the type of fixation used according to their dehydration process. Next, the critical point drying (CPD) process proceeded. The CPD machine used was K850 critical point drier. The critical-point dried specimen was mounted on to specimen stubs using a double-sided tape, coated with approximately 20mA for 80 seconds of platinum about 30

nm of thickness using a Jeol model JEC-3000FC auto-fine coater. The samples were examined through JSM-IT500HR Field Emission Scanning Electron Microscope (FESEM). To gather clearer view of each parameter, the Field Emission Scanning Electron Microscope (FESEM) images were captured in different magnifications (Table 3.2).

Table 3.2: Parameters of the structures of the leaves

Structure	Parameters
Epidermal	Shape and arrangement
Stomatal complex	Location abundance and orientation
	Subsidiary cell
Trichomes (if presence)	Type of trichomes

3.3.2.1 Dehydration Process for 4% Glutaraldehyde

For field emission scanning electron microscope (FESEM) using the 4% glutaraldehyde the method used was according to McDowell and Trump (1976). The leaves was fixed in 4% glutaraldehyde and was prepared in 0.1 M phosphate buffer. The samples then were stored in the refrigerator at 4 °C for at least 2 hours before proceeding to CPD methods. The samples was washed with buffer for 3 times and 10 minutes each. Postfix in 1% Osmium tetroxide prepared in the same buffer before at room temperature for 1-2 hours. Then, washed in distilled water for 2 times for 10 minutes. Next, the samples was dehydrate in dehydration series with a little modification starting with 50% ethanol (15 minutes), 70% ethanol (15 minutes), 90% ethanol (15 minutes x 2 times), 100% ethanol (20 minutes x 3 times). The last step, the specimen was put in inside the cpd holder (the CPD holder was immersed in ethanol to avoid hydration. The specimen holder was contained/immersed

enough ethanol to covered the tissues (15-30 minutes) of 100% ethanol. Next proceed to the critical point drying (CPD) method.

3.3.2.2 Dehydration Process for Formalin-Acetic Acid-Alcohol

For Formalin-Acetic Acid-Alcohol (FAA), the method used was according to Ickert-Bond et al. (2018) with modifications. The dehydration process used to prepare for Field Emission Standard Electron Microscope (FESEM) was 70% ethanol and absolute ethanol thus proceeded with critical-point-drier

3.3.2.3 Critical Point Drying (CPD) method

After going through series of dehydration process, the critical point drying (CPD) continuous. The dehydrated specimens dry up in Acetone or Ethanol (only) this is due to using liquid carbon dioxide in this process. In advance, the valves were all closed. Firstly, the chambers were pre-cooled and maintained approximately below 10 °C – 5 °C (4 minutes) this is to avoid excessive flow and freezing up. Specimens were load and chamber was inserted, ensure thumbscrews was tightened correctly. Before starting the method, chamber was checked if it was depressurized. The chamber was filled with carbon dioxide and with meniscus to centre of the view window using inlet valve while all the other valves were closed. During the soaking process (1-3 minutes) the specimen was stirred for 3 minutes. Next the purge chamber was maintained with the meniscus at least mid-way on the view window using slow, steady flow using balance of inlet valve and exhaust valve. The specimen in the chambers were then soaked and stirred again for (1-3 minutes). Chambers were pre-cooled using a cool valve while all the other valves were closed (this step is only necessary if the temperature inside the valve starts to increase). The steps were repeated from

the filling chamber until the exhaust valve. Then, the chamber was filled to the centre of chamber to the top of the upper red line. All valves were closed. The liquid carbon dioxide tank was also closed. The heater was switched on. This is to allow stable conditions 100 psi/minute +35 °C in 10 minutes. After the chamber reached 35 °C, the heater was switched off and the process de-pressurised takes place. The exhaust and bleed valve turned until the chamber de-pressurised.

3.3.2.4 Stomata Density Formula

The method below is used to measure the stomatal density according to Phil (2015):

Area of field of view (FOV) = πr^2

$$\text{Stomata Density} = \frac{\text{Number of stomata in FOV}}{\text{Area of FOV}}$$

3.3.3 Sample Preparations Palynology

Two methods were used in palynological research to compare pollen images. The first method employed mature flowers from carefully selected specimens. Fresh male inflorescence samples from the selected species were used to collect pollen grains. The pollen grains from the male flower's anther head were gently brushed off onto the double-sided adhesive tape mounted on the aluminium stub after the male flower's anther heads were cut off from the androphore with a surgical blade. The anther head was also mounted to be examined with the pollen grain position. Following that, the mounted samples were coated with platinum for approximately 80 seconds using an Auto-fine Coater (Jeol/JEC-3000FC) at a current of 20 mA. A FESEM was used to examine the pollen image. The pollen

grains were photographed at various magnifications and voltages to obtain clearer images of the pollen grains. The pollen grain image data was analysed and identified based on pollen characteristics such as aperture form and exine sculpture, pollen unit and shape, and pollen tetrad scale. The pollen grains were calculated using the ImageJ software. In the palynological analysis, the findings were then compared to prior studies for identification.

The mature flowers from selected specimens were used in the second method for palynological studies. The pollen grains were collected fresh and then preserved in 70% ethanol this method was according to Syauqina Syasya (2019). The anthers heads of the male flower were then cut off the androphore with a surgical blade and washed in distilled water for about 3 minutes to remove the excess 70% ethanol. For 3-5 minutes, the specimen was immersed in glucose-isotonic water. The specimens were then washed again with distilled water and air-dried for about 1-2 hours in a zip-lock bag with silica gel. The anther then adhered to the double-sided adhesive tape mounted on the aluminium stub. Following that, the mounted samples were coated with platinum for approximately 80 seconds using an Auto-fine Coater (Jeol/JEC-3000FC) at a current of 20 mA. A FESEM was used to view the pollen image. The pollen grains were photographed at various magnifications and voltages to obtain clearer images of the pollen grains. The pollen grain image data was analysed and identified based on pollen characteristics such as aperture form and exine sculpture, pollen unit and shape, and pollen tetrad scale. The pollen grains were calculated using the ImageJ software. The findings were then compared to prior studies for identification in the palynological analysis.

CHAPTER 4

RESULTS

4.1 Documentation of Aquatic and Marsh Plants in Kuching, Samarahan, and Serian divisions

4.1.1 Diversity Aquatic and Marsh Plant

A total of 23 families, 41 genera, and 50 taxa were recorded during the study. The family Araceae was the largest, representing 10 taxa, followed by Lentibulariaceae (seven spp.), Cyperaceae, and Nymphaeaceae with four species each. While Pontederiaceae and Onagraceae a total of three species. Plantaginaceae and Pandanaceae have two species, respectively. The remaining 15 families represent only one species. Figure 4.1 depicts the graph for diversity of aquatic and marsh plant species according to their families.

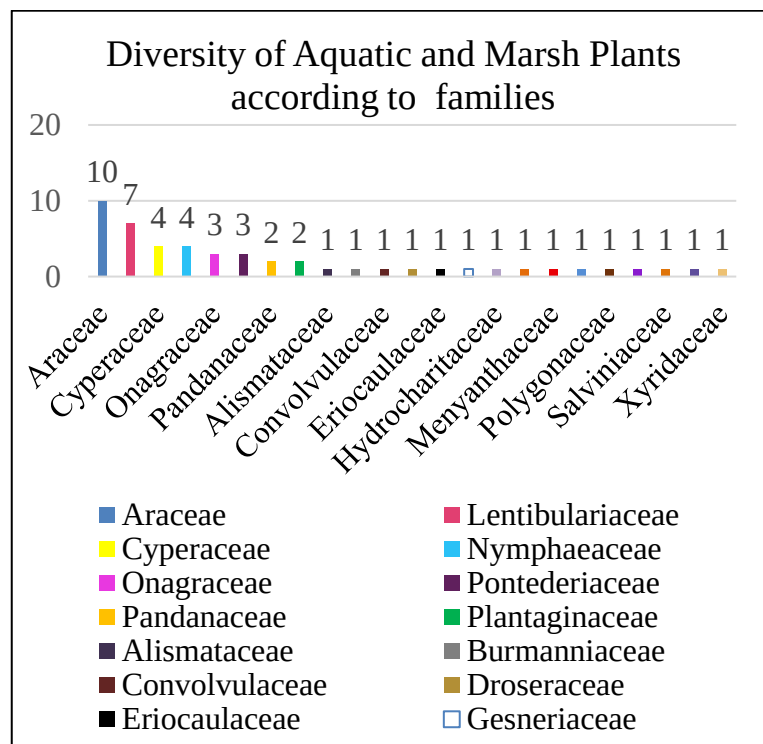


Figure 4.1: Diversity of aquatic and marsh plants according to the families

The family Lentibulariaceae, which is represented by a single genus, is probably the most common among all the aquatic plants recorded in western Sarawak. Whereas *Drosera spatulata* var. *bakoensis* from the family Droseraceae that was recorded in Bako National Park is considered hyperendemic, as it has never been recorded elsewhere yet. Mostly the aquatic species found are focusing on vascular plants. Among these species the biggest aquatic plant found was *Pandanus helicopus* and the smallest is *Lemna minor*. Throughout the species found, some are endemic to Sarawak which are mostly from the *Cryptocoryne*. Some species found were categorized as invasive plants: *Ludwigia leptocarpa*, *Pontederia crassipes*, and *Salvinia molesta*. Some of the aquatic species discovered, including *Ceratopteris thalictroides* var. *thalictroides*, *Ipomoea aquatica*, *Limnocharis flava*, *Monochoria hastata* and *M. vaginalis*, are edible to humans and provide food sources with potential economic significance. These species can also be used in medicine. Table 4.1 shows the listing of aquatic and marsh plant according to their family, genera, and their common or vernacular name.

Table 4.1: The list of aquatic and marsh plant species found in the western of Sarawak

No	Family	Genus	Species	Common/ vernacular name
1	Alismataceae	<i>Limnocharis</i>	<i>L. flava</i>	Paku rawan, Keladi itik, Sawah-flower, Sawah lettuce and Yellow burrhead.
2	Araceae	<i>Cryptocoryne</i>	<i>C. auriculata</i>	Water trumpets
			<i>C. longicauda</i>	Water trumpets (with the long tail)
			<i>C. striolata</i>	N/A
			<i>C. lingua</i>	N/A
			<i>C. zadiana</i>	N/A

Table 4.1: Continued

			<i>C. cordata</i> var <i>zonnata</i>	N/A
		<i>Bucephalandra</i>	<i>Bucephalandra</i> sp.	N/A
		<i>Rhynchopyle</i>	<i>Rhynchopyle</i> sp.	N/A
		<i>Lemna</i>	<i>L. wolffia</i>	Common duckweed
		<i>Lasia</i>	<i>L. spinosa</i>	Geli-geli, Bekil, Spiny Lasia
3	Burmanniaceae	<i>Burmannia</i>	<i>Burmannia</i> sp.	Bluethread
4	Convolvulaceae	<i>Ipomoea</i>	<i>I. aquatica</i>	Kangkong (local name), swamp cabbage, swamp morning-glory, water morning glory, water spinach
5	Cyperaceae	<i>Fimbristylis</i>	<i>F.</i> <i>polytrichoides</i>	Rusty sedge
		<i>Schoenoplectus</i>	<i>Schoenoplectus</i> sp.	Lakeshore bulrush
		<i>Rhynchospora</i>	<i>R. asperula</i>	Nees
		<i>Cyperus</i> sp.	<i>Cyperus</i> sp.	Papyrus sedges, flat sedges, nutsedges, umbrella-sedges and galingales
6	Droseraceae	<i>Drosera</i>	<i>D. spatulata</i> var. <i>bakoensis</i>	Sundews, spoon- leaved sundew
7	Eriocaulaceae	<i>Eriocaulon</i>	<i>Eriocaulon</i> sp.	Pale pipeworts
8	Gesneriaceae	<i>Loxocarpus</i>	<i>Loxocarpus</i> sp.	N/A
9	Hydrocharitaceae	<i>Hydrilla</i>	<i>H. verticillata</i>	Water thymes
10	Lentibulariaceae	<i>Utricularia</i>	<i>U. aurea</i>	Golden floating bladderwort
			<i>U. bifida</i>	2 flower bladderworts

Table 4.1: Continued

			<i>U. caerulea</i>	White bladderwort
			<i>U. gibba</i>	Humped or floating bladderwort
			<i>U. hirta</i>	Hairy bladderwort
			<i>U. minutissima</i>	Minute bladderwort
			<i>U. subulata</i>	Slender bladderwort, Zigzag bladderwort
11	Linderniaceae	<i>Lindernia</i>	<i>Lindernia</i> sp.	Malaysian false pimpernel
12	Nymphaeaceae	<i>Barclaya</i>	<i>B. motleyi</i>	N/A
		<i>Nymphaea</i>	<i>N. lotus</i>	Egyptian lotus, tiger lotus, white lotus, or Egyptian white waterlily
			<i>N. pubescens</i>	Pink waterlily or hairy waterlily
			<i>N. nouchali</i>	Blue lotus, star lotus, red water lily, dwarf aquariu, lily, Ati-ati Payau, Telipok Merah, Telipuk, and Teratai Kecil.
13	Menyanthaceae	<i>Nymphoides</i>	<i>Nymphoides</i> sp.	Water snowflake, fringed waterlily, Water Gentian, Telipok Tasik
14	Onagraceae	<i>Ludwigia</i>	<i>L. adscendens</i>	Water primrose, Inai paya, Tinggar bangau, Inai Pasir, Ubat kulit
			<i>L. leptocarpa</i>	N/A
			<i>L. repens</i>	N/A
15	Pandanaceae	<i>Pandanus</i>	<i>P. yvanii</i>	N/A

Table 4.1: Continued

			<i>P. helicopus</i>	Giant Swamp Pandan and Rasau
16	Parkeriaceae	<i>Ceratopteris</i>	<i>C. thalichoides</i> var. <i>thalichoides</i>	Paku Roman, Antler Fern, Indian Fern, Oriental Water Fern, Paku Ruan, Sayur Kodok and Hornfern
17	Plantaginaceae	<i>Bacopa</i>	<i>Bacopa</i> sp.	Beremi or Brahmi
		<i>Limnophila</i>	<i>Limnophila</i> sp.	Indian Marshweed
18	Polygonaceae	<i>Persicaria</i>	<i>P. attenuata</i> subsp. <i>pulchra</i>	Daun Kesum
19	Pontederiaceae	<i>Pontederia</i>	<i>P. crassipes</i>	Bunga Jamban, Keladi Bunting, Kemeling Telur, and water hyacinths
		<i>Monochoria</i>	<i>M. hastata</i>	Leaf pondweed
			<i>M. vaginalis</i>	Arrow-leaf Pickerel Weed, Keladi Agak, Kelayar, Oval-leaved Monochoria, oval- leaved Pondweed
20	Rubiaceae	<i>Neonauclea</i>	<i>Neonauclea</i> sp.	N/A
21	Salviniaceae	<i>Salvinia</i>	<i>S. molesta</i>	Floating fern, Giant Salvinia, Kariba Weed, Kiambang Kecil
22	Typhaceae	<i>Typha</i>	<i>T. angustifolia</i>	Cat Tail or Lesser Bulrush
23	Xyridaceae	<i>Xyris</i>	<i>Xyris</i> sp.	N/A

** Notes: No information available (N/A)

According to the findings of this study, the Samarahan division, which has a total of 32 taxa, has the greatest richness and distribution of aquatic and marsh plants. The type of habitats in Samarahan were mainly disturbed areas and peat swamp forest. Kuching came in second with 23 taxa, whereas Serian had seven taxa. This discovery could be attributed to Figure 4.2 displays the number of families, genera, and taxa discovered, while Figure 4.3 depicts the distribution of aquatic and marsh plants across the three divisions of western Sarawak according to the family: 23 families are spread. Table 4.2 displays the specimens gathered from all locations according to their life form, which is emergent, floating-leaved, emergent free-floating, submerged, submerged free-floating, aquatic marsh, and rheophyte.

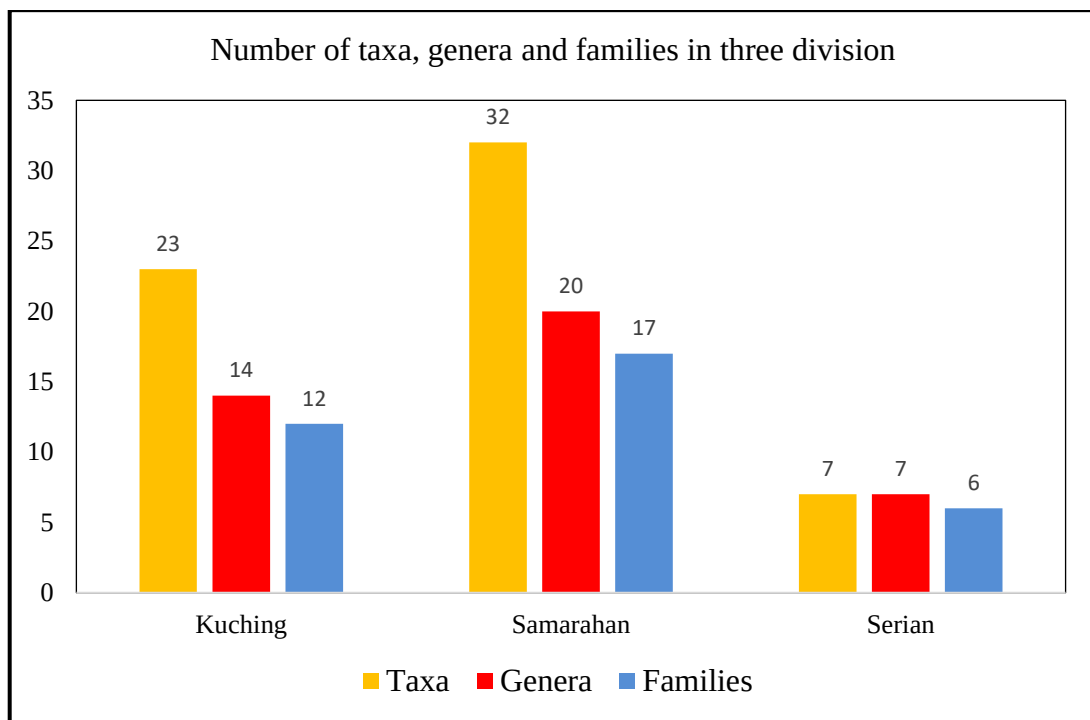


Figure 4.2: Number of taxa, genera, and families in three division of western Sarawak.

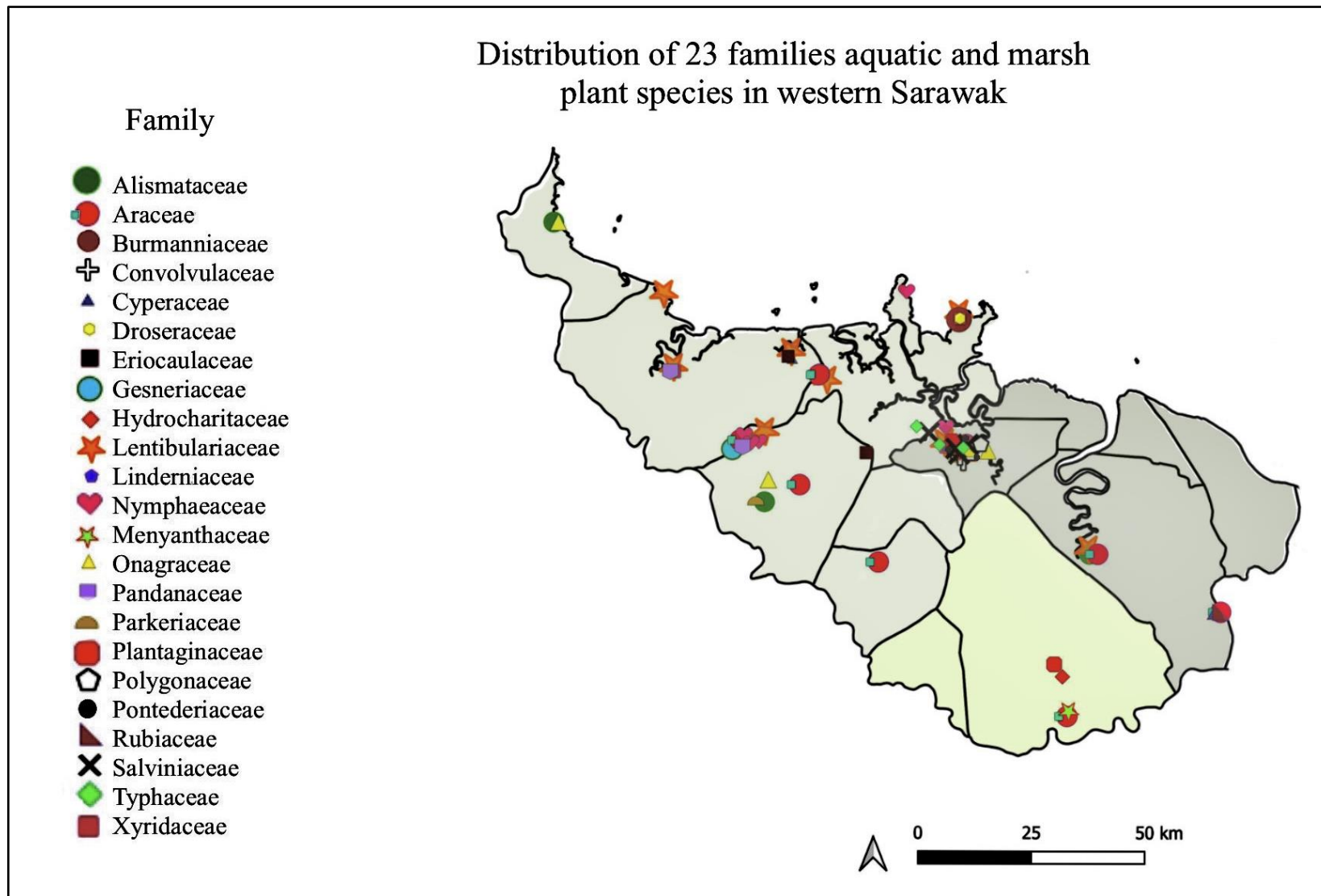


Figure 4.3: Map distribution of 23 families throughout western Sarawak.

In this research each of the aquatic plant were divided into seven aquatic lifeform groups: emergent, floating-leaved, emergent free-floating, submerged, submerged free-floating, aquatic marsh, and rheophyte. The aquatic marsh and emergent are the two highest lifeforms, with a total of 14 taxa found with 13 species and one variety throughout the three divisions and emergent plants have a total of 14 taxa, 12 species, one variety and one subspecies. These two lifeforms are dominant in the three divisions. The least lifeform found was a submerged free-floating plant with a total of two species found, which are *Hydrilla verticillata* and *Ludwigia repens*. Rheophyte lifeforms are the second-least number of species found with a total of four species, this group consists of families that are mainly from the family Araceae, Gesneriaceae, and Rubiaceae. Figure 4.4 shows the percentage of lifeforms found throughout the three divisions. The distribution of the species in three divisions was grouped according to their life forms, as seen in Table 4.2.

Many aquatic plants grow completely submerged or float on the water's surface. Some plants with deep roots produce floating leaves or thrust their flowers above the water's surface. These plants are so reliant on the water for survival that they would perish on land or develop stunted forms. Other aquatic plants colonise the water-land interaction which occurs usually in the riparian zone, where they are commonly referred to as marsh plant. They grow on wet soil near the water's edge or in shallow water, where shoots and leaves develop in the air. Some marsh plants can adapt to being submerged. One of the most important ecosystems on the planet, riparian zones serve as the ecological engineers that enhance river health by providing a variety of ecosystem services (Singh et al., 2021). The family of aquatic plants found are widely diverse; thus, the distribution of species was divided according to lifeform to see the distribution of species clearly.

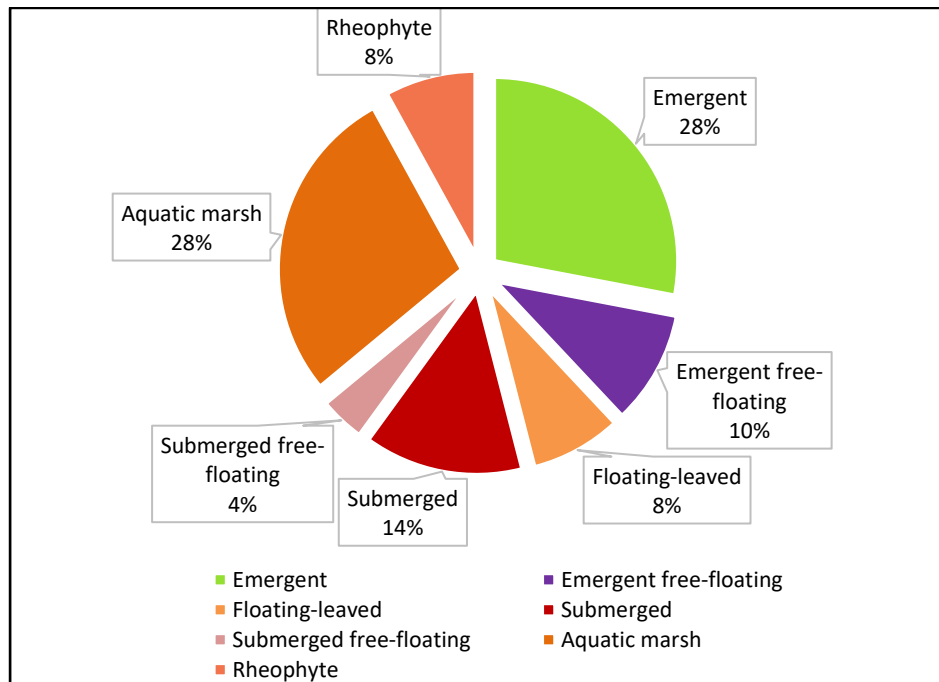


Figure 4.4: The percentage of lifeforms found throughout the three divisions (Kuching, Samarahan, and Serian).

4.1.2 Distribution of species according to group

Emergent

A total of 14 species found as an emergent plant, which are *Limnocharis flava*, *Pontederia crassipes*, *Monochoria hastata*, *M. vaginalis*, *Ceratopteris thalichoides* var. *thalichoides*, *Bacopa* sp., *Lindernia* sp., *Ludwigia adscendens*, *Ludwigia leptocarpa*, *Pandanus helicopus*, *Typha angustifolia*, *Lasia spinosa*, *Ipomoea aquatica* and *Persicaria attenuata* subsp *pulchra*. Out of all the 14 species, the most widely distributed species was *Limnocharis flava*. This species can be found in Kuching and Samarahan divisions and is considered an introduced species. *Pontederia crassipes* and *L. leptocarpa* are two species that are considered invasive.

While one species is classified as an exotic species: *Typha angustifolia*. *Monochoria hastata*, *M. vaginalis*, *Ceratopteris thalichoides* var *thalichoides*, *Pandanus helicopus*, *Ludwigia adscendens*, *Ipomoea aquatica*, *Bacopa* sp. and *Lasia spinosa* are some of the native species found. The remaining species, *Lindernia* sp. and *Persicaria attenuata* subsp. *pulchra*, are considered non-native. Figure 4.5 shows the distribution of the emergent plant in the three divisions. Species that overlaps in localities are mostly from Samarahan division. One emergent species have been recorded in the Serian Division which was *Lasia spinosa*.

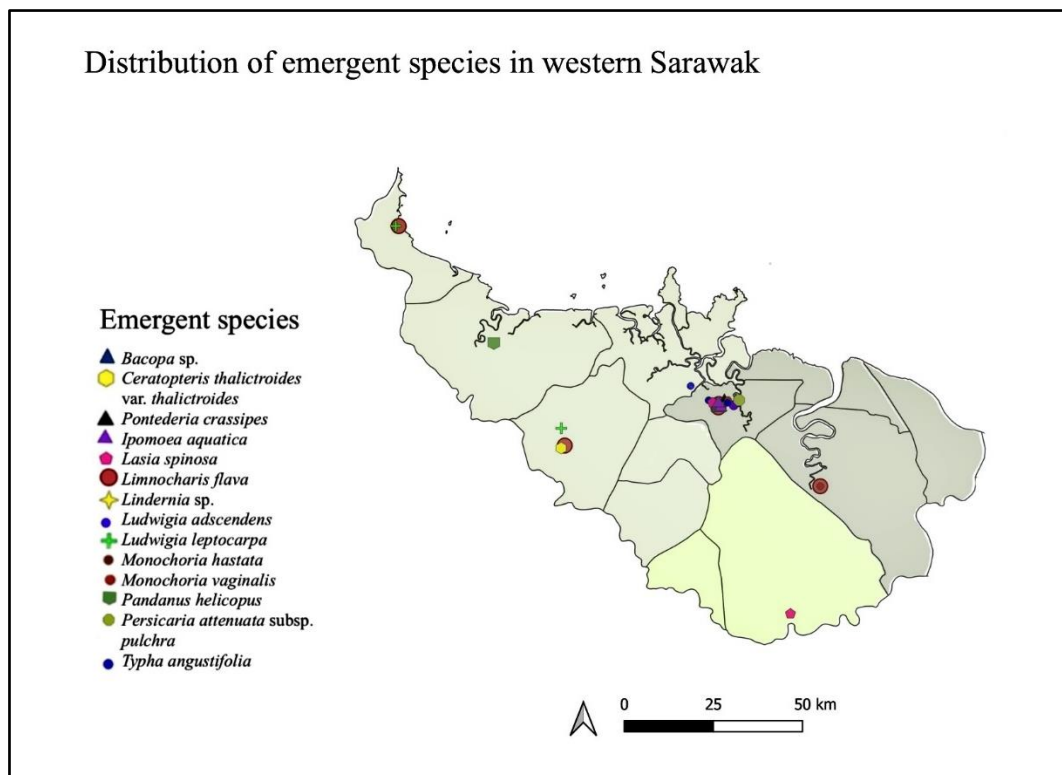


Figure 4.5: Distribution of emergent plant species in western Sarawak.

Floating-leaved

Nymphaeaceae plants with floating leaves include *N. lotus*, *N. nouchalli*, and *N. pubescens*. The species was only recorded in the Samarahan division. In Serian, one Menyanthaceae species, which is *Nymphoides* sp., was documented. In the Kuching

division, no floating-leaved species were found during the field surveys. *Nymphaea nouchali* is the species with the widest distribution within the group, as it has been documented in several locations within the Samarahan division (Table 4.2). All species of floating leaves are native to Malaysia. Figure 4.6 depicts the distribution of aquatic plant species with floating leaves across the three divisions. There was an area where species coordination overlapped which are *N. nouchalli*, *N. pubescens* and *N. lotus* found co-exist in one locality.

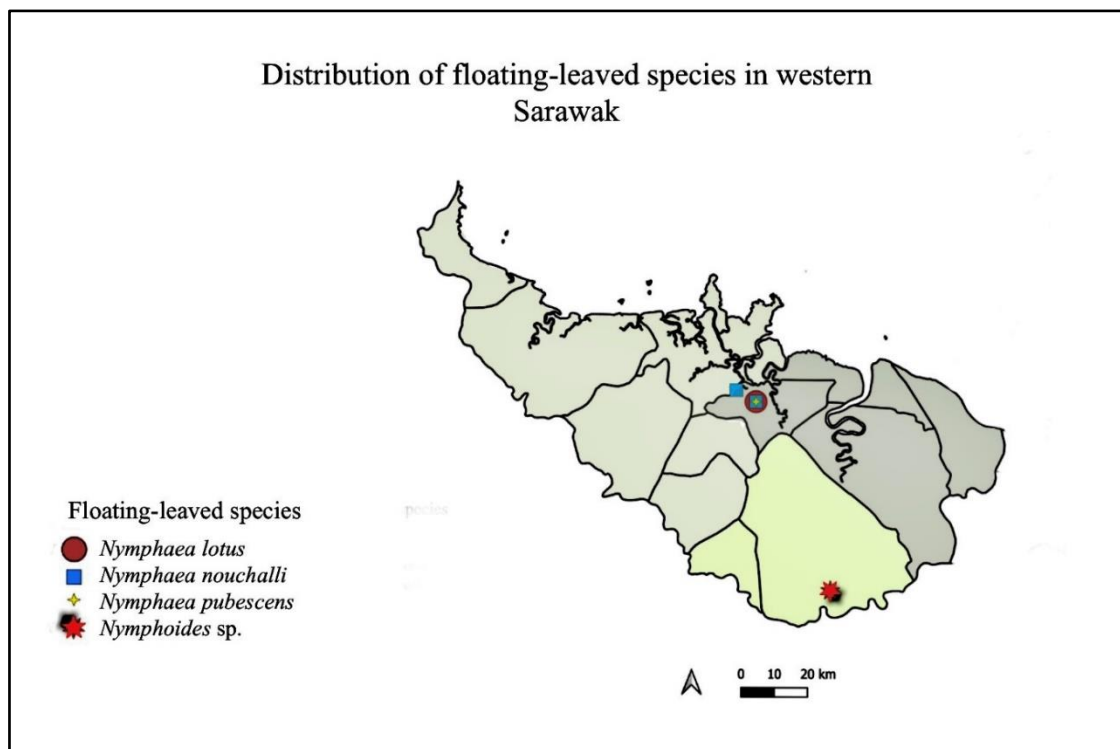


Figure 4.6: Distribution of floating-leaved plant species in western Sarawak.

Emergent free-floating

There are total of five species in the emergent free-floating plant found in three divisions which are *Lemna minor*, *Limnophila sp.*, *Salvinia molesta*, *Utricularia aurea* and *U. gibba*. The genus *Utricularia* species (*U. aurea* and *U. gibba*) are found widely distributed compared to the other species. Both species can be found in Kuching and

Samarahan division however, no record in Serian for *Utricularia*. *Salvinia molesta* is the most invasive plant of the five species observed, whereas the other four species are native. *Salvinia molesta* and *Lemna minor* have only been found in the Samarahan division, whereas *Limnophila* species are exclusive to the Serian division. Figure 4.7 shows where the species are distributed in the three divisions map and specific distribution according to the division and localities were presented in Table 4.2 and Table 4.3.

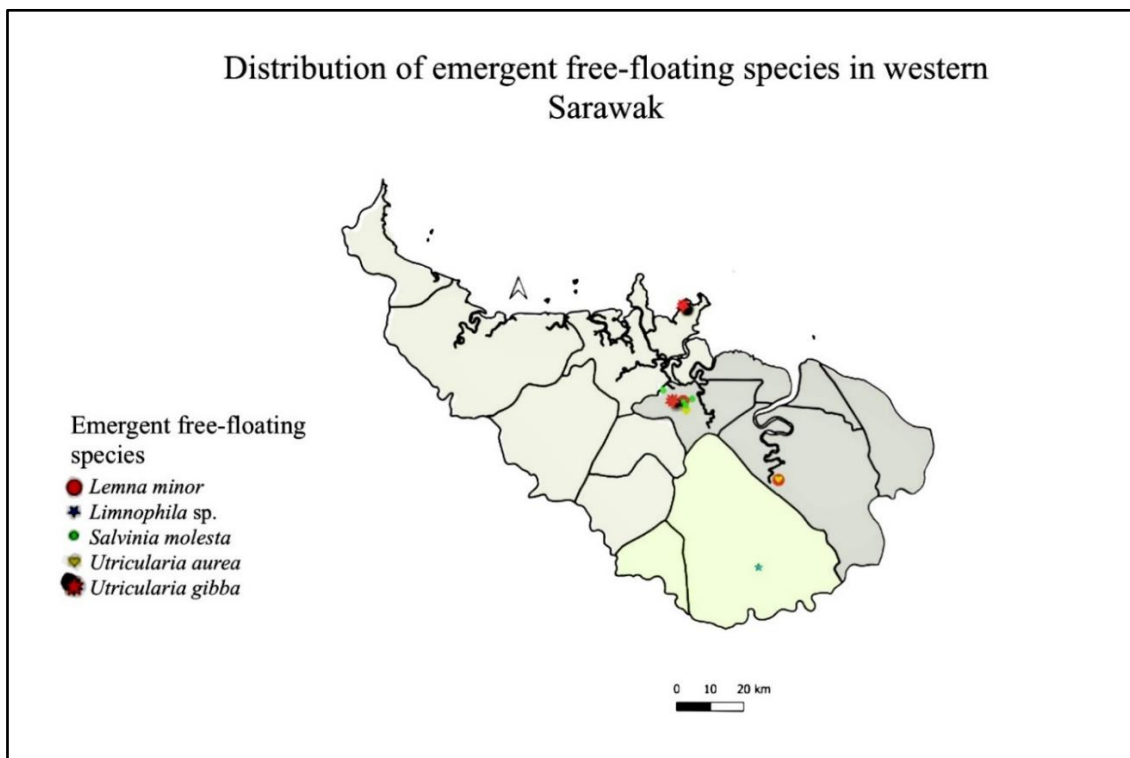


Figure 4.7: Distribution of emergent free-floating plant species in western Sarawak.

Submerged

The submerged aquatic lifeform contained *Barclaya motleyi*, *Cryptocoryne auriculata*, *C. cordata* var. *zonnata*, *C. lingua*, *C. longicauda*, *C. striolata*, and *C. zadiana*. This species was only discovered in the Samarahan and Kuching regions, with no reports in the Serian division. The submerged group found were dominated by the Araceae family and a species of Nymphaeaceae (*B. motleyi*). All the species recorded are native.

Barclaya motleyi is considered the most widely distributed in western Sarawak where it can be found in both Samarahan and Kuching divisions. Figure 4.8 and Table 4.2 illustrate the species' distribution and locality, respectively. *Cryptocoryne lingua* and *C. zadiana*, were based on specimens at UNIMAS's nursery, that was cultivated for educational purposes in the nursery.

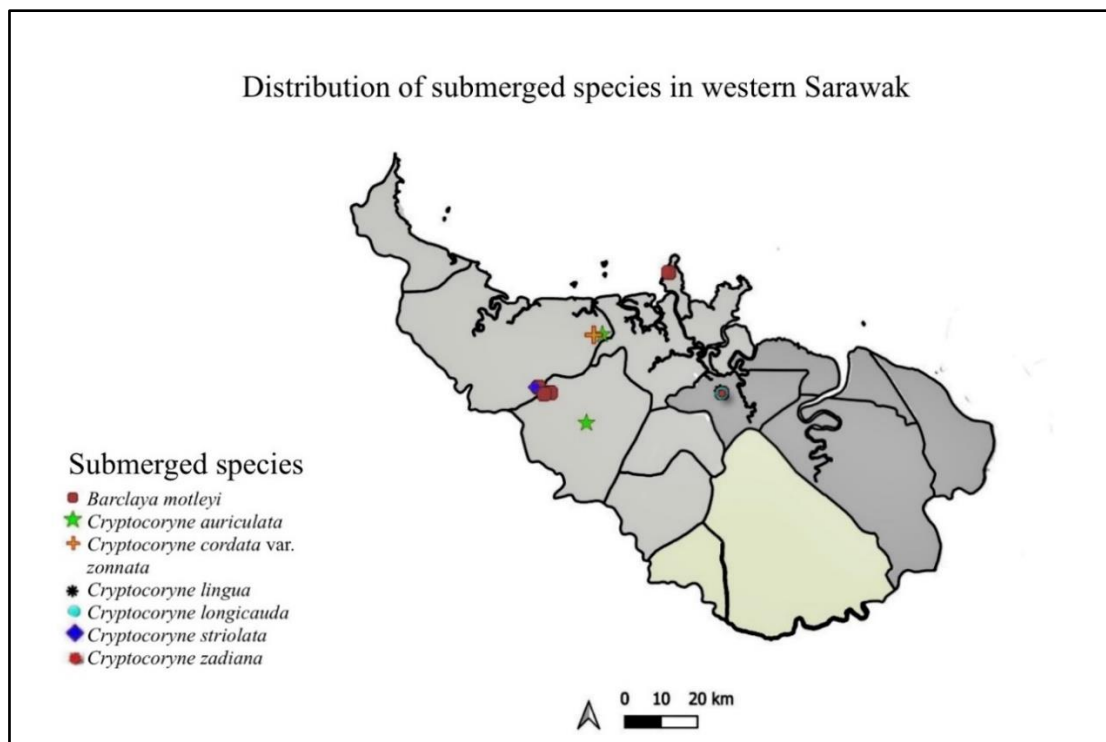


Figure 4.8: Distribution of submerged plant species in western Sarawak.

Submerged free floating

Ludwigia repens and *Hydrilla verticillata* are the only species recorded for the submerged-free floating lifeform group, which has the fewest species of any other group. This species is only found in the Samarahan and Serian divisions; Kuching has no record of it. However, *Ludwigia repens* was only observed in the Samarahan division. *Hydrilla verticillata* is considered native, whereas the category of *L. repens* remain unknown. The

species distribution is depicted in Figure 4.9. Due to identical localities and coordinates, the species legend on the map for the Samarahan division was overlapping (Figure 4.9).

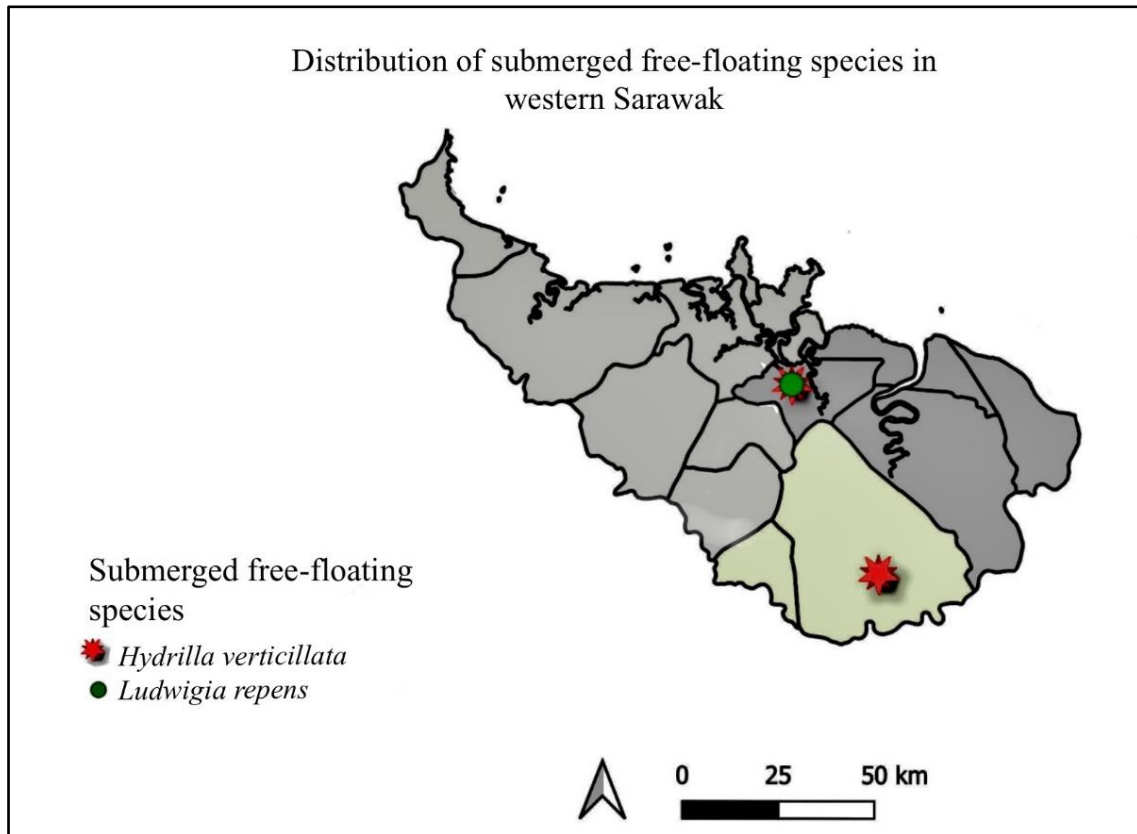


Figure 4.9: Distribution of submerged free-floating plant species in western Sarawak.

Aquatic marsh

The aquatic marsh has a total of 14 recorded species, including *Burmannia* sp., *Cyperus* sp., *Drosera spatulata* var. *bakoensis*, *Eriocaulon* sp., *Fimbristylis polytrichoides*, *Rhynchospora asperula*, *Pandanus yvanii*, *Schoenoplectus* sp., *Utricularia bifida*, *U. caerulea*, *U. hirta*, *U. minutissima* *U. subulata* and *Xyris* sp. Most of the species recorded belong to the Lentibulariaceae with five species, followed by the Cyperaceae family, which contains four genera. Figure 4.9 depicts the distribution of all species although some of the legends overlap localities. This group lifeform can be found

in all three divisions. Three species (*U. minutissima*, *U. caerulea*, and *U. bifida*) of the genus *Utricularia* were widely distributed in the Samarahan and Kuching divisions (Table 4.2 and 4.3). *Drosera spatulata* var. *bakoensis* is hyper-endemic species that is exclusive to Bako National Park. All the *Utricularia* species, *Eriocaulon* sp., *Fimbristylis asperula*, *Xyris* sp., *Pandanus yvanii*, *Burmannia* sp., and *Drosera spatulata* var *bakoensis* found are native, while *Schoenoplectus* sp., *Rhynchospora asperula*, and *Cyperus* sp. are non-native. Figure 4.10 depicts the distribution of aquatic marsh plant in western Sarawak shown.

Rheophyte

There is a total of four rheophyte species, including *Bucephalandra* sp., *Rhynchochrysis* sp., *Loxocarpus* sp., and *Neonauclea* sp. The majority of rheophytes are members of the Araceae. In this map depicts no overlapping of coordinates. Though there are no species recorded as rheophytes in the Serian division. Only two of the species are native to Malaysia which were *Bucephalandra* sp. and *Rhynchochrysis* sp. while the other two are categorized as unknown. Figure 4.11 shows the distribution of rheophyte in western Sarawak where each species was found in four different localities Table 4.2.

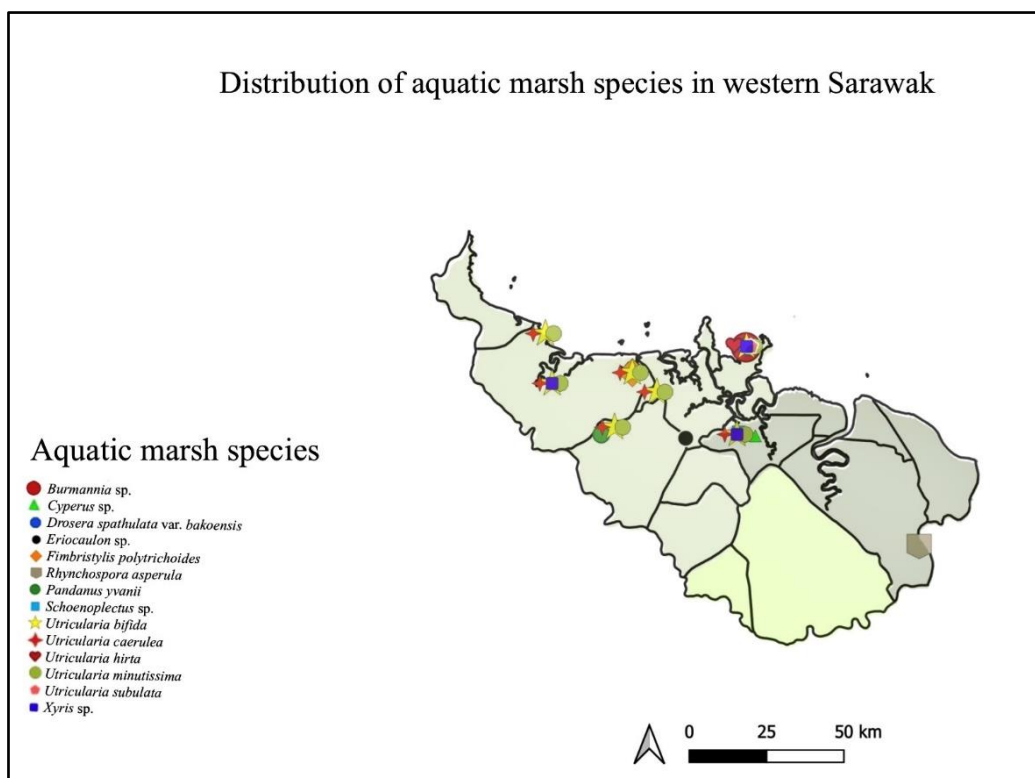


Figure 4.10: Distribution of aquatic marsh plant species in western Sarawak.

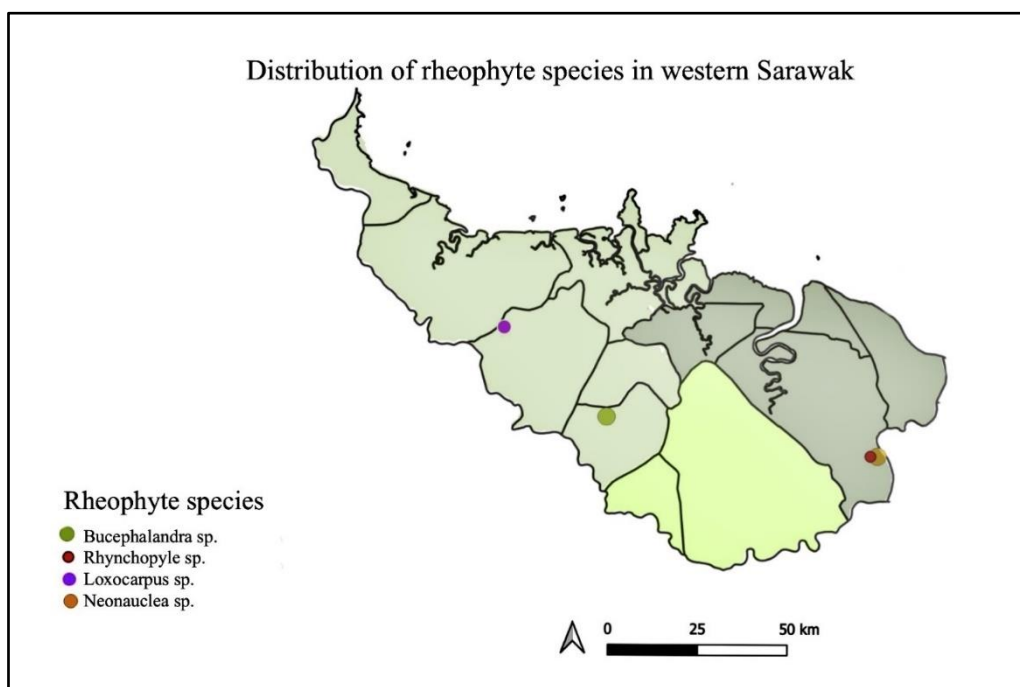


Figure 4.11: Distribution of rheophyte plant species in western Sarawak.

Table 4.2: The division, localities, latitude, longitude, elevation, and collector of 50 aquatic and marsh plant species in western Sarawak

Species	Division	Localities	Latitude	Longitude	Elevation (m)	Collector
Emergent						
<i>Bacopa</i> sp.	Samarahan	UNIMAS	1° 27' 40" N	110° 27' 16" E	10	Umie Naylisa, M. A., Nabilah Huda, M. H
<i>Ceratopteris thalichoides</i> var <i>thalichoides</i>	Kuching	Kampung Bogag, Bau	1° 21' 1" N	110° 3' 27" E	51	Umie Naylisa, M. A., Meekiong, K.
<i>Pontederia crassipes</i>	Samarahan	Kota Samarahan roadside	1° 28' 15" N	110° 28' 41" E	10	Umie Naylisa, M. A., Meekiong, K. Nabilah Huda, M. H.
<i>Limnocharis flava</i>	Samarahan	UNIMAS	1° 27' 40" N	110° 27' 16" E	10	Umie Naylisa, M. A., Meekiong, K.
	Kuching	Jalan Sematan	1° 54' 34" N	109° 38' 53" E	20	
	Samarahan	Jalan Gedong-Simunjan Gedong	1° 15' 15" N	110° 42' 37" E	20	
	Kuching	Kampung Bogag, Bau	1° 21' 24" N	110° 3' 59" E	51	
	Samarahan	Summer Mall	1° 27' 10" N	110° 27' 13" E	6	
<i>Lindernia</i> sp.	Samarahan	UNIMAS	1° 27' 40" N	110° 27' 16" E	10	Umie Naylisa, M. A., Nabilah Huda, M. H
<i>Ludwigia adscendens</i>	Samarahan	Klinik Kota Samarahan,	1° 27' 30" N	110° 29' 32" E	14	Umie Naylisa, M. A., Meekiong, K.
<i>Ludwigia leptocarpa</i>	Samarahan	UNIMAS	1° 27' 47" N	110° 27' 13" E	14	Umie Naylisa, M. A., Meekiong, K.

Table 4.2: Continued

	Kuching	Samunsam Sanctuary	Wildlife	1° 54' 34" N	109° 38' 53" E	20	
	Kuching	Kampung Bogag, Bau		1° 24' 1" N	110° 3' 27" E	30	
<i>Monochoria hastata</i>	Samarahan	PPT, UNIMAS		1° 27' 58" N	110° 26' 55" E	6	Umie Naylisa, M. A., Meekiong, K.
	Samarahan	Kota Samarahan-Asajaya roadside		1° 27' 26" N	110° 27' 34" E	5	
<i>Monochoria vaginalis</i>	Samarahan	Summer Mall		1° 27' 10" N	110° 27' 36" E	6	Umie Naylisa, M. A., Meekiong, K.
	Samarahan	Jalan Atro - Gedong		1° 15' 15" N	110° 42' 37"	65	
	Samarahan	Kota Samarahan – Asajaya roadside		1° 28' 15" N	110° 28' 41" E	10	
<i>Pandanus helicopus</i>	Kuching	Samunsam Sanctuary	Wildlife	1° 36' 49" N	109° 53' 16" E	10	Umie Naylisa, M. A., Meekiong, K.
<i>Typha angustifolia</i>	Samarahan	Kota Samarahan- roadside	Asajaya	1° 27' 52" N	110° 28' 35" E	5	Umie Naylisa, M. A., Meekiong, K.
	Samarahan	Faculty of Resource	Science	1° 28' 14" N	110° 25' 45" E	10	
	Samarahan	Kota Samarahan – Tabuan Jaya roadside		1° 30' 24" N	110° 23' 27" E	5	
<i>Ipomoea aquatica</i>	Samarahan	Near Summer Mall		1° 27' 10" N	110° 27' 36" E	6	Umie Naylisa, M. A., Meekiong, K., Nabilah Huda, M. H.

Table 4.2: Continued

	Samarahan	East Campus Malaysia (UNIMAS)	Universiti Sarawak	1° 27' 47" N	110° 27' 13" E	10	
<i>Lasia spinosa</i>	Samarahan	East Campus Malaysia (UNIMAS)	Universiti Sarawak	1° 27' 53" N	110° 27' 14" E	10	Umie Naylisa, M. A., Meekiong, K.
	Kuching	Gunung Apeng		0° 55' 59" N	110° 39' 00" E	59	
<i>Persicaria attenuata</i> subsp. <i>pulchra</i>	Samarahan	Kota Samarahan – Asajaya roadside		1° 28' 15" N	110° 28' 41" E	10	Umie Naylisa, M. A., Nabilah Huda, M. H
Emergent free-floating							
<i>Lemna minor</i>	Samarahan	Jalan Simunjan-Gedong roadside		1° 15' 15" N	110° 42' 37" E	20	Umie Naylisa, M. A., Meekiong, K.
	Samarahan	UNIMAS (east campus)		1° 27' 40" N	110° 27' 16" E	10	
<i>Limnophila</i> sp.	Serian	Jalan Mentung-Sangai, Sungai Paon Gahat, Serian		1° 28' 14" N	110° 26' 17"	14	Meekiong, K.
<i>Salvinia molesta</i>	Samarahan	UNIMAS (east campus)		1° 27' 40" N	110° 27' 16" E	10	Umie Naylisa, M. A.,
	Samarahan	Kota Samarahan – Asajaya roadside		1° 28' 15" N	110° 28' 41" E	10	Meekiong, K.
	Samarahan	Infront of La Promenade Mall		1° 29' 39" N	110° 24' 6" E	4	
	Samarahan	Summer Mall		1° 27' 10" N	110° 27' 36" E	6	
<i>Utricularia aurea</i>	Samarahan	Jalan Atro - Gedong		1° 15' 15" N	110° 42' 37" E	65	Umie Naylisa, M. A., Meekiong, K.

Table 4.2: Continued

	Samarahan	UITM Samarahan roadside	1° 26' 11" N	110° 27' 43" E	5	
<i>Utricularia gibba</i>	Samarahan	UNIMAS (east campus lake)	1° 27' 40" N	110° 27' 16" E	10	Umie Naylisa, M. A., Meekiong, K.
	Kuching	Jalan Haji Taha, Bako NP	1° 39' 10" N	110° 26' 35" E	10	
Floating-leaved						
<i>Nymphaea lotus</i>	Samarahan	UNIMAS east campus	1° 27' 47" N	110° 27' 13" E	10	Umie Naylisa, M. A., Meekiong, K.
<i>Nymphaea nouchalli</i>	Samarahan	UNIMAS east campus	1° 27' 47" N	110° 27' 13" E	10	Umie Naylisa, M. A., Meekiong, K.
	Samarahan	In front of La Promenade Mall	1° 29' 39" N	110° 24' 6" E	4	
<i>Nymphaea pubescens</i>	Samarahan	UNIMAS east campus	1° 27' 47" N	110° 27' 13" E	10	Umie Naylisa, M. A., Meekiong, K.
<i>Nymphoides</i> sp.	Serian	Sungai Paon Gahat, Kampung Melaban,	1° 28' 14" N	110° 26' 17" E	14	Meekiong, K.
Submerged						
<i>Barclaya motleyi</i>	Samarahan	UNIMAS	1° 27' 56" N	110° 27' 15" E	23	Umie Naylisa, M. A., Meekiong, K.
	Kuching	Sungai Stom	1° 28' 44" N	110° 0' 5" E	109	
	Kuching	Stenggang trail, Banjaran Undan	1° 27' 55" N	110° 1' 50" E	80	
	Kuching	Simpadah trail, Banjaran Undan	1° 27' 45" N	110° 0' 54" E	86	
	Kuching	Santubong NP	1° 45' 46" N	110° 19' 20" E	816	
<i>Cryptocoryne auriculata</i>	Kuching	Matang Wildlife	1° 36' 34" N	110° 9' 31" E	13	

Table 4.2: Continued

	Kuching	Buddhiat Shrine, Bau	1° 23' 27" N	110° 7' 11" E	21	Umie Naylisa, M. A., Meekiong, K
<i>Cryptocoryne cordata</i> var. <i>zonnata</i>	Kuching	Matang wildlife	1° 36' 30" N	110° 9' 25" E	50	Umie Naylisa, M. A., Meekiong, K
<i>Cryptocoryne lingua</i>	Samarahan	(PPT), UNIMAS	1° 27' 58" N	110° 26' 55" E	6	Umie Naylisa, M. A., Meekiong, K
<i>Cryptocoryne longicauda</i>	Samarahan	UNIMAS (peat swamp)	1° 27' 53" N	110° 27' 14" E	10	Umie Naylisa, M. A., Meekiong, K
<i>Cryptocoryne striolata</i>	Samarahan	Sungai Stom Muda Bau- Lundu	1° 28' 44" N	110° 0' 5" E	109	Umie Naylisa, M. A., Meekiong, K
<i>Cryptocoryne zadiana</i>	Samarahan	(PPT), UNIMAS	1° 27' 58" N	110° 26' 55" E	6	Umie Naylisa, M. A., Meekiong, K
Submerged free-floating						
<i>Hydrilla verticillata</i>	Samarahan	East campus, UNIMAS	1° 27' 47" N	110° 27' 13" E	10	Umie Naylisa, M. A., Meekiong, K
	Serian	Jalan Mentung-Sangai, Sungai Paon Gahat	1° 1' 11" N	110° 39' 26" E	25	
<i>Ludwigia repens</i>	Samarahan	East campus, UNIMAS	1° 27' 47" N	110° 27' 13"	10	Umie Naylisa, M. A., Meekiong, K
Aquatic marsh						
<i>Burmannia</i> sp.	Kuching	Bako National Park (Lintang trail)	1° 43' 06" N	110° 27' 03" E	30	Umie Naylisa, M. A., Meekiong, K
<i>Cyperus</i> sp.	Samarahan	East campus, UNIMAS	1° 27' 40" N	110° 27' 16" E	10	Umie Naylisa, M. A., Meekiong, K

Table 4.2: Continued

<i>Drosera spatulata</i> var. <i>bakoensis</i>	Kuching	Bako National Park (Lintang Trail)	1° 43' 14" N	110° 27' 10" E	120	Umie Naylisa, M. A., Meekiong, K
<i>Eriocaulon</i> sp.	Samarahan	East campus, UNIMAS	1° 27' 40" N	110° 27' 16" E	10	Umie Naylisa, M. A., Meekiong, K
	Kuching	Matang-Sempadi roadside	1° 38' 41" N	110° 7' 15" E	50	Umie Naylisa, M. A., Meekiong, K
<i>Fimbristylis polytrichoides</i>	Kuching	Matang-Lundu roadside	1° 38' 41" N	110° 7' 15" E	17	Umie Naylisa, M. A., Meekiong, K
<i>Rhynchospora asperula</i>	Kuching	Mount Krian, Bau Lake	1° 8' 24" N	110° 1' 8" E	-	Umie Naylisa, M. A., Meekiong, K
<i>Pandanus yvanii</i>	Kuching	Stenggan trail, Banjaran Undan	1° 27' 55" N	110° 1' 50" E	80	Umie Naylisa, M. A., Meekiong, K
<i>Schoenoplectus</i> sp.	Serian	Sungai Paon Gahat	1° 28' 20" N	110° 25' 44" E	14	Umie Naylisa, M. A., Meekiong, K
<i>Utricularia bifida</i>	Samarahan	East campus, (UNIMAS)	1° 27' 56" N	110° 25' 30" E	9	Umie Naylisa, M. A., Meekiong, K
	Kuching	Kubah National Park	1° 35' 19" N	110° 11' 31" E	780	
	Kuching	Matang – Sempadi roadside	1° 38' 41" N	110° 7' 15" E	50	
	Kuching	Lundu	1° 45' 30" N	109° 52' 6" E	12	
	Kuching	Stenggang- Bau roadside	1° 29' 11" N	110° 4' 9" E	109	
	Kuching	Samunsam Wildlife Sanctuary roadside	1° 36' 49" N	109° 53' 16" E	10	
	Kuching	Bako national Park	1° 43' 22" N	110° 26' 56" E	100	

Table 4.2: Continued

<i>Utricularia caerulea</i>	Samarahan	East campus, (UNIMAS)	1° 27' 56" N	110° 25' 30" E	9	Umie Naylisa, M. A., Meekiong, K
	Kuching	Kubah National Park	1° 35' 19" N	110° 11' 31" E	780	
	Kuching	Matang – Sempadi roadside	1° 38' 41" N	110° 7' 15" E	50	
	Kuching	Lundu	1° 45' 30" N	109° 52' 6" E	12	
	Kuching	Stenggang- Bau roadside	1° 29' 11" N	110° 4' 9" E	109	
	Kuching	Samunsam Wildlife Sanctuary roadside	1° 36' 49" N	109° 53' 16" E	10	
	Kuching	Bako national Park	1° 43' 22" N	110° 26' 56" E	100	
<i>Utricularia hirta</i>	Kuching	Bako National Park	1° 43' 22" N	110° 26' 56" E	100	Umie Naylisa, M. A., Meekiong, K
<i>Utricularia minutissima</i>	Samarahan	East campus, (UNIMAS)	1° 27' 56" N	110° 25' 30" E	9	Umie Naylisa, M. A., Meekiong, K
	Kuching	Kubah National Park	1° 35' 19" N	110° 11' 31" E	780	
	Kuching	Matang – Sempadi roadside	1° 38' 41" N	110° 7' 15" E	50	
	Kuching	Lundu	1° 45' 30" N	109° 52' 6" E	12	
	Kuching	Stenggang- Bau roadside	1° 29' 11" N	110° 4' 9" E	109	
	Kuching	Samunsam Wildlife Sanctuary roadside	1° 36' 49" N	109° 53' 16" E	10	
	Kuching	Bako national Park	1° 43' 22" N	110° 26' 56" E	100	
<i>Utricularia subulata</i>	Kuching	Bako National Park	1° 43' 22" N	110° 26' 56" E	100	Umie Naylisa, M. A., Meekiong, K

Table 4.2: Continued

<i>Xyris</i> sp.	Kuching	Bako National Park	1° 43' 22" N	110° 26' 56" E	100	Umie Naylisa, M. A., Meekiong, K
Rheophytes						
<i>Bucephalandra</i> sp.	Kuching	Small river limestone Bra'ang	1° 14' 17" N	110° 16' 33" E	91	Umie Naylisa, M. A., Meekiong, K
<i>Rhynchospora</i> sp.	Kuching	Gunung Buri, Sabal	1° 8' 24" N	110° 57' 15" E	96	Umie Naylisa, M. A., Meekiong, K
<i>Loxocarpus</i> sp.	Kuching	Stenggang trail, Banjaran Undan	1° 27' 40" N	110° 1' 8" E	52	Umie Naylisa, M. A., Meekiong, K
<i>Neonauclea</i> sp.	Kuching	Gunung Buri, Sabal	1° 8' 24" N	110° 57' 15" E	96	Umie Naylisa, M. A., Meekiong, K

Table 4.3: The Distribution Presence of Species According to Aquatic Lifeform in Three Divisions.

Species	Kuching	Samarahan	Serian
Emergent			
<i>Bacopa</i> sp.	-	+	-
<i>Ceratopteris thalichoides</i> var. <i>thalichodes</i>	+	-	-
<i>Pontederia crassipes</i>	-	+	-
<i>Limnocharis flava</i>	+	+	-
<i>Lindernia</i> sp.	-	+	-
<i>Ludwigia adscendens</i>	-	+	-
<i>Ludwigia leptocarpa</i>	+	+	-
<i>Monochoria hastata</i>	-	+	-
<i>Monochoria vaginalis</i>	-	+	-
<i>Pandanus helicopus</i>	-	+	-
<i>Typha angustifolia</i>	-	+	-
<i>Ipomea aquatica</i>	-	+	-
<i>Lasia spinosa</i>	+	+	-
<i>Persicaria attenuata</i> subsp. <i>pulchra</i>	-	+	-
Emergent free-floating			
<i>Lemna minor</i>	-	+	-
<i>Limnophila</i> sp.	-	-	+

Table 4.3: Continued

<i>Salvinia molesta</i>	-	+	-
<i>Utricularia aurea</i>	+	+	-
<i>Utricularia gibba</i>	+	+	-
Floating-leaved			
<i>Nymphaea lotus</i>	-	+	-
<i>Nymphaea nouchalli</i>	-	+	-
<i>Nymphaea pubescens</i>	-	+	-
<i>Nymphoides</i> sp.	-	-	+
Submerged			
<i>Barclaya motleyi</i>	+	+	-
<i>Cryptocoryne auriculata</i>	+	-	-
<i>Cryptocoryne cordata</i> var. <i>zonnata</i>	+	-	-
<i>Cryptocoryne lingua</i>	-	+	-
<i>Cryptocoryne longicauda</i>	-	+	-
<i>Cryptocoryne striolata</i>	+	-	-
<i>Cryptocoryne zadiana</i>	-	+	-
Submerged free-floating			
<i>Hydrilla verticillata</i>	-	+	+
<i>Ludwigia repens</i>	-	+	-

Table 4.3: Continued

Aquatic marsh			
<i>Burmannia</i> sp.	+	-	-
<i>Cyperus</i> sp.	-	+	-
<i>Drosera spatulata</i> var. <i>bakoensis</i>	+	-	-
<i>Eriocaulon</i> sp.	+	+	-
<i>Fimbristylis polytrichoides</i>	+	-	-
<i>Rhynchospora asperula</i>	-	-	+
<i>Pandanus yvanii</i>	+	-	-
<i>Schoenoplectus</i> sp	-	-	+
<i>Utricularia bifida</i>	+	+	-
<i>Utricularia caerulea</i>	+	+	-
<i>Utricularia hirta</i>	+	-	-
<i>Utricularia minutissima</i>	+	+	-
<i>Utricularia subulata</i>	+	-	-
<i>Xyris</i> sp.	+	+	-
Rheophytes			
<i>Bucephalandra</i> sp.	+	-	-
<i>Rhynchopyle</i> sp.	-	-	+
<i>Loxocarpus</i> sp.	+	-	-
<i>Neonauclea</i> sp.	-	-	+

** Notes: (+) presence, (-) absent

4.2 Ecological characteristics and Habitat Aquatic and Marsh Plant

Malaysian wetlands can be categorised into 10 main groups. They include lakes, oxbow lakes, river systems, marshes, wet rice paddies, mangroves, mudflats, nipa swamps, freshwater, freshwater swamp forest, peat swamp forest, lakes, oxbow lakes, river systems, marshes, and wet rice paddies. The important environments for aquatic macrophytes include freshwater swamp forest, peat swamp forest, lakes, oxbow lakes, river systems, marshes, and wet rice fields. Most oxbow lakes and marshes are in East Malaysia (Borneo) (Khan, 1991).

4.2.1 Habitat and Ecology of Aquatic and Marsh Plant

The habitats and ecologies of the 50 aquatic and marsh species were recorded and tabulated in Table 4.4. The type of aquatic habitats in which all the 50 species thrive in forest was the Sandstone plateau, disturbed area, limestone forest lowland dipterocarp, peat swamp forest, and mixed dipterocarp forest. Most of the species found were in disturbed area of forest. However, few species were found in sandstone plateau and limestone forest such as *Drosera spatulata* var. *bakoensis*, *Utricularia hirta*, *U. subulata*, *Burmannia* sp. and *Xyris* sp. in sandstone plateau and *Cryptocoryne auriculata* in limestone forest.

Emergent

Most emergent plants were in disturbed habitats, which include either roadside drainage or, marshland and wet rice fields. In the habitat around pond areas, only three species were identified: *Bacopa* sp., *Lindernia* sp., and *Ludwigia leptocarpa*. The rest of the emergent species were found in disturbed areas with direct sunlight in an open region except

for one species *Lasia spinosa*. These species were found in habitats that has minimal sunlight and shady wetlands.

Emergent free-floating

Essentially all species of emerging free-floating lifeforms are dominant in disturbed environments. The habitat of the species is either man-made lakes or highway drainage. Only two species are found in ponds and roadside drains, namely *Salvinia molesta*, *Utricularia aurea* and *U. gibba*. It appeared that emergent free-floating plants require slow-moving water to thrive.

Floating-leaved

One species *Nymphaea nouchalli*, was discovered in the roadside drainage. All floating-leaved plants originate from disturbed environments. These species like still or slowly moving waters and are found in open locations with direct sunlight.

Submerged

The type of forest found for submerge aquatic species are peat swamp forest, mixed dipterocarp forest, and limestone forest. Peat swamp forest and mixed dipterocarp forest dominate the submerged lifeform and usually found in swamps and slow-moving streams. There are a total of four species that are found in peat swamp forest which are *Barclaya motleyi*, *Cryptocoryne lingua*, *C. longicauda* and *C. zadiana* these species are found in peat swamp areas where the water was stagnant. The mixed dipterocarp species found are *Barclaya motleyi*, *Cryptocoryne auriculata*, *C. cordata* var. *zonnata* and *C. striolata*. It appeared that *Barclaya motleyi* can be found thriving in both peat swamp forests and mixed dipterocarp forests. *Cryptocoryne auriculata* is the only species found in Limestone Forest

where it was thriving in small slowing stream at the edge of the limestone cave in Buddhist Shrine, Bau.

Submerged free-floating

A disturbed area of small ponds was where both Submerged free-floating species are found. Usually, these species were found co-existing with some other aquatic plants such as the floating leaved species from the Nymphaeaceae and Menyanthaceae family.

Aquatic marsh

Forest type that the aquatic marsh thrives are mainly from sandstone plateau, peat swamp forest, mixed dipterocarp forest, and disturbed areas. All these habits can be found in marshland or wetlands areas. Wetlands are transitional regions between land and water bodies and are distinguished by the presence of submerged, emergent, or floating plants as well as shallow water overlaying saturated soil (Srivastava et al., 2008). Disturbed areas have the highest number of species found which are *Cyperus* sp., *Eriocaulon* sp., *Fimbristylis polytrichoides*, *Rhynchospora asperula*, *Utricularia bifida*, *U. caerulea*, *U. minutissima*, and *Xyris* sp. Sandstone plateau species are *Drosera spatulata* var. *bakoensis*, *Utricularia hirta*, *U. subulata*, *Burmannia* sp., *U. bifida*, *U. caerulea*, and *U. minutissima*. *Pandanus yvanii* was the only species found in the peat swamp forest. In the mixed dipterocarp forest can only found *Schoenoplectus* sp., *Utricularia bifida*, *U. caerulea* and *U. minutissima*. Some of these species are found in all the various types of forest for the aquatic marsh except peat swamp forest which are *Utricularia bifida*, *U. caerulea*, *U. minutissima* and *Xyris* sp.

Rheophyte

Rheophytes species are exclusive to the mixed dipterocarp forest and are typically found on the rocks of running rivers. These species were discovered in various sites; however, they shared the same environment.

Table 4.4: Type of forest and habitat of 50 aquatic and marsh plant in western Sarawak

Species	Type of forest	Habitat	Herbarium no.
Emergent			
<i>Bacopa</i> sp.	Settlement area	Pond, marshland	UN0004
<i>Ceratopteris thalichoides</i> var. <i>thalichodes</i>	DA	Roadside drainage	UN0061, UN0062, UN0063, UN0064
<i>Pontederia crassipes</i>	DA	Marshland, Wet rice fields	UN0024
<i>Limnocharis flava</i>	Oil Palm Plantation Village	Roadside drainage	UN0047
<i>Lindernia</i> sp.	DA	Marshland, pond	UN0006
<i>Ludwigia adscendens</i>	DA	Roadside drainage	UN0016
<i>Ludwigia leptocarpa</i>	DA, Village	Roadside drainage, Pond	UN0011
<i>Monochoria hastata</i>	DA	Roadside drainage	UN0027
<i>Monochoria vaginalis</i>	DA	Roadside drainage	UN0005
<i>Pandanus helicopus</i>	SF	Swamp	UN0055
<i>Typha angustifolia</i>	DA	Roadside drainage, wet rice fields.	UN0007
<i>Ipomoea aquatica</i>	DA	Marshland, wet rice fields	UN0009
<i>Lasia spinosa</i>	PSF	Peat swamp	UN0035, UN0036
<i>Persicaria attenuata</i> subsp. <i>pulchra</i>	DA	Marshland, wet rice fields	UN0034
Emergent free-floating			
<i>Lemna minor</i>	DA	Pond, Roadside drainage	UN0048
<i>Limnophila</i> sp.	DA	Pond	UN0058

Table 4.4: Continued

<i>Salvinia molesta</i>	DA	Pond, roadside drainage	UN0017
<i>Utricularia aurea</i>	DA	Pond, Roadside drainage	UN0044, UN0045, UN0046
<i>Utricularia gibba</i>	DA	Pond, Roadside drainage	UN0018
Floating-leaved			
<i>Nymphaea lotus</i>	DA	Pond	UN0012
<i>Nymphaea nouchalli</i>	DA	Pond, Roadside drainage	UN0013
<i>Nymphaea pubescens</i>	DA	Pond	UN0014
<i>Nymphoides</i> sp.	Oil Palm Plantation	Pond	UN0059
Submerged			
<i>Barclaya motleyi</i>	PSF, MDF	Peat swamp	UN0019, UN0020
<i>Cryptocoryne auriculata</i>	MDF, LF	Peat swamp, stream	UN0051, UN0032, UN0033
<i>Cryptocoryne cordata</i> var. <i>zonnata</i>	MDF	Stream	UN0050
<i>Cryptocoryne lingua</i>	Riparian	Cultivated	UN0040 UN0041
<i>Cryptocoryne longicauda</i>	PSF	Peat swamp	UN0021
<i>Cryptocoryne striolata</i>	SF	Stream	UN0022
<i>Cryptocoryne zadiana</i>	Riparian	Cultivated	N/A
Submerged free-floating			
<i>Hydrilla verticillata</i>	DA	Pond	UN0008
<i>Ludwigia repens</i>	DA	Pond	UN0010
Aquatic marsh			
<i>Burmannia</i> sp.	SP	Marshland	UN0049
<i>Cyperacea</i> sp.	DA	Marshland	UN0015
<i>Drosera spatulata</i> var. <i>bakoensis</i>	SP	Marshland	UN0052
<i>Eriocaulon</i> sp.	DA	Marshland	UN0003, UN0025
<i>Fimbristylis polytrichoides</i>	DA	Marshland	UN0026

Table 4.4: Continued

<i>Rhynchospora asperula</i>	DA	Marshland	UN0037
<i>Pandanus yvanii</i>	PSF	Peat swamp forest	UN0056
<i>Schoenoplectus</i> sp.	DA	Marshland	UN0060
<i>Utricularia bifida</i>	DA, MDF, SP	Marshland	UN0028
<i>Utricularia caerulea</i>	DA, MDF, SP	Marshland	UN0029, UN0030
<i>Utricularia hirta</i>	SP	Marshland	UN0053
<i>Utricularia minutissima</i>	DA, MDF, SP	Marshland	UN0031
<i>Utricularia subulata</i>	SP	Marshland	UN0054
<i>Xyris</i> sp.	SP, DA, MDF	Marshland	UN0057
Rheophyte			
<i>Bucephalandra</i> sp.	MDF	River	UN0023
<i>Rhynchoyle</i> sp.	DA	River	UN0039, UN0042
<i>Loxocarpus</i> sp.	MDF	River	UN0038
<i>Neonauclea</i> sp.	MDF	River	UN0043

** Notes: Disturbed Area (DA), Swamp Ares (SF), Peat Swamp Forest (PSF), Limestone Forest (LF), Sandstone Plateau (SP), Mixed Dipterocarp Forest (MDF), No information available (N/A)

4.2.2 The Temperature and pH of Water for Aquatic and Marsh Environment

Most plants exhibit a significant ability to “temperature acclimatise,” or modify their photosynthetic traits in response to their growing temperature. To maximise the photosynthetic rate at the growth temperature, the most common scenario involves a change in the ideal temperature for photosynthesis plants that undergo these plastic modifications may be able to photosynthesize more effectively at their new growth temperatures (Yamori et al., 2014). The best indication of whether the temperature is suitable for the plants comes from the plants themselves, while other conditions for good growth must also be met. Only when the other parameters that are essential to the plants are met, can make favourable temperature effective. The growth of the plants will be slowed if the temperature is too low,

and the leaves will fall off. A seed or fruit's early abortion or failure to fertilise can result from structural and functional defects in the reproductive organs caused by cold stress during the reproductive period (Thakur et al., 2010).

Aquatic plants survive in a variety of pH and water temperatures, from acidic to alkaline. The standard pH range is often between 0 and 14, with 7 being neutral. However, pH values below 7 indicate acidity, and pH values over 7 signify alkalinity. The range pH of water for the aquatic species found in western Sarawak was from 3.87 to 9.44 pH while the temperature found was as low as 26.0 °C to 33.0 °C. Each of the lifeform group data was recorded for their pH of water and temperature that has tabulated in Table 4.5. *Monochoria vaginalis* survived in the lowest pH of water in the emergent lifeform which is 4.22-6.35 pH while the temperature is 28-33 °C while the highest from this group is 6.28-6.67 pH (*Ipomoea aquatica*) with temperature 29-33 °C. In the emergent free-floating the most acidic aquatic plant is *Utricularia aurea* which is 4.22-5.5 pH with temperature of 28.0-29.1 °C while the highest is between 6.58-7.0 pH and 27.6-30.0 °C (*Salvinia molesta*).

Floating-leaved and submerged free-floating, mainly were found in the same locality thus having the same pH and temperature of water which are 6.85-7.0 pH and 27.6-28.7 °C there was not much to compare the highest or lowest range. The submerged plant has the widest range pH of water among all the aquatic lifeform which is between 3.87-9.44 pH. The most acidic plant in this group is *Cryptocoryne longicauda* which holds the pH of water from 3.87-4.04 and the temperature of water 26.0-26.3 °C while the alkaline species is *C. auriculata* 6.61-9.44 pH and the temperature is 26.8-27.7 °C.

In the aquatic marsh, the lowest pH of water is between 4.18-4.25 pH in a 25.2-25.3 °C temperature environment, however, there are three plants which share this ecology due to sharing same coordination which are *Drosera spatulata* var. *bakoensis*, *Utricularia hirta*,

and *U. subulata*. All these species were found co-existing with each other sharing the same habitat. Other than that, in the aquatic marsh also consist of an almost neutral pH of water which is *Rhynchospora asperula* from 7.4-7.5 pH in temperature of 31.9 °C. Lastly rheophyte, where *Loxocarpus* sp. was found in a mixed dipterocarp forest where the river holds a pH of water 5.23-5.55 pH which indicates an acidic characteristics while the highest pH of water in this group would be *Neonauclea* sp. and *Rhynchopyle* sp. where these species were found in the same habitat and locality which is 7.32-7.41 pH of water in a 27.2-29.8 °C temperature. It was concluded that *Cryptocoryne longicauda* lives in the most acidic pH of water compared to the other 50 taxa, while *Cryptocoryne auriculata* lives in slightly acidic to alkali pH of water which was 6.61-9.44 pH. The data recorded can be seen in Table 4.5.

Table 4.5: The pH of water and temperature for 50 aquatic plant species in western Sarawak

Species	pH of water	temperature °C
Emergent		
<i>Bacopa</i> sp.	6.58 - 6.67	29.1 - 30.0
<i>Ceratopteris thalichoides</i> var. <i>thalichodes</i>	N/A	N/A
<i>Pontederia crassipes</i>	6.28 - 6.35	32 - 33
<i>Limnocharis flava</i>	6.58 - 6.67	29.1 - 30.0
<i>Lindernia</i> sp.	6.58 - 6.67	29.1 - 30.0
<i>Ludwigia adscendens</i>	N/A	N/A
<i>Ludwigia leptocarpa</i>	6.58 - 6.67	29.1 - 30.0
<i>Monochoria hastata</i>	N/A	N/A
<i>Monochoria vaginalis</i>	4.22 - 6.35	28 - 33
<i>Pandanus helicopus</i>	N/A	N/A
<i>Typha angustifolia</i>	6.28 - 6.35	29.1 - 30
<i>Ipomoea aquatica</i>	6.28 - 6.67	29 - 33
<i>Lasia spinosa</i>	N/A	N/A

Table 4.5: Continued

<i>Persicaria attenuata</i> subsp. <i>pulchra</i>	6.28 - 6.35	32 - 33
Emergent free-floating		
<i>Lemna minor</i>	4.22 - 7.0	27.6 - 29.1
<i>Limnophila</i> sp.	N/A	N/A
<i>Salvinia molesta</i>	6.58 - 7.0	27.6 - 30.0
<i>Utricularia aurea</i>	4.22 - 5.5	28.0 - 29.1
<i>Utricularia gibba</i>	6.58 - 6.67	29.1 - 30.0
Floating-leaved		
<i>Nymphaea lotus</i>	6.85 - 7.0	27.6 - 28.7
<i>Nymphaea nouchalli</i>	6.85 - 7.0	27.6 - 28.7
<i>Nymphaea pubescens</i>	6.85 - 7.0	27.6 - 28.7
<i>Nymphoides</i> sp.	N/A	N/A
Submerged		
<i>Barclaya motleyi</i>	4.35 - 6.43	26.3 - 29.4
<i>Cryptocoryne auriculata</i>	6.61 - 9.44	26.8 - 27.7
<i>Cryptocoryne cordata</i> var. <i>zonnata</i>	7.8 - 8.04	26.9 - 28.1
<i>Cryptocoryne lingua</i>	N/A	N/A
<i>Cryptocoryne longicauda</i>	3.87 - 4.02	26.0 - 26.3
<i>Cryptocoryne striolata</i>	6.31 - 6.43	26.3 - 26.8
<i>Cryptocoryne zadiana</i>	N/A	N/A
Submerged free-floating		
<i>Hydrilla verticillata</i>	6.85 - 7.0	27.6 - 28.7
<i>Ludwigia repens</i>	6.85 - 7.0	27.6 - 28.7
Aquatic marsh		
<i>Burmannia</i> sp.	4.31 - 4.85	25.6
<i>Cyperus</i> sp.	N/A	N/A
<i>Drosera spatulata</i> var. <i>bakoensis</i>	4.18 - 4.25	25.2 - 25.3
<i>Eriocaulon</i> sp.	6.58 - 6.67	29.1 - 30.0
<i>Fimbristylis polytrichoides</i>	N/A	N/A
<i>Rhynchospora asperula</i>	7.4 - 7.5	31.9

Table 4.5: Continued

<i>Pandanus yvanii</i>	N/A	N/A
<i>Schoenoplectus</i> sp.	N/A	N/A
<i>Utricularia bifida</i>	5.3 - 5.4	31.6 - 31.7
<i>Utricularia caerulea</i>	5.3 - 5.4	31.6 - 31.7
<i>Utricularia hirta</i>	4.18 - 4.25	25.2 - 25.3
<i>Utricularia minutissima</i>	5.3 - 5.4	31.6 - 31.7
<i>Utricularia subulata</i>	4.18 - 4.25	25.2 - 25.3
<i>Xyris</i> sp.	4.18 - 4.25	25.2 - 25.3
Rheophyte		
<i>Bucephalandra</i> sp.	N/A	N/A
<i>Rhynchosyche</i> sp.	7.32 - 7.41	27.2 - 29.8
<i>Loxocarpus</i> sp.	5.23 - 5.55	28.8 - 29.4
<i>Neonauclia</i> sp.	7.32 - 7.41	27.2 - 29.8

** Notes: No information available (N/A)

4.2.3 The moisture and pH of soil of aquatic and marsh plant

Testing the pH value of a soil can determine whether it is naturally acidic or alkaline. The right pH is necessary for proper plant development and soil moisture is the amount of water in the soil. The pH of the soil is likely the most helpful parameter for determining soil properties. In a single glance, pH reveals significantly more information about soil than whether it is acidic or basic. Because of their recognised interaction with pH, it is possible to assess the availability of important nutrients and toxicity of other elements (Thomas, 1996).

For many, the chemistry and fertility of soils depend entirely on the pH of the soil. The study of the soil and its features considering wider ecosystem activities through a multidisciplinary approach was necessary, nevertheless, to recognise the functions of soil that go beyond plant nutrient delivery and the role that soil plays as a medium for plant

development (Neina, 2019). In this research not much data of soil pH and moisture were collected due to the habitat, most of the aquatic plant were thriving in the water bodies. Unless emergent and marsh plants where sometimes these species grow along the wetland environment or on the side of water bodies where moisture of soil is high (riparian zone). Among the seven lifeform, emergent free-floating, floating-leaved, submerged free-floating, and rheophytes have no data recorded due to the true aquatic plant species. For emergent aquatic plant, the data taken from the field were from the edges of the pond or marshland nearby. The pH of soil for emergent plant species ranges from 5-6.6 pH and the moisture of soil would be more than 7.

Submerged aquatic plants the lowest pH of soil is *Barclaya motleyi* where the soil is from 4.4 to 6.6 pH and the moisture is more than 7 this species was found in the Mixed dipterocarp forest, and the data taken were at the edge of the stream. *Cryptocoryne auriculata* pH of soil is slightly acidic towards neutral compared to *Barclaya motleyi*, the pH of soil is 6.6-6.8 pH while the moisture is lower when compared which is 3.0-55 moisture. Other than that, the aquatic marsh lifeform pH of soil and moisture were also taken.

The lowest pH of soil recorded was 5.6-6.2 pH and the moisture of soil is very low compared to all the soil moisture of aquatic plant species in western Sarawak which is 1.0-1.5 moisture. This species where the data was recorded were *Fimbristylis polytrichoides*. Lastly, the pH of soil taken was from the *Utricularia* genus where a total of three species recorded having the same data due to always co-exist together which were *Utricularia bifida*, *U. minutissima* and *U. caerulea*. These species thrive in slightly acidic soils which were approximately from 6.3-6.8 pH and the moisture was from 5.0 and 6.5.

4.3 Morphological and Palynological Characteristics of Aquatic and Marsh Plants

There are a total of seven habit lifeforms found in the aquatic plant which are emergent, free-floating, emergent free-floating, submerged, submerged free-floating, marsh plant, and rheophytes. The seven type of habits were illustrated in Figure 4.12 that was modified from Tanaka et al. (2019) diagram of aquatic plant lifeforms. All the species elaborated and mentioned can be observed below in Table 4.6 where the data were tabulated and recorded according to their lifeform group. The species examined can be observed in Appendix 3.

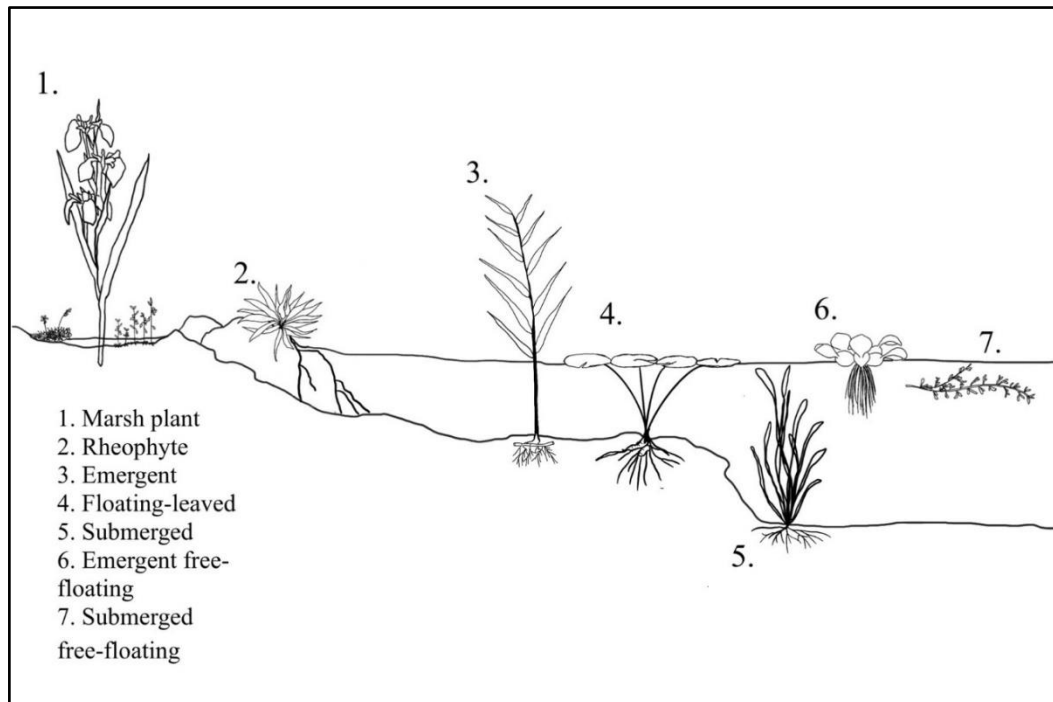


Figure 4.12: The lifeform of aquatic and marsh plants in western Sarawak

4.3.1 Morphology

4.3.1.1 Species characteristics

Emergent

Emergent plant roots in the three division found were predominantly rhizome, stoloniferous, or a combination of the two which is stoloniferous rhizome. A total of four species each falls into the stoloniferous and rhizomes root category, and three species which is a combination of both (stoloniferous rhizomes) . Two species recorded that have a virgate characteristics for the stem and roots which are *Ceratopteris thalichoides* var. *thalichoides* and *Ludwigia leptocarpa*. Though, *Pandanus helicopus* was the only species in the emergent group that has pneumatophores characteristics as roots. Pneumatophores are specialised root structures that extend from the water's surface and allow the essential aeration for root respiration in hydrophytic plants, such as many mangrove species (Berlyn et al., 2023).

Emergent free-floating

Nearly all the species roots with emergent free-floating habits has a stoloniferous roots except for *Lemna minor* and *Salvinia molesta* where the characteristic was rosette. The roots of the *Utricularia* species were surprisingly difficult to identify. *Utricularia* species (bladderworts) are among the most intriguing carnivorous plants due to their tiny traps and obvious lack of roots (Juniper et al., 1989). The body structure of *Utricularia* lacks well defined boundaries between typical plant organs (such as stems and leaves) or visible roots (Rutishauser & Isler, 2001). As for the leaf shape, *Lemna minor* and *Salvinia molesta* has an oblong shaped leaf while both *Utricularia aurea* and *U. gibba* have linear filiform leaves. The *Utricularia* leaves sometimes might be mistaken with roots as mentioned before.

Limnophila sp. was the only species found with a pinnatisect leaf characteristic for this group. The flowers for this species were predominantly zygomorphic and all the species are solitary.

Floating-leaved

Occasionally the flowers will protrude slightly above the water. The roots type for floating leaves found are all stoloniferous rhizome whereas it is a combination stolon and rhizomes. A stolon is a horizontally growing above-ground stem that produces a daughter plant (ramets or clonal plants) at the end, and is also referred to as a runner. While rhizomes are modified stems that grow horizontally, except that they develop underground (Guo et al., 2021). Mostly the *Nymphaea* species have all circular shape for their leaves on the contrary the *Nymphoides* sp. have a widely depressed ovate leaf shape. The inflorescence of floating leaved the ones were found were all solitary, it is rarely to found the floating leaved species having other characteristics other than solitary and the type of flowers found were all actinomorphic in the floating-leaved lifeform.

Submerged

Only *Barclaya motleyi* species was stoloniferous rhizome while all the cryptocoryne species had stolons as stem. The leaves shape for each species were different where *Barclaya motleyi* had an orbicular shape; *Cryptocoryne auriculata* had a slightly ovate-rhombic; *C. cordata* var. *zonnata* had a cordate shape leaf; *C. lingua* and *C. longicauda* had an ovate shape leaf except *C. lingua* is slightly lingular and *C. striolata* leaf shape were ovate. The inflorescence of submerged species were all solitary and for *Barclaya motleyi*, the type of flower is actinomorphic, for *Cryptocoryne* genus flowers were zygomorphic.

Submerged free-floating

These plants typically lack of roots. The submerged free floating found as mentioned before were *Ludwigia repens* and *Hydrilla verticillata*. Both of these plants have stoloniferous roots as characteristics. However their leaf shape are very much different where *Hydrilla verticillata* have a linear leaves while *Ludwigia repens* have more like an ovate shaped.

Aquatic marsh plant

Many tropical and subtropical marsh plants exhibit common adaptations to the cyclical change of rain-intensive and rain-deficient seasons, whether they are living in permanent waters or in flood zones of stagnant or rushing waters (Kasselmann, 2003). Other aquatic plants colonise the zone where water and land meet; they are commonly known as marsh plants and they grow on damp soil along the borders of the water or in shallow water such that shoots and leaves form in the air. Some marsh plants can endure brief periods of drought in their ecosystem, while others may adapt to being submerged (Muhlberg, 1982). The aquatic marsh plant there are a total three type of roots characteristic which were rosette, virgate and caespitose. Total number of rosette root are eight species, six species have caespitose roots and only one species have a virgate characteristics of roots which is *Pandanus yvanii*. All of the characteristics was tabulated and recorded in Table 4.6. There are five types of leaf shapes in the marsh group which are lanceolate, linear, spatulate, linear subulate and linear-lanceolate. The majority of leaves shape in the marsh lifeform group were linear leaves shape where a total of nine species recorded. While the remaining shape of leaf have one species in each type of leaf shape. As for their inflorescence there were three type of inflorescence arrangement recorded: umbel, cymes and solitary. The majority of inflorescence were solitary, whereas cymes and umbel only include one species

each: umbel, *Burmannia* sp., and cymes, *Drosera spatulata* var *bakoensis*. In the marsh plant lifeform, five species have zygomorphic flowers and three have actinomorphic flowers.

Rheophyte

Rheophytes are plants species that are native to the beds of swift-moving streams and rivers and grow there up to the flood level, but not beyond the reach of recurrent floods (Casper & van Steenis, 1981). Their most notable adaptations are their leaf forms; rheophytes typically have narrow, willow-like leaves that appear to give little resistance to water flowing over them, allowing them to survive flooding with minimal harm (Dransfield, 1992). Majority of the roots found for rheophyte plants are rhizomes where the roots were anchored to the rocks in or near the river streams. mentioned before by Dransfield the leaves are typically narrow, the species found in Sarawak have various shapes but narrow in size thus, the statement given was agreeable. The *Bucephalandra* sp. had a narrowly rhombic leaf shape while *Rhynchosyris* sp. leaf shape was narrowly frullate-lanceolate. However, *Neonauclea* sp. had an obovate shape for the leaves and *Loxocarpus* sp. was narrowly obtrulate. The inflorescence in these species were solitary though there were no sight of the *Neonauclea* sp. inflorescence during the field survey. The flowers for all the species in this lifeform were all zygomorphic.

Table 4.6: The species characteristics of 50 taxa found in western Sarawak

Species / Characteristics	Roots	Leaf shape	Inflorescence	Flower
Emergent				
<i>Bacopa</i> sp.	Stoloniferous	Very widely ovate	Solitary	Actinomorphic
<i>Ceratopteris thalichoides</i> var. <i>thalichodes</i>	Virgate	Bipinnate / Oblique	-	-
<i>Pontederia crassipes</i>	Stoloniferous rhizome	Ovate	Raceme	Zygomorphic
<i>Limnocharis flava</i>	Stoloniferous	Widely ovate	Umbel	Actinomorphic
<i>Lindernia</i> sp.	Stoloniferous	Widely ovate	Solitary	Zygomorphic
<i>Ludwigia adscendens</i>	Stoloniferous rhizome	Oblong- ovate	Solitary	Actinomorphic
<i>Ludwigia leptocarpa</i>	Virgate	Broadly lanceolate	Solitary	Actinomorphic
<i>Monochoria hastata</i>	Rhizomes	Triangular ovate	Raceme	Actinomorphic
<i>Monochoria vaginalis</i>	Rhizomes	Elliptic-ovate	Raceme	Actinomorphic
<i>Pandanus helicopus</i>	Pneumatophores	Lanceolate-linear	Raceme	-
<i>Typha angustifolia</i>	Stoloniferous rhizome	Linear	-	-
<i>Ipomea aquatica</i>	Stoloniferous	Lanceolate arrowhead	Solitary	Actinomorphic
<i>Lasia spinosa</i>	Rhizomes	Deltate	-	-
<i>Persicaria attenuata</i> subsp. <i>pulchra</i>	Rhizomes	Lanceolate	-	-
Emergent free-floating				

Table 4.6: Continued

<i>Lemna minor</i>	Rosette	Oblong	-	-
<i>Limnophila</i> sp.	-	Pinnatisect	-	-
<i>Salvinia molesta</i>	Stoloniferous	Oblong	-	-
<i>Utricularia aurea</i>	Stoloniferous	Linear filiform	Solitary	Zygomorphic
<i>Utricularia gibba</i>	Stoloniferous	Linear filiform	Solitary	Zygomorphic
Floating-leaved				
<i>Nymphaea lotus</i>	Stoloniferous rhizomes	Circular	Solitary	Actinomorphic
<i>Nymphaea nouchalli</i>	Stoloniferous rhizomes	Circular	Solitary	Actinomorphic
<i>Nymphaea pubescens</i>	Stoloniferous rhizomes	Circular	Solitary	Actinomorphic
<i>Nymphoides</i> sp.	Stoloniferous	Widely depressed ovate	Solitary	Actinomorphic
Submerged				
<i>Barclaya motleyi</i>	Stoloniferous rhizomes	Orbicular	Solitary	Actinomorphic
<i>Cryptocoryne auriculata</i>	Stoloniferous	Slightly ovate-rhombic	Solitary	Zygomorphic
<i>Cryptocoryne cordata</i> var. <i>zonnata</i>	Stoloniferous	Cordate	-	-
<i>Cryptocoryne lingua</i>	Stoloniferous	Ovoid-lingular	-	-
<i>Cryptocoryne longicauda</i>	Stoloniferous	Ovoid	Solitary	Zygomorphic
<i>Cryptocoryne striolata</i>	Stoloniferous	Ovate	-	-
<i>Cryptocoryne zadiana</i>	-		-	-

Table 4.6: Continued

Submerged free-floating				
<i>Hydrilla verticillata</i>	Stoloniferous	Linear	-	-
<i>Ludwigia repens</i>	Stoloniferous	Ovate	-	-
Aquatic marsh				
<i>Burmannia</i> sp.	Rosette	Lanceolate	Umbel	Actinomorphic
<i>Cyperus</i> sp.	Caespitose	Linear	-	-
<i>Drosera spatulata</i> var. <i>bakoensis</i>	Rosette	Spathulate	Cymes	Actinomorphic
<i>Eriocaulon</i> sp.	Caespitose	Linear	-	-
<i>Fimbristylis polytrichoides</i>	Caespitose	Linear	-	-
<i>Rhynchospora asperula</i>	Caespitose	Linear	-	-
<i>Pandanus yvanii</i>	Virgate	Lanceolate -linear	-	-
<i>Schoenoplectus</i> sp.	Caespitose	Linear	-	-
<i>Utricularia bifida</i>	Rosette	Linear	Solitary	Zygomorphic
<i>Utricularia caerulea</i>	Rosette	Spatulate	Solitary	Zygomorphic
<i>Utricularia hirta</i>	Rosette	Linear	Solitary	Zygomorphic
<i>Utricularia minutissima</i>	Rosette	Linear	Solitary	Zygomorphic
<i>Utricularia subulata</i>	Rosette	Linear	Solitary	Zygomorphic
<i>Xyris</i> sp.	Rosette	Linear-subulate	Solitary	Actinomorphic

Table 4.6: Continued

Rheophyte				
<i>Bucephalandra</i> sp.	Rhizome	Narrowly Rhombic	Solitary	Zygomorphic
<i>Rhynchopyle</i> sp.	Rhizome	Narrowly frullate- lanceolate	-	Zygomorphic
<i>Loxocarpus</i> sp	Rhizome	Narrowly obtrullate	Solitary	Zygomorphic
<i>Neonuclea</i> sp.	-	Obovate	-	-

** Notes: No data applied for (-)

4.3.1.2 Leaf characteristic

Leaf characteristics are important because the shape of leaves is mostly a result of the anatomical and physiological adaptations plants use to survive in their habitats, and it is a component of the natural inventory of plant biodiversity (Lowe, 2017). Table 4.7 showed that the leaf morphology of aquatic and marsh species is extremely diverse and varied. Each of the lifeform group have their own characteristics of leaf whether its liner, rounded or lanceolate in shape or arrangement. All the data were tabulated in Table 4.7. The largest area of leaves was *Pandanus helicopus* while the smallest is *Utricularia minutissima*.

Emergent

Leaves arrangement that was found in the emergent lifeform have five types of arranged which were opposite, alternate, whorled, equitant, and spiral. But some of these characteristics were diversified or combined with some other characteristics. The opposite species were *Bacopa* sp. and *Lindernia* sp. As for *Bacopa* sp. the arrangement is opposite but slightly decussate. Next alternate, there are a total of six species that were arranged in this form which were *Ceratopteris thalichoides* var. *thalichoides*, *Limnocharis flava*, *Ludwigia adscendens*, and *Ludwigia leptocarpa*. However, for *Limnocharis flava*, the arrangement is alternate-distichous and *Ludwigia leptocarpa* is alternate-spiral. The *Pontederia crassipes* was the only species arranged in whorled form. Three species were arranged in equitant form which where two species were from the Pontederiaceae family (*Monochoria hastata* and *M. vaginalis*) and one species which was *Typha angustifolia*. The *Pandaus helicopus* were spirally arranged in 3 ranks. *Cryptocoryne* encomposes cataphyll, such sheaths also serve the purpose of temporarily enclosing and protecting the subsequent young leaves (Muhlberg, 1982).

Emergent free-floating

In the emergent free-floating, the arrangements are whorled, alternate, and folded and compactly arranged. Two species that were arranged in whorled were *Lemna minor* and *Limnophila* sp., though the *Limnophila* sp. characteristics were slightly different where the leaves were whorled and opposite. Two *Utricularia* species in this form were alternately arranged. The arrangement of leaves in *Salvinia molesta*, where the leaves of these species are somewhat complex, where it is folded and compactly arranged. Most of these species have acute apex while the remaining apex type were obtuse and truncate/emarginate. The base of the species is mainly sessile, segmented, and cuneate.

Floating-leaved

Almost all the floating leaves were organized in whorls, with only one species, *Nymphoides* sp., arrayed in alternate spirals. The leaves apex for the floating leaves were all rounded while the base was peltate except for *Nymphoides* sp. where the base is sagittate.

Submerged

All submerged plant species were grouped in whorls. Except for *Cryptocoryne striolata*, whose apex is acuminate, the majority of *Cryptocoryne* discovered had leaves with an acute apex, but *Barclaya motleyi* has a rounded apex. In the submerged habit, there are two varieties of leaf base: cordate and cuneate. The bases of *Cryptocoryne auriculata* and *Cryptocoryne lingua* are subcordate, whilst the bases of the remaining species are cordate.

Submerged free-floating

Species from both submerged free-floating have a different arrangement and base of leaf which are *Hydrilla verticillata* whorled leaf arrangement and the base is sessile while *Ludwigia repens*, opposite decussate and the base attachment is attenuate. However, both species share the same characteristics for their apex, acute.

Aquatic marsh

The aquatic marsh species are very diversified where there was a total of 14 species where the arrangement of leaves was mainly spiral, alternate and rosette. Spirally arranged are the highest type of leaf arrangement in the aquatic marsh form, second is alternately arranged. However, one species (*Burmannia* sp.) where the leaf arrangement was a combined of both alternately spiral. Only one species was arranged in rosette which is *Eriocaulon* sp., and one species have 3-ranked arrangement which was *Pandanus yvanii*. In the aquatic marsh, the varieties of leaf apex are acute, acuminate, rounded, caudate, and falcate. An acute and rounded type of apex predominates in these habits. The types of leaf base discovered were sessile, cordate, sagittate petiolate, and obtuse. However, a total of nine species of sessile base were detected in this life form.

Rheophytes

Rheophytes have three types of arrangement which are whorled, spiral, and opposite decussate. The two species that have whorled arrangement are *Bucephalandra* sp. and *Loxocarpus* sp. While *Rhynchosyris* sp. leaves are arranged spirally and *Neonauclea* sp. were arranged in opposite decussate. There are four types of leaf apex for each species which are acuminate-acute, apiculate, acute-falcate, and cuspidate-mucronate. Though there are only two types of leaf base found which are cuneate and attenuate.

According to Muhlberg (1982) numerous leaf characteristics and leaf shapes exist. Although alternating leaf arrangements is uncommon in aquatic plants, it does exist in a few species. In this research, a total of 15 species found that the leaves arrangement is in alternating position which can be seen in Table 4.7.

Table 4.7: The leaf arrangement, apex, base and measurement of 50 taxa of aquatic and marsh plant in western Sarawak.

Species / Characteristics	Leaf arrangement	Apex	Base	Measurement (cm)	
				Length	Breadth
Emergent					
<i>Bacopa</i> sp.	Opposite decussate	Rounded	Sessile	0.693 - 0.751	0.555 - 0.660
<i>Ceratopteris thalichoides</i> var. <i>thalichodes</i>	Alternate	Obtuse	Oblique	15 - 30	1.5 - 5
<i>Pontederia crassipes</i>	Whorled	Acute	Rounded	4 - 11	3.5 - 9
<i>Limnocharis flava</i>	Alternate-distichous (equitant)	Mucronate	Attenuate	22 - 26	13 - 20
<i>Lindernia</i> sp.	Opposite	Acute	Sessile	-	-
<i>Ludwigia adscendens</i>	Alternate	Acute	Attenuate	0.4 - 10	0.7 - 4.0
<i>Ludwigia leptocarpa</i>	Alternate-spiral	Slightly acuminate	Cuneate	1.1 - 9.7	4.11 - 11.39
<i>Monochoria hastata</i>	Equitant	Attenuate	Sagittate	22 - 26	17 - 20
<i>Monochoria vaginalis</i>	Equitant	Attenuate	Hastate – cordate	3 - 8	1.4 - 4.5
<i>Pandanus helicopus</i>	Spirally arranged in 3 ranks	Acuminate	Truncate	230	5
<i>Typha angustifolia</i>	Equitant	Mucronate	Sheathing (sessile)	82 - 210	0.54 - 1.01
<i>Ipomoea aquatica</i>	Alternate	Acuminate	Cordate	5 - 15	2 - 6
<i>Lasia spinosa</i>	Alternate	Caudate	Sagittate	15.0 - 33.0	5.5 - 12
<i>Persicaria attenuata</i> subsp. <i>pulchra</i>	Alternate	Acuminate	Obtuse	4.8 - 9.5	0.8 - 1.6
Emergent free-floating					
<i>Lemna minor</i>	Whorled	Obtuse	Sessile	0.5 - 1.0	0.5 - 0.8
<i>Limnophila</i> sp.	Whorled opposite	Acute	Sessile	0.5 - 1.0	0.16 - 0.22
<i>Salvinia molesta</i>	Folded and compactly arranged	Truncate / emarginate	Cuneate	1.6 - 2.3	0.325 - 0.574

Table 4.7: Continued

<i>Utricularia aurea</i>	Alternate	Acute	Segmented	1 - 1.5	-
<i>Utricularia gibba</i>	Alternate	Acute	Segmented	1 - 1.5	-
Floating-leaved					
<i>Nymphaea lotus</i>	Whorled	Rounded	Peltate	18.0 - 22.5	15 - 21.5
<i>Nymphaea nouchalli</i>	Whorled	Rounded	Peltate	18 - 26	17 - 25
<i>Nymphaea pubescens</i>	Whorled	Rounded	Peltate	24 - 28	20.0 - 27.0
<i>Nymphoides</i> sp.	Alternate spiral	Rounded	Sagittate	8.8 - 10	8.8 - 10
Submerged					
<i>Barclaya motleyi</i>	Whorled	Rounded	Cordate	1.4 - 9.0	1.4 - 9.3
<i>Cryptocoryne auriculata</i>	Whorled	Acute	Subcordate	2.6 - 7.0	1.4 - 2.65
<i>Cryptocoryne cordata</i> var. <i>zonnata</i>	Whorled	Acute	Cordate	2.8 - 19	2.0 - 5.5
<i>Cryptocoryne lingua</i>	Whorled	Acute	Cuneate	2 - 7	1 - 3.5
<i>Cryptocoryne longicauda</i>	Whorled	Acute	Cordate	3.2 - 15	1.2 - 8.5
<i>Cryptocoryne striolata</i>	Whorled	Acuminate	Cordate	5.2 - 5.7	1.3 - 2.5
<i>Cryptocoryne zadiana</i>	Whorled	N/A	N/A	N/A	N/A
Submerged free-floating					
<i>Hydrilla verticillata</i>	Whorled	Acute	Sessile	0.1 - 1.5	0.003
<i>Ludwigia repens</i>	Opposite decussate	Acute	Attenuate	0.587 - 1.422	0.193 - 0.458
Aquatic marsh plant					
<i>Burmussia</i> sp	Alternate spiral	Acute	Sessile	2.0 - 5.0	0.14 - 0.465
<i>Cyperacea</i> sp.	Spirally	Acuminate	Sessile	25 - 78	0.51 - 2
<i>Drosera spatulata</i> var. <i>bakoensis</i>	Spirally	Rounded	Sessile	1.5 - 4	0.2 - 1.0

Table 4.7: Continued

<i>Eriocaulon</i> sp.	Rosette	Acute	Sessile	1.5 - 5.5	0.145 - 0.335
<i>Fimbristylis polytrichoides</i>	Spirally	Acute	Sessile	3.0 - 9.5	1.10 - 2.70
<i>Rhynchospora asperula</i>	Spirally	Acute	Sessile	65	0.8 - 1.0
<i>Pandanus yvanii</i>	Spirally arranged in 3 ranks	Falcate	Sessile	10 - 62	1.6 - 2.0
<i>Schoenoplectus</i> sp	Spirally	Acuminate	Sessile	-	-
<i>Utricularia bifida</i>	Alternate	Rounded	Petiolate	0.43 - 0.29	0.06 - 0.04
<i>Utricularia caerulea</i>	Alternate	Rounded	Petiolate	0.1 - 0.4	0.08 - 0.04
<i>Utricularia hirta</i>	Alternate	Rounded	Petiolate	-	-
<i>Utricularia minutissima</i>	Alternate	Rounded	Petiolate	0.56 - 0.08	0.05 - 0.03
<i>Utricularia subulata</i>	Alternate	Rounded	Petiolate	-	-
<i>Xyris</i> sp.	Spirally	Acuminate	Sessile (sheathing)	2.3 - 3.5	0.07 - 0.155
Rheophyte					
<i>Bucephalandra</i> sp.	Whorled	Acuminate- acute	Cuneate	3.5 - 10	1.5 - 4.0
<i>Rhynchopyle</i> sp.	Spirally	Apiculate	Cuneate-assymetrical	5.0 - 11.5	1.1 - 3.0
<i>Loxocarpus</i> sp.	Whorled	Acute (slightly falcate)	Attenuate	3.7 - 5.8	0.3 - 0.6
<i>Neonauclea</i> sp.	Opposite decussate	Cuspidate-mucronate	Attenuate-cuneate	6.0 - 15.0	2.5 - 5.5

** Notes: No data applied (-)

4.3.1.3 Species examined

4.3.1.3.1 Key to families

- 1a. Non-angiosperm group, Tracheophytes-----2
- 1b. Angiosperm group, Monocotyledon or Dicotyledon-----3
- 2a. Aquatic fern, fronds usually long and broad with bristly surface cased by the hair-like strands-----Salviniaceae
- 2b. Aquatic or subaquatic fern, fronds erect and stipitate with 2-3 pinnatifid, sporangia solitary and scattered along the veins-----Parkeriaceae
- 3a. Monocotyledon, the count of parts of the flower is a multiple of three or equal to three--
-----4
- 3b. Dicotyledon, the count of parts in a dicot flower is a multiple of four or five or equal to four or five -----14
- 4a. Non- aquatic herbs, water plants rooting in mud, trees, lianas-----5
- 4b. Aquatic herbs, herbs, or shrubs-----6
- 5a. Leaves floating on water, circular or almost circular, split at base-----
-----Nymphaeaceae
- 5b. Leaves alternate or spiral or tristichous or four ranked (rarely), linear or lanceolate, sessile at base-----Pandanaaceae
- 6a. Flower usually sepal and petal-----7
- 6b. Flower usually tepal or spadix-----9

- 7a. Flower, unequal sepal but not bilabiate, persistent; petal usually three in yellow (usually), white, blue-----Xyridaceae
- 7b. Flower, three or two sepals; petal three or two in white, pink, purple, occasionally yellow, or purple spots-----8
- 8a. Leaves, non-sheathing; stamen 3,6,9 or numerous-----Alismataceae
- 8b. Leaves, sheathing; stamen 2, or 4, or 3, or 6-----Eriocaulaceae
- 9a. Inflorescence, spikelet-----10
- 9b. Inflorescence, cymose or racemes-----11
- 10a. Flower, almost always surrounded by a modified leaf called spathe-----
-----Araceae
- 10b. Flower, solitary, or 1-50 in spikelet often numerous in branched paniculate-----
-----Cyperaceae
- 11a. Leaf base, sessile-----12
- 11b. Leaf base, petiolate-----Pontederiaceae
- 12a. Stamen 3 or more-----13
- 12b. Stamen one only-----Hydrocharitaceae
- 13a. Ovary, partly inferior; seed non-fleshy, dehiscent capsule-----
-----Burmanniaceae
- 13b. Ovary, superior; seed non fleshy dehiscent carpel-----Typhaceae

14a. Herbs, shrubs, twinning herbs or woody veins-----	15
14b. Non-herbs, water plants, trees-----	16
15a. Leaves floating on water, broadly ovate to subcordate-----	Menyanthaceae
15b. Leaves simple, opposite with interpetiolar stipules-----	Rubiaceae
16a. Flowers irregular-----	17
16b. Flower regular-----	19
17a. Petals more than 4 -----	18
17b. Petals 2-lipped and spurred-----	Lentibulariaceae
18a. Fruits usually capsule sometimes berry like-----	Gesneriaceae
18b. Fruits capsule, dehiscence septicidal, or irregular-----	Linderniaceae
19a. Inflorescence in cymose or racemose-----	20
19b. Inflorescence in spikes -----	21
20a. Sepals 4 persistently in fruits, stamen 4 with large anthers-----	Plantaginaceae
20b. Sepals 3-5 petal like and colourful, stamen usually 8-----	Polygonaceae
21a. Leaves simple, alternate, opposite, and without stipule-----	22
21b. Leaves simple, spiral with glandular tentacles-----	Droseraceae
22a. Sepals usually 5, calyx often persist around the fruit; ovary superior-----	
-----	Convolvulaceae

22b. Sepals tube usually 3-6; ovary inferior immersed in the calyx tube and joined to it throughout its length-----Onagraceae

4.3.1.3.2 **Dicotyledon**

A. Lentibulariaceae

General description: Herbs growing in water or in damp places; leaves in submerged species finely cut into many segments, in other species small, round or narrow and crowded; flowers irregular, borne in upright usually unbranched spikes, calyx with 2-5 usually unequally sepals, corolla 2-lipped and spurred, the lower lip larger, undivided or divided into 2-5 petals, stamens 2, arising from near the bottom of the corolla tube, ovary superior, fruit a capsule.

Figure 4.13 showed the Lentibulariaceae found.

Species collected and examined:

1. *Utricularia aurea* Lour
2. *Utricularia gibba* L.
3. *Utricularia caerulea* L.
4. *Utricularia minutissima* Vahl.
5. *Utricularia bifida* L.
6. *Utricularia hirta* Klien ex Link
7. *Utricularia subulata* L.

Distributions: East campus lake, UNIMAS; UITM Samarahan roadside; Jalan Atro-gedong, Simunjan; Jalan Haji Taha Bako National Park; Bako National Park, Kuching; Kubah National Park, Kuching; Matang-Sempadi roadside, Kuching; Lundu, Kuching; Stenggang-Bau roadside, Kuching; Samunsam Wildlife Sanctuary roadside, Kuching.

Field key to *Utricularia* species from western Sarawak:

1. Corolla yellow, upper lip bilobed or broadly ovate -----2

- Corolla not yellow, upper lip bilobed or narrowly oblong-----5
2. Bracteoles absent, bract basifixed or basisolute-----3
- Bracteoles present, bract basifixed -----4
3. Bract basifixed, spur parallel and shorter than lower corolla ----- *U. gibba*
- Bract basisolute, spur subulate and narrowly cylindrical ----- *U. subulata*
4. Corolla upper lip bilobed----- *U. bifida*
- Corolla upper lip broadly ovate ----- *U. aurea*
5. Corolla upper lip bilobed ----- *U. caerulea*
- Corolla upper lip narrowly oblong----- 6
- 6 Calyx pubescent, densely covered with long to short multicellular hairs-----
- *U. hirta*
- Calyx not pubescent, glabrous ----- *U. minutissima*

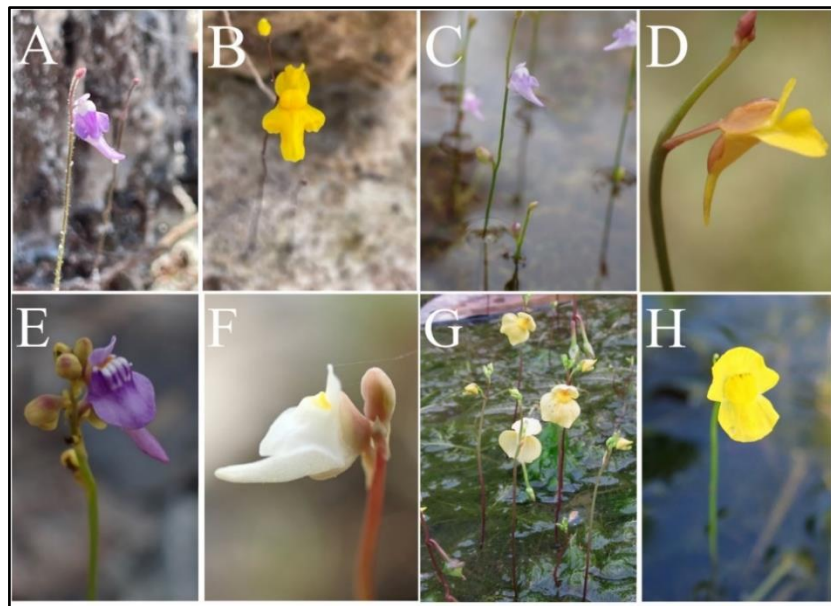


Figure 4.13: Lentibulariaceae, the species from genus *Utricularia* found in western Sarawak, species A and B were found in Bako NP, species C, D, F, and H were found in UNIMAS while species E was taken in Matang-Sempadi roadside while G was taken in jalan Atro-Gedong A. *Utricularia hirta*. B. *U. subulata*. C. *U. minutissima*. D. *U. bifida*. E and F. *U. caerulea*. G. *U. aurea*. H. *U. gibba*.

Notes: This species is called bladderworts characterized by their tiny bladder or traps, which they use to capture small aquatic invertebrates such as protozoans, water fleas, and mosquito larvae. Figure 4.13 shows the species of *Utricularia* found in western Sarawak. Many species of *Utricularia* are popular among horticulturists, and they are grown as ornamental plants in aquaria or bog gardens. Additionally, some species are used in traditional medicine to treat a variety of ailments, including respiratory infections, infections, digestive disorders, and skin conditions.

B. Convolvulaceae

General description: usually twinning herbs or woody vines, usually with milky latex in the tissues, leaves alternate, simple, without stipules; flowers regular, often large and showy, calyx of 5, usually free, calyx which often persists around the fruit, corolla trumpet or funnel-shaped with usually 5 short, spreading petals or sometimes the petals long, stamens 5, their stalks arising from near the base of the corolla tube, ovary superior; fruit sometimes a capsule, sometimes a berry.

Species collected and examined: *Ipomoea aquatica* Forssk.

Distribution: Near summer mall roadside, Kota Samarahan; East campus, UNIMAS, Kota Samarahan.

Notes: Figure 4.14 depicts the species of *Ipomoea aquatica* discovered. Many members of this family are popular ornamental plants with useful medical benefits. This is known as water spinach or kangkong and cultivated as a leafy vegetable.

C. Droseraceae

General description: small herbs with glandular tentacles on the simple, spirally arranged leaves; flowers regular, rather small, in upright spikes, sepals 5 joined only at the base, petals

5, free, stamens 5, ovary superior, fruit a capsule opening by valves and containing many seeds.

Species collected and examined: Drosera spatulata Labill. var. *bakoensis* A. Fleischm. & Chi C. Lee

Distribution: Bako National Park, Kuching

Notes: The leaves of the *Drosera spatulata* subspecies are spatula-shaped, and the tips feature crimson tentacles that exude sticky mucilage that traps insects. *Drosera* species are fascinating plants because of their carnivorous nature and unique insect catching methods. Figure 4.15 exhibits *Drosera spatulata* var. *bakoensis* found at Bako NP. They are popular among hobbyist who grow them for their beauty and distinctive development patterns.

D. Menyanthaceae

General characteristics: Water plants rooting in mud with submerged, cylindrical stems, leaves floating broadly ovate to subcordate, base cordate; flowers many and clustered at nodes, yellow or white. Floating on the water surface. Sepals 5, petals 5, stamens 5; ovary superior or partly inferior; fruits fleshy or non-fleshy berry-like or capsule, seeds many.

Species collected and examined: Nymphoides sp.

Distribution: Sungai Paon Gahat, Kampung Melaban.

Notes: *Nymphoides* species are widely used in aquariums and water gardens due to their attractive appearance and easy maintenance. Khan et al. (2018) report that Unani medicine, Asarun (Asarum), and many pharmaceuticals use it to treat brains and nervous systems diseases such migraine, insomnia, anxiety, and epilepsy. *Nymphoides* species cure anaemia, jaundice, and asthma. Figure 4.16 shows the *Nymphoides* sp.

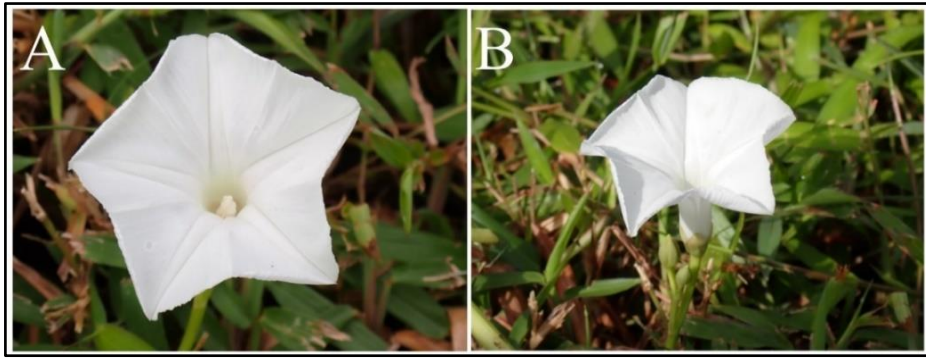


Figure 4.14: Convolvulaceae, from the genus *Ipomoea*. A. and B. *Ipomoea aquatica* found in Samarahan division.

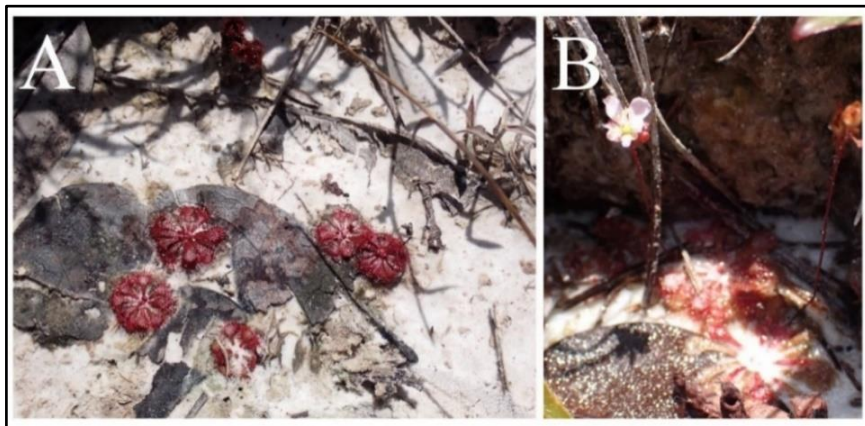


Figure 4.15: Droseraceae, from the genus *Drosera*. A. *Drosera spatulata* var. *bakoensis* in the habit of Bako NP sandstone plateau. B. the inflorescence of *D. spatulata* var. *bakoensis*.



Figure 4.16: Menyanthaceae from the genus *Nymphoides*. A. Inflorescence, *Nymphoides* sp. B. *Nymphoides* sp. in its habit in Sungai Paon Gahat, Kampung Melaban

E. Onagraceae

General description: Herbs, leaves opposite or alternate, simple; flowers usually solitary in the leaf axils, regular, usually yellow, sometimes white, calyx tube with 3-6 sepals, ovary immersed in the calyx tube and joined to it throughout its length, petals 3-6 from the edge of the calyx tube, stamens as many as petals, or twice as many, ovary inferior, fruit a capsule, usually opening lengthwise, or breaking up irregularly, seeds many.

Species collected and examined:

1. *Ludwigia adscendens* (L.) H. Hara
2. *Ludwigia leptocarpa* (Nutt.) H. Hara
3. *Ludwigia repens* J.R. Forst.

Key to *Ludwigia* species from western Sarawak:

1. Leaves opposite-----*Ludwigia repens*
Leaves alternate-----2
2. Corolla usually yellow, growth habit upright-----*L. leptocarpa*
Corolla usually white, growth habit creeping-----*L. adscendens*

(Related to aquatic plant)

Distribution: Klinik Kota Samarahan roadside, Samarahan; East campus UNIMAS, Samarahan; Samunsam Wildlife Sanctuary, Kuching; Kampung Bogag, Bau, Kuching.

Notes: Several *Ludwigia* species are popularly referred to as water primroses and are popular as decorative plants in ponds and aquariums. Figure 4.17 depicts the *Ludwigia* species found in western Sarawak. This species is also used in traditional medicine for its medicinal characteristics to cure a variety of diseases such as inflammation, fever, and liver disorders.

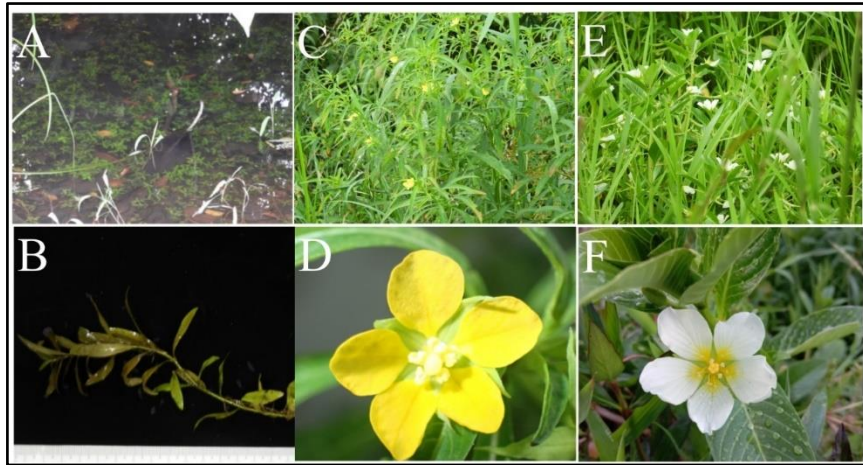


Figure 4.17: Onagraceae, from the genus *Ludwigia*, A, C, and E are the species found in its habit. A and B. *Ludwigia repens*. C and D. *L. leptocarpa*. E and F. *L. adscendens*.

F. Plantaginaceae

General description: Herbs; leaves usually in a rosette from the base of stem; flowers regular, small, greenish, in long spikes, sepals 4, persisting in fruit. Corolla papery, shortly tubular with 4 short spreading petals, stamens 4 with large anthers, ovary superior, fruit a capsule, splitting around the middle and opening by a lid.

Species collected and examined:

1. *Bacopa* sp.
2. *Limnophila* sp.

Distribution: East campus, UNIMAS, Samarahan

Notes: Plantaginaceae family species have many of which are used in traditional medicine for their therapeutic properties. The *Bacopa* genus, commonly used in Ayurvedic medicine for its cognitive-enhancing and anti-anxiety effects (Kumar et al., 2016). *Limnophila* species are usually popular in aqua scaping due to their attractive appearance and ease of cultivation.

Figure 4.18 depicts the species in Plantaginaceae.

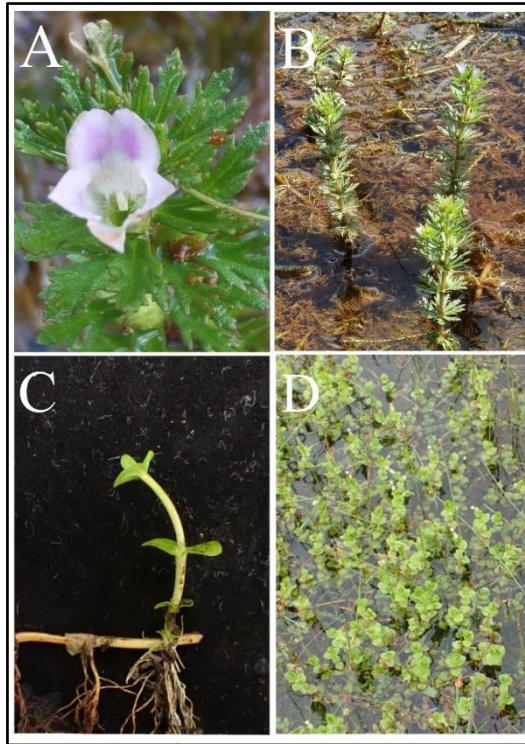


Figure 4.18: Plantaginaceae, species found was from the genus *Limnophila* and *Bacopa*. A. inflorescence, *Limnophila* sp. B. Habit, *Limnophila* sp. C. leaves, *Bacopa* sp. D. habit, *Bacopa* sp.

G. Polygonaceae

General description: Herbs or shrubs; swollen nodes; leaves simple, peculiar pair of fused, sheathing stipules, alternately on stems; flower solitary or aggregate, small to regular, 3-5 sepals, petals lack and some, the sepals are like petal-like and colourful. Stamens 8, ovary superior; fruits non fleshy usually a nut, seeds with starch

Species collected and examined: *Persicaria attenuata* (R. Br.) Sojak ssp. *pulchra* (Sojak)

K.L. Wilson

Distribution: Kota Samarahan-Asajaya roadside, Samarahan.

Notes: *Persicaria attenuata* subsp. *pulchra* is depicted in Figure 4.19. This family is renowned for plant species with swollen nodes on their stems. *Persicaria attenuata* is native

to Asia and has been imported as an attractive plant to various regions of the world. Traditional medicine can also benefit from this species.

H. Rubiaceae

General description: Trees, shrubs (mostly) or herbs; leaves simple, opposite leaves with interpetiolar stipules; flowers aggregated or solitary; in cymes or in panicles, calyx sometimes absent in some taxa, usually lobes and fused at the base; corolla is sympetalous, mostly white, or creamy but also yellow; stamen are alternipetalous and epipetalous; ovary inferior; fruits berry or capsule or drupe, seeds are endospermous.

Species collected and examined: *Neonauclea* sp.

Distribution: Gunung Buri, Sabal, Mount Krian, Kuching.

Notes: Figure 4.20 displays Rubiaceae species (*Neonauclea*). Numerous species in this family are known for their therapeutic characteristics and have ever been used traditionally for a variety of purposes such as curing fevers, infections, and digestive issues. Traditional medicine has employed *Neonauclea* species to treat a variety of ailments.

I. Gesneriaceae

General description: Herbs or shrubs, often hairy; leaves simple, often toothed, opposite or apparently alternate by the suppression or reduction of one of a pair; flowers usually showy, irregular, sepals tubular, with 5 sepals; corolla tubular and more or less 2-lipped, with 5 petals stamens 4 in unequal pairs or only 2, infertile and reduced stamens often present, anthers of each pair usually pressed together, ovary superior, fruit usually a capsule, sometimes a berry, seeds numerous, small.

Species collected and examined: *Loxocarpus* sp.

Distribution: Stenggang trail, Banjaran Undan, Kuching.

Notes: Figure 4.21 depicts Gersneriaceae species *Loxocarpus* sp. Numerous species are grown as ornamentals for their attractive foliage.

J. Linderniaceae

General Description: Herbs or shrubs; leaves simple or compound, opposite, petiolate (sometimes basally fused) to sessile; flower solitary or aggregated (in racemes or head), sepals 4 or 5, petals 4 or 5, stamens 2 or 4, ovary superior; fruits capsules, dehiscence septicidal, or irregular, seeds cylindrical, ellipsoid, oblong to narrowly obconic, or irregularly angled wings absent.

Species collected and examined: *Lindernia* sp.

Distribution: East campus, UNIMAS, Samarahan.

Notes: Figure 4.22 shows *Lindernia* sp. found in western Sarawak. Some species from this genus have been used in traditional medicine. In terms of modern medicinal research, studies have shown that certain species of *Lindernia* contain bioactive compounds with potential health benefits (Tsai et al., 2020)



Figure 4.19: Polygonaceae, from the genus *Persicaria*. A. inflorescence, *Persicaria attenuata* subsp. *pulchra*. B. leaves, *P. attenuata* subsp. *pulchra*.



Figure 4. 20: Rubiaceae, from the genus *Neonauclea*. A. habit, *Neonauclea* sp. B. leaves, *Neonauclea* sp.



Figure 4.21: Gesneriaceae, from the genus *Loxocarpus*. A. inflorescence, *Loxocarpus* sp. B. habit, *Loxocarpus* sp.

4.3.1.3.3 Monocotyledon

A. Alismataceae

General distribution: Herbs; leaves simple, alternate, petiolate, or sessile; flower aggregate in ‘inflorescences’ (usually), cymose or racemose solitary; sepals three which usually persist in the fruit, petals three usually conspicuous, white, pink, purple, occasionally yellow, or purple spots; stamen 3,6,9 or numerous, ovary superior, fruits head of nutlets, carpels, non-fleshy; an aggregate. Seeds have no endosperm and a curved or folded embryo.

Species collected and examined: *Limnocharis flava* (L.) Buchenau

Distribution: East campus, UNIMAS, Samarahan; Jalan Gedong-Simunjan, Samarahan; Jalan Sematan, Kuching; Kampung Bogag, Kuching.

Notes: Figure 4.23 *Limnocharis flava* also so known as the yellow burrhead or sawah lettuce known for its striking yellow flowers and used as medicinal herb to treat a variety of ailments, including fever, cough, and digestive disorders. It is also used as a food source in some cultures, with the leaves and stems being cooked and eaten as a vegetable.



Figure 4.22: Linderniaceae, from the genus *Lindernia* found in UNIMAS. A. habit, *Lindernia* sp. B. inflorescence, *Lindernia* sp.



Figure 4.23: Alismataceae, from the genus *Limnocharis*. A. habit in UNIMAS, *Limnocharis flava*. B. inflorescence, *L. flava*.

B. Araceae

General description: Shrubs or herbs; leaves simple or compound, small to very large; alternate; spiral or distichous, petiolate; flower spike (very rare), spadix which almost always surrounded by a modified leaf called spathe, tepals absent or up to (12) rarely, stamen 1-4, or 6 or 8-12, ovary superior; fruits fleshy or non-fleshy capsule or berry or drupe, seeds short to fairly long sometimes developing into a storage organ or absent.

Species collected and examined:

1. *Cryptocoryne auriculata* Engl.
2. *Cryptocoryne longicauda* Becc. ex Engl.
3. *Cryptocoryne striolata* Engl.
4. *Cryptocoryne lingua* Becc. ex Engl.
5. *Cryptocoryne zadiana* Ipor & Tawan
6. *Cryptocoryne cordata* var *zonnata* de Wit
7. *Bucephalandra* sp.
8. *Rhynchopyle* sp.

9. *Lemna minor* L.

10. *Lasia spinosa* (L.) Thw.

Key to genera:

1. Plants free-floating aquatics; leaves rosulate-----*Lemna minor*
Plants rheophytes or submerged or emergent; leaves petiolate-----2
2. Rheophytes plant; base leaf cuneate-----3
Submerged or emergent plant, base leaf cordate or saggitate-----4
3. Leaves usually narrowly frullate-lanceolate; apex apiculate-----*Rhynchophyle*
Leaves usually rhombic; apex usually acuminate- acute-----*Bucephalandra*
4. Submerged or sometimes emergent (inflorescence part only), base leaf cordate; stem
sometimes pubescence present or absent-----*Cryptocoryne*
Emergent, base sagittate; stems usually have thorns-----*Lasia*

Distribution: Pusat Penyelidikan Tumbuhan (PPT), UNIMAS, Samarahan; Jalan Simunjan-Gedong roadside, Samarahan; Peat swamp forest, UNIMAS, Samarahan; Sungai Stom Muda Bau-Lundu, Kuching; Matang wildlife, Kuching Budhiat Shrine, Bau, Kuching; Gunung Apeng, Kuching; Small River limestone hill near to Bra'ang, Kuching; Gunung Buri, Sabal, Mount Krian, Kuching.

Notes: Figure 4.24 depicts the Araceae family, which is widespread in western Sarawak. *Cryptocoryne* are often employed as aesthetic plants in freshwater aquariums. *Bucephalandra* are endemic to Borneo and are frequently used in aqua scaping, which is the art of creating landscapes. Because of their ability to absorb huge amounts of nutrients and heavy metals from polluted water, *Lemna* are often employed in wastewater treatment. *Lasia* are Southeast Asian natives that are frequently utilised in traditional medicine.



Figure 4.24: Araceae, from the genera *Lasia*, *Bucephalandra*, *Rhynchophyle*, *Lemna*, and *Cryptocoryne* found in western Sarawak. A. *Lasia spinosa*. B. *Cryptocoryne auriculata*. C. *Bucephalandra* sp. D. *Rhynchophyle* sp. E. *Lemna minor*. F. inflorescence, *Cryptocoryne longicauda*.

C. Burmanniaceae

General distribution: Herbs; Leaves simple, alternate, spiral sessile, sheathing, usually linear to ovate; flowers solitary or aggregated in inflorescence when aggregated, in cymes or in racemes, tepals 6 or 3, joined; stamens 3, ovary partly inferior; fruit non-fleshy, dehiscent, capsule, capsules splitting irregularly, seeds scantily endospermic, winged, numerous fruits.

Species collected and examined: *Burmannia* sp.

Distribution: Bako National Park, Kuching.

Notes: *Burmannia* are usually characterized by their lack of chlorophyll and their reliance on mycorrhizal fungi for their nutrition Figure 4.25 show the species of *Burmannia*.

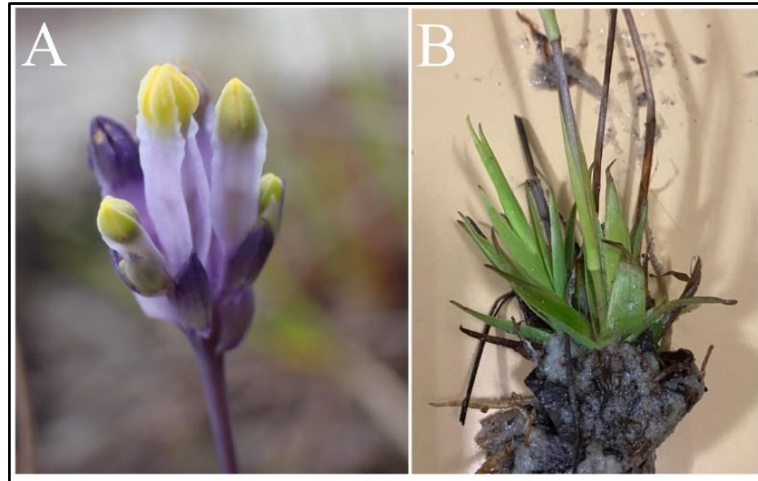


Figure 4.25: Burmanniaceae, from the genus *Burmannia* in Bako NP. A. inflorescence, *Burmannia* sp. B. leaves, *Burmannia* sp.

D. Cyperaceae

General description: Herbs; leaves simple, alternate, spiral (rarely), or distichous (often), or tristichous (usually), flat or folded, or rolled, or terete, sessile or petiolate (occasionally), linear to obovate, parallel-veined; flower aggregated in inflorescences in spikelet, units cymose or racemose, flower solitary or 1-50 in spikelet) often numerous, in branched, paniculate. Tepals or vestigial (represented by bristles or hairs) or absent; when present, often 6; stamens 1-3, or 4-6, ovary superior, 1 locular; fruits non-fleshy dehiscent, achene-like, or a drupe (very rarely).

Species collected and examined:

1. *Fimbristylis polytrichoides* (Retz.) Vahl
2. *Schoenoplectus* sp.
3. *Rhynchospora asperula* (Nees) Steud.
4. *Cyperus* sp.

Key to genus:

1. Spikes 1 per stem-----*Schoenoplectus*

- Spikes usually 2 or more per stem-----2
2. Scales of spikes distichous (arranged in 2 ranks) -----*Cyperus*
- Scales of spikes spirally arranged (3 or more ranks) -----3
3. Ligule absent, leaves shape lanceolate to linear, apex acuminate-----*Rhynchospora*
- Ligule present, leaves shape linear, apex acute-----*Fimbristylis*

Distribution: East campus, UNIMAS, Samarahan; Matang-Lundu roadside, Kuching; Mount Krian, Bau Lake, Kuching; Sungai Paon Gahat, Serian.

Notes: The Cyperaceae species present in western Sarawak are depicted in Figure 4.26. They are distinguished by their triangular stems, which are frequently solid, and their basal leaves with closed sheaths. *Schoenoplectus* is recognised for its robust, sturdy stems, which have traditionally been used to make baskets and mats.

E. Eriocaulaceae

General Description: Herbs; leaves simple, alternate, spiral (usually), or distichous (rarely), flat or folded or terete, sessile, sheathing (but at the base only); flower aggregated in inflorescence, racemose, bracteate, minute, or small, cyclic; sepal and petal are distinct, or sepaline (the corolla sometimes small, vestigial or missing in female flowers, sepal 2, or 3, petal 2, or 3; stamens 2, or 4, or 3, or 6, ovary superior; fruit non fleshy, dehiscent, capsule, seeds with starch.

Species collected and examined: *Eriocaulon* sp.

Distribution: East campus, UNIMAS, Samarahan; Matang-Sempadi roadside, Kuching.

Notes: Figure 4.27 shows *Eriocaulon* species found. Some *Eriocaulon* species are used for decorative purposes, such as in aquariums or as ornamental plants in gardens.

F. Hydrocharitaceae

General description: Aquatic herbs; leaves simple, opposite to whorled, or alternate (subopposite or subverticillate) sessile, sheathing; flower solitary, axillary, with (male) or without (female) a spathe like set of scales and a flask-shaped or two-lipped involucre; tepals or vestigial or absent; stamen 1, sessile with anthers, ovary superior; Fruit non fleshy, carpel indehiscent, seeds non-endospermic, with starch.

Species collected and examined: *Hydrilla verticillata* (L. f.) Royle

Distribution: East campus, UNIMAS, Samarahan; Jalan Mentung-Sangai, Sungai Paon Gahat, Serian.

Notes: *Hydrilla verticillata* is commonly used as an aquarium plant and as a food source for aquatic animals. Figure 4.28 show the species of *Hydrilla verticillata* in western Sarawak. According to Zhu et al. (2022) can also help to improve water quality by removing excess nutrients from the water, which can reduce the growth of harmful algae and improve the health of fish populations.

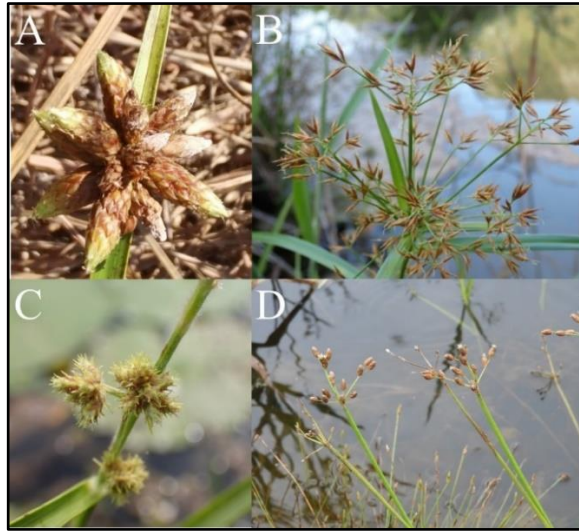


Figure 4.26: Cyperaceae, the genera found in western Sarawak are *Fimbristylis*, *Schoenoplectus*, *Cyperus*, and *Rhynchospora*. A. *Schoenoplectus* sp. B. *Rhynchospora asperula*. C. *Cyperus* sp. D. *Fimbristylis polytrichoides*



Figure 4.27: Eriocaulaceae, from the genus *Eriocaulon*. A. habit, *Eriocaulon* sp. B. inflorescence, *Eriocaulon* sp.



Figure 4.28: Hydrocharitaceae, from the genus *Hydrilla*. A. leaves, *Hydrilla verticillata*. B. habitat, *H. verticillata*.

G. Nymphaeaceae

General description: Water plants rooting in mud with submerged, horizontal stems, leaves floating, circular, or almost circular, split at the base, flowers solitary, large, showy, and regular. Floating on the water surface or raised a short way above it. Sepals 4-6, petals many, stamens many; fruits berry-like, splitting irregularly, many seeded, ripening underwater.

Species collected and examined:

1. *Nymphaea nouchalli* Burm. f.
2. *Nymphaea lotus* L.
3. *Nymphaea pubescens* Willd.
4. *Barclaya motleyi* Hook. f.

Key to species:

1. Plants submerged aquatics, leaves widely obovate-----*Barclaya motleyi*
Plants free-floating leaved aquatics, leaves widely ovate-----2
2. Leaves abaxial pubescence absent, margin entire to slightly spinose-----
-----*N. nouchalli*
Leaves abaxial pubescence present, margin slightly spinose and dentate or denticulate -
-----3
3. Leaves margin slightly spinose; flower sepal apex attenuate-----*N. lotus*
Leaves margin slightly dentate or denticulate; flower sepal apex acute-----
-----*N. pubescens*

Distribution: East campus, UNIMAS, Samarahan; Peat swamp forest, UNIMAS, Samarahan; La Promenade Mall roadside, Samarahan; Stenggang trail, Banjaran Undan, Kuching; Simpadah trail, Banjaran Undan, Kuching; Santubong National Park, Kuching.

Notes: Figure 4.29 depicts the species of Nymphaeaceae found in western Sarawak. *Nymphaea* and *Barclaya* are both valued for their ornamental value and are commonly used in aquatic gardens and aquariums. The species are also important, they provide habitat for aquatic animals and help to filter and clean water in wetland ecosystems.

H. Pandanaceae

General description: Trees, shrubs or lianas; leaves simple, medium-sized to very large; alternate; spiral (appearing so, through torsion of the stem), or tristichous or four-ranked (rarely), leathery, sessile, linear, or lanceolate, parallel veined; flower aggregated in ‘inflorescence’ in panicles, racemes, and in heads (often crowded into dense panicles), terminal, spatheate, minute or small; tepals or absent; fruits fleshy to non-fleshy, more or less an aggregate, or not and aggregate. Seeds collar not conspicuous.

Species collected and examined:

1. *Pandanus yvanii* Solms

2. *Pandanus helicopus* Kurz ex Miq.

Distribution: Samunsam Wildlife Sanctuary, Kuching; Stenggang trail, Banjaran Undan, Kuching.

Notes: The *Pandanus* genus is depicted in Figure 4.31. Some species’ fruits are edible and have a sweet, pineapple-like flavour, while others are utilised for their fibres and have traditionally been used in weaving.

I. Pontederiaceae

General description: Aquatic herbs; leaves simple, alternate, or whorled, spiral, petiolate, linear, or lanceolate, or ovate, or parallel-veined; flower solitary, or aggregated in inflorescence in racemes, or in spikes, or in panicles; tepals 6; free or joined; 2 whorled; spotted (occasionally), or without spots; similar in the two whorls; white, or violet, or blue, or yellow (rarely); stamens 1 or 3 or 6, ovary superior; fruit non-fleshy, dehiscent (when trilocular) or indehiscent, capsule or a nut, seed with starch.

Species collected and examined:

1. *Pontederia crassipes* Mart.
2. *Monochoria hastata* (L.) Solms
3. *Monochoria vaginalis* Burm. f.

Key to species:

1. Inflorescence spike, perianth segments united into a tube below-----
-----*Pontederia crassipes*
Inflorescence umbel-like or raceme, perianth segments free to base-----2
2. Leaves shape sagittate or hastate-----*Monochoria hastata*
Leaves elliptic, ovate, or heart-shaped and occasionally linear-----
-----*M. vaginalis*

Distribution: Kota Samarahan roadside, Samarahan; Pusat Penyelidikan Tumbuhan (PPT), UNIMAS, Samarahan; Kota Samarahan- Asajaya roadside, Samarahan; Summer mall roadside, Samarahan; Jalan Atro-Gedong, Samarahan

Notes: Figure 4.32 depict the Pontederiaceae species found in Sarawak. These plants have a variety of uses, including as ornamental plants, food sources, and medicinal plants.

J. Typhaceae

General Description: Aquatic herbs; leaves simple, alternate, distichous, triangular in section or flat, sessile, sheathing, linear, parallel-veined; flower compound, densely aggregated in inflorescence, dense in spikes, perianth vestigial (in the form of simple, lobed, or forked hairs); fruit non-fleshy carpel dehiscent.

Species collected and examined: *Typha angustifolia* L.

Distribution: Faculty of Science Resource Technology (FSTS), UNIMAS, Samarahan; Kota Samarahan-Asajaya roadside, Samarahan; Kota Samarahan-Tabuan Jaya roadside, Samarahan.

Notes: Figure 4.30 depicts Typhaceae. *Typha angustifolia* has a wide variety of uses and benefits. It has been utilised historically for food, medicinal, and as a source of materials for weaving and construction. The plant's young branches and roots, which have a mildly sweet taste, can be eaten raw or cooked.

K. Xyridaceae

General description: Herbs; Leaves simple, with a basal aggregation of leaves, alternate, spiral, or distichous, mostly flat, or terete, sessile, sheathing, linear, parallel-veined; flower aggregate inflorescences in spike and in heads, scapiflorous, usually a simple, flowers bracteate, sepal unequal but not bilabiate, persistent; petals 3, yellow (usually), or white, or blue, stamen 3, ovary superior; fruits non-fleshy, dehiscent, a capsule.

Species collected and examined: *Xyris* sp.

Distribution: Bako National Park, Kuching.

Notes: *Xyris* plants have a wide range of applications and advantages. Figure 4.33 shows the *Xyris* species. Several species have long been utilised medicinally by indigenous people, such as to alleviate digestive issues, headaches, and respiratory diseases. Furthermore, several *Xyris* species are grown for their edible roots, which are high in starch and can be utilised as a source of food.

4.3.1.3.4 Tracheophytes

A. Salviniaceae

General description: Aquatic fern: leaves fronds, long and broad, with bristly surface caused by the hair-like strands that join at the end to form trimerous whorls, sessile, producing spore in different sizes

Species collected and examined: *Salvinia molesta* Mitchell

Distribution: East campus, UNIMAS, Samarahan; Kota Samarahan-Asajaya roadside, Samarahan; La Promenade mall roadside, Samarahan; Summer mall roadside, Samarahan.

Notes: Figure 4.34 shows the invasive species of *Salvinia*. Despite being invasive, *Salvinia molesta* have some potential uses and benefits where in some parts of the world, it is used as a biofertilizer to improve soil quality in agricultural fields, and as a feed supplement for livestock.

B. Parkeriaceae

General description: Erect aquatic or subaquatic ferns of moderate size; leaves frond, erect, stipitate, 2-3 pinnafid; sporangia solititary, scattered along the veins, exindusiate but protected by the continuous reflexed margin of the lamina, large, short-stalked

Species collected and examined: *Ceratopteris thalichoides* (L.) Brongn. var. *thalichoides*

Distribution: Kampung Bogag, Bau, Kuching.

Notes: Figure 4.35 depicts the Parkeriaceae species. This species is commonly used in aquariums and water gardens as an ornamental plant, as it is easy to grow and maintain.



Figure 4.29: Nymphaeaceae, found in western Sarawak, genera found are *Nymphaea* and *Barclaya*. A. *Nymphaea pubescens*. B. *Nymphaea lotus*. C. *Nymphaea nouchalli*. D. *Barclaya motleyi*.

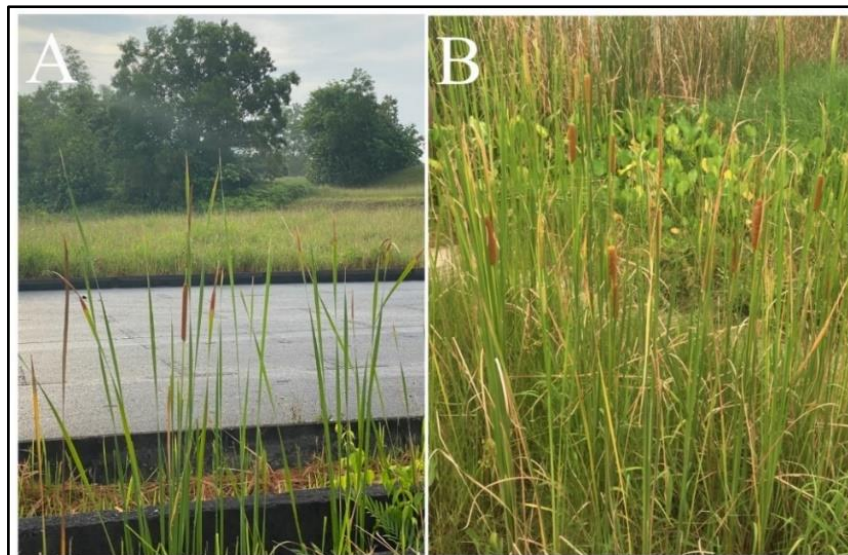


Figure 4.30: Typhaceae, the genus found in this family was *Typha*. A. *Typha angustifolia*. B. habit, *T. angustifolia*.

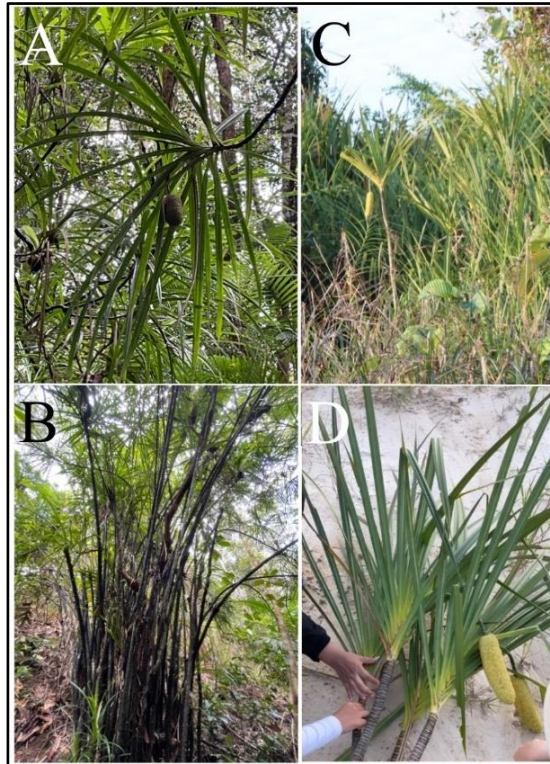


Figure 4.31: Pandanaceae, genus found in western Sarawak was *Pandanus*. A. fruit and leaves, *Pandanus yvanii*. B. habit, *P. yvanii*. C. habit, *Pandanus helicopus*. D. fruit and leaves, *P. helicopus*.



Figure 4.32: Pontederiaceae, genera found in western Sarawak were *Pontederia* and *Monochoria*. A. inflorescence, *Pontederia crassipes*. B. inflorescence, *Monochoria hastata*. C. Habit, *P. crassipes*. D. Habit, *M. hastata*.



Figure 4.33: Xyridaceae, the genus that found in western Sarawak was *Xyris*. A. habit, *Xyris* sp. B. inflorescence, *Xyris* sp.

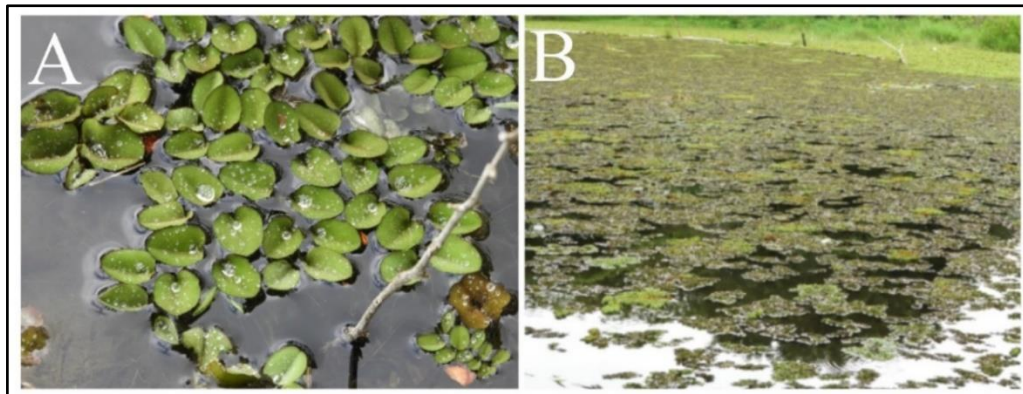


Figure 4.34: Salviniaceae, the genus found was *Salvinia*. A. leaves, *Salvinia molesta*. B. habit, *S. molesta*.



Figure 4.35: Parkeriaceae, the genus found for this aquatic fern was *Ceratopteris*. A. habitat, *Ceratopteris thalichoides* var. *thalichoides*. B. leaves, *C. thalichoides* var. *thalichoides*

4.3.2 Micromorphology

In addition to morphology and anatomy studies, micromorphology elements are also crucial for plant ecology and taxonomy research, for a better understanding of plant life. Though micromorphology works are a bit tedious with chemicals and technologies (e.g., FESEM and SEM), the results seem to be promising to value added in the taxonomic sympathetic. For example, Barclay (2007) mentioned that if developmental pathways of stomatal complexes could be describe and proved to be uniquely connected with different taxonomic groupings, taxonomist would have possessed a potent new tool for distinguishing natural plant groups and this has been proven by the years up until now with composing a total of fourteen types of stomatal complex. Past research on Amborella, Nymphaeales, Schizandraceae, Trimeniaceae, and Austrobailea revealed that these basal angiosperm clades contain various stomatal complex types (Carpenter, 2005). It is usual to have multiple types of stomatal complexes to exist within the same family (Baranova, 1987). This proves that taxonomists had been using micromorphological characteristics even on the earliest times to aid with plant taxonomy identification. For this part, 27 species from various types of habit (aquatic-related plants) were selected. Seven types of habits for aquatic-related plants were identified, i.e. (i) emergent, (ii) floating-leaved, (iii) submerged, (iv) submerged free-floating, (v) submerged floating, (vi) marsh and (vii) rheophyte. The species were randomly selected, but with every type of habit must be represented by at least one species. Only two elements were examined for this study: stomata and trichomes. The parameters observed and recorded for stomata include the type, appearance, and density. While the parameter for trichomes was the type.

4.3.2.1 Stomata characteristics

Stomata and trichomes were studied on 27 selected species of aquatic and marsh plant. The observation was made on both adaxial and abaxial leaf surfaces. A total of six species are hypostomatic, 16 species are amphistomatic, four species epistomatic and one species with no stomata (Table 4.8). The Stomata results tabulated shown in Table 4.8 were on both sides of the leaves abaxial and adaxial. The results were on the stomata occurrence, presence of stomata, type of stomata, stomata appearance and presence of trichomes (special features).

Occurrence of stomata

There are three types of occurrences and positions of stomata which were hypostomatic, epistomatic and amphistomatic. The only species that did not have stomata on both adaxial and abaxial surfaces was *Hydrilla verticillata*. Hypostomatic were usually where the stomata are only present on the abaxial surface of the leaf while adaxial stomata are absent. Meanwhile, amphistomatic was where both sides of the surface leaf (adaxial and abaxial) have the present of stomata and epistomatic, the stomata present on the adaxial surface only.

Stomata appearance

Three types of stomata appearance commonly detected on the leaf surfaces, namely, raised, semi-raised or sunken. Observations were made on the leaves of 27 selected species. Out of the total number, only 23 species were distinguished with semi-raised stomata appearance. Only three species with sunken stomata type, viz. *Limnocharis flava*, *Salvinia molesta* and *Xyris* sp. While not applicable recorded for *Hydrilla verticillata*, no stomata were perceived on its leaf.

Type of stomata

According to Barclay et al. (2007), the identification of stomata type was based on the number of subsidiary cells. In the study, Barclays's method was adopted to identify the type of stomata. Observations were made using SEM images and, as result, a total of seven basic types of stomata were identified. The basic types are anisocytic, diacytic, hemiparacytic, paracytic, pericytic, stephanocytic and tetracytic (Figure 4.36). Out of 27 selected species that were examined, 10 species with paracytic and six with tetracytic. While the remaining (five species), one for each remaining type of stomata, and five species were not detected or not clear due to the wicked sample's condition and no stomata were found in *H. verticillata*.

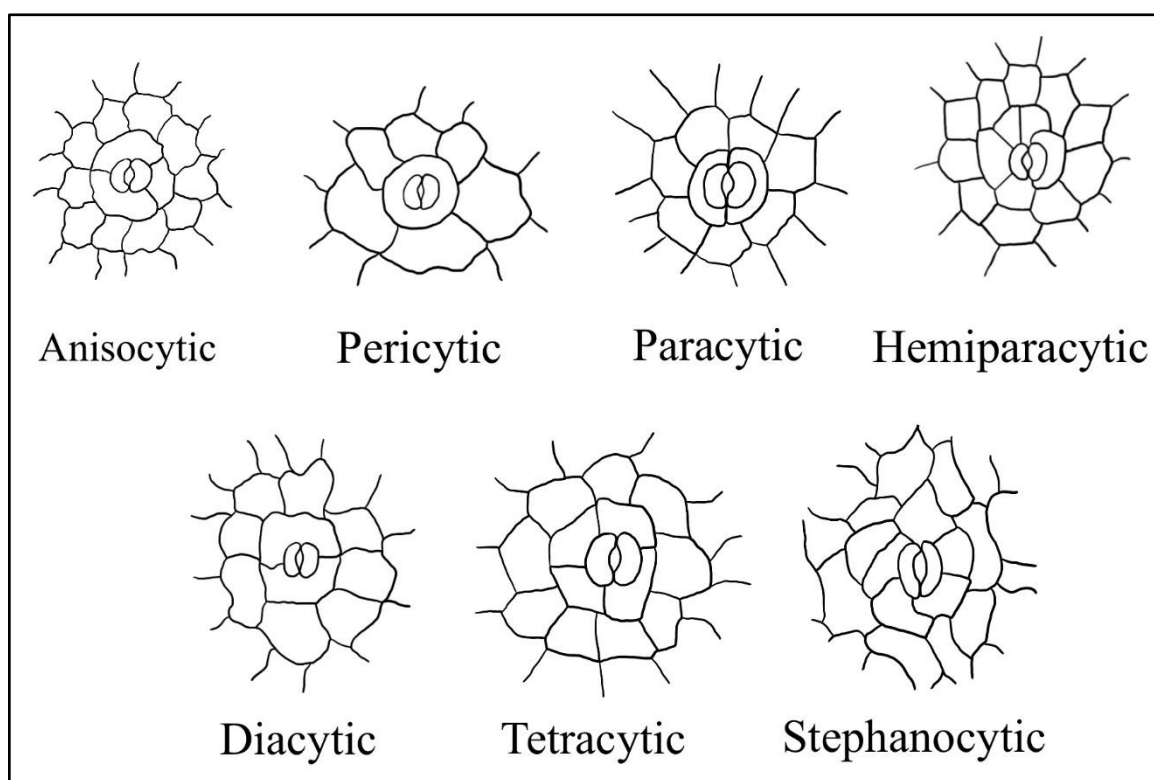


Figure 4.36: Type of stomata found in aquatic and marsh plant in Western part of Sarawak.

Table 4.8: Stomata characteristics for aquatic and marsh plant species in western Sarawak

No	Name of species	Stomata occurrence	Stomata surface	Stomata presence	Type of stomata	Stomata appearance	Special features
Emergent							
1	<i>Bacopa</i> sp.	Hypostomatic	Adaxial	Absent	N/A	N/A	No trichome
			Abaxial	Present	N/A	Semi-raised	No trichome
2	<i>Pontederia crassipes</i>	Amphistomatic	Adaxial	Present	Paracytic	Semi-raised	No trichome
			Abaxial	Present	Paracytic	Semi-raised	No trichome
3	<i>Limnocharis flava</i>	Amphistomatic	Adaxial	Present	Paracytic	Sunken	No trichome
			Abaxial	Present	Paracytic	Sunken	No trichome
4	<i>Monochoria hastata</i>	Amphistomatic	Adaxial	Present	Paracytic	Semi-raised	No trichome
			Abaxial	Present	Paracytic	Semi-raised	No trichome
5	<i>Ipomoea aquatica</i>	Amphistomatic	Adaxial	Present	Paracytic	Semi-raised	Multi-celled glandular
			Abaxial	Present	Paracytic	Semi-raised	Multi-celled glandular
6	<i>Lasia spinosa</i>	Amphistomatic	Adaxial	present	N/A	Semi-raised	No trichome
			Abaxial	present	N/A	Semi-raised	No trichome
7	<i>Persicaria attenuata</i> subsp. <i>pulchra</i>	Amphistomatic	Adaxial	Present	Paracytic	Semi-raised	No trichome
			Abaxial	Present	Paracytic	raised	No trichome
Submerged free-floating							
8	<i>Ludwigia repens</i>	Amphistomatic	Adaxial	Present	Diacytic	Semi-raised	Multi-celled glandular
			Abaxial	Present	Diacytic	Semi-raised	Multi-celled glandular
9	<i>Hydrilla verticillata</i>	No stomata	Adaxial	N/A	N/A	N/A	No trichome
			Abaxial	N/A	N/A	N/A	No trichome
Free floating							
10	<i>Nymphaea nouchalli</i>	Epistomatic	Adaxial	Present	N/A	Semi-raised	No trichome
			Abaxial	Absent	N/A	N/A	Unicellular

Table 4.8: Continued

Submerged							
11	<i>Barclaya motleyi</i>	Amphistomatic	Adaxial	Present	Stephanocyti c	Semi-raised	Unicellular and hydropotes
			Abaxial	Present	Stephanocyti c	Semi-raised	Unicellular and hydropotes
12	<i>Cryptocoryne auriculata</i>	Amphistomatic	Adaxial	Present	Tetracytic	Semi-raised	No trichome
			Abaxial	Present	Tetracytic	Semi-raised	No trichome
13	<i>Cryptocoryne lingua</i>	Amphistomatic	Adaxial	Present	Tetracytic	Semi-raised	No trichome
			Abaxial	Present	Tetracytic	Semi-raised	No trichome
14	<i>Cryptocoryne longicauda</i>	Amphistomatic	Adaxial	Present	Tetracytic	Semi-raised	No trichome
			Abaxial	Present	Tetracytic	Semi-raised	No trichome
15	<i>Cryptocoryne striolata</i>	Hypostomatic	Adaxial	Absent	N/A	N/A	Unicellular
			Abaxial	Present	Tetracytic	Semi-raised	Unicellular
16	<i>Cryptocoryne zadiana</i>	Amphistomatic	Adaxial	Present	Tetracytic	Semi-raised	No trichome
			Abaxial	Present	Tetracytic	Semi-raised	No trichome
Emergent free floating							
17	<i>Lemna minor</i>	Epistomatic	Adaxial	present	N/A	Semi-raised	No trichome
			Abaxial	Absent	N/A	N/A	No trichome
18	<i>Salvinia molesta</i>	Epistomatic	Adaxial	Present	Anisocytic	Sunken	Multicellular uniserate
			Abaxial	N/A	N/A	N/A	N/A

Table 4.8: Continued

Aquatic marsh plant							
19	<i>Cyperus</i> sp.	Hypostomatic	Adaxial	Absent	N/A	N/A	No trichome
			Abaxial	Present	Paracytic	Semi-raised	No trichome
20	<i>Drosera spatulata</i> var. <i>bakoensis</i>	Amphistomatic	Adaxial	Present	Pericytic	Semi-raised	Multi-celled glandular and Glandular hair
			Abaxial	Present	Pericytic	Semi-raised	Multi-celled gland
21	<i>Eriocaulon</i> sp.	Amphistomatic	Adaxial	Present	Paracytic	Semi-raised	No trichome
			Abaxial	Present	Paracytic	Semi-raised	No trichome
22	<i>Fimbristylis polytrichoides</i>	Epistomatic	Adaxial	Present	Hemiparacytic	Semi-raised	No trichome
			Abaxial	Absent	N/A	N/A	No trichome
23	<i>Pandanus yvanii</i>	Amphistomatic	Adaxial	Present	N/A	Semi-raised	No trichome
			Abaxial	Present	N/A	Semi-raised	No trichome
24	<i>Xyris</i> sp.	Amphistomatic	Adaxial	Present	Paracytic	Sunken	No trichome
			Abaxial	Present	Paracytic	Sunken	No trichome
Rheophyte							
25	<i>Bucephalandra</i> sp.	Hypostomatic	Adaxial	Absent	N/A	N/A	No trichome
			Abaxial	Present	Paracytic	Semi-raised	No trichome
26	<i>Neonauclea</i> sp.	Hypostomatic	Adaxial	Absent	N/A	N/A	Unicellular
			Abaxial	Present	Paracytic	Semi-raised	Unicellular
27	<i>Rhynchosytle</i> sp.	Hypostomatic	Adaxial	Absent	N/A	N/A	No trichome
			Abaxial	Present	Tetracytic	Semi-raised	No trichome

**Notes: No data applied = N/A

4.3.2.2 Stomata size and density

Stomata size

The length and width of the guard cell determine the stomatal size (Taylor et al., 2012). The stomata size of 27 selected species was analysed based on the SEM images. As a result, the stomata size of 27 selected species can be divided into seven informal groups based on their habits, excluding *Hydrilla verticillata* (stomata absent). The largest stomata (92.333 μm) were detected in the marsh plant, which was *Xyris* sp., while the smallest (9.9605 μm) were detected in the floating-leaf, *Nymphaea nouchalli*.

In the study, each of the group habits had been analysed the largest size of stomata in each group. Emergent a total of seven species, the largest stomata size average in length *Pontederia crassipes* (abaxial) 51.145 μm , submerged free-floating two species largest average length stomata is *Ludwigia repens* 27.888 μm . As for floating-leaved only one species which is *Nymphaea nouchalli*, 9.6905 μm . Submerged plant a total of six species, *Cryptocoryne auriculata* being the largest length for stomata size 35.456 μm and emergent free-floating two species *Lemna minor* average length size of stomata is bigger than *Salvinia molesta*, which is 22.042 μm . Aquatic marsh being the largest number of species nine species, largest average length of stomata size is *Xyris* sp, 92.333 μm . Data can be seen in Table 4.9 and the length of high and low species were highlighted grey colour.

Stomata density

Stomatal density is the number is the number of stomata per unit area of a leaf (Saupe, 2009). Stomal density differs across monocots and dicots, plant species and the adaxial and abaxial of the plants' leaves. In Table 4.9 data showed that *Cyperus* sp. had the highest stomata density compared to all the 27 species analysed which is 358.2803mm⁻² while the

lowest stomata density found was *Barclaya motleyi* with results of 7.7618 mm⁻². In this study, each of the group's habits were analysed to see the highest and the lowest density. Emergent, the highest stomata density is *Bacopa* sp. with 533.4395 mm⁻² while the lowest from this group is *Lasia spinosa* with 63.6943 mm⁻² amount of density. In the submerged group there is only one stomata density that could be analysed because this group only consists of two species which was *Ludwigia repens* and *Hydrilla verticillata* thus the stomata density for *Ludwigia repens* was 135.3503 mm⁻². Floating leaves only have one species thus there was no stomata density to be compared between other species in this group. The stomata density for *Nymphaea nouchali* was 286.62.42 mm⁻². Next, the submerged plant where the highest stomata density for this group is *Cryptocoryne striolata* on the abaxial surface 55.7325 mm⁻² though, *Barclaya motleyi* had the lowest which is 7.9618 mm⁻². *Cyperus* sp. has the highest density in the aquatic marsh group, which was 358.3803 mm⁻² on the abaxial surface, however the lowest density is *Fimbristylis polytrichoides* which was 23.8854 mm⁻². Lastly the rheophyte group where the highest stomata density was from the Rubiaceae family, *Neonauclea* sp. with 270.700 mm⁻² and *Rhynchochyle* sp. having the lowest density with 55.7325 mm⁻². The highest and lowest stomata density has been highlighted with grey in Table 4.9.

Figure 4.37, 4.38, 4.39, 4.40 and 4.41 showed the SEM and FESEM image of the selected species of the adaxial leaf while Figure 4.42, 4.43, 4.44, 4.45 and 4.46 depicts the species abaxial leaves of aquatic and marsh plant found in western Sarawak.

Table 4.9: Average, size, and density of stomata for aquatic and marsh species stomata in western Sarawak.

No	Name of species	Stomata	Average of stomata (µm)		Size of stomata (µm)		Stomata density (mm ⁻²)
			Length	Breadth	Length	Breadth	
Emergent							
1	<i>Bacopa</i> sp.	Adaxial	N/A	N/A	N/A	N/A	N/A
		Abaxial	20.559	15.143	19.268 - 21.849	11.869 - 18.417	533.4395
2	<i>Pontederia crassipes</i>	Adaxial	39.833	17.222	38.583 - 41.083	15.444 - 19.000	95.5414
		Abaxial	51.145	22.125	45.500 - 56.789	20.000 - 24.249	111.465
3	<i>Limnocharis flava</i>	Adaxial	21.273	7.245	17.094 - 25.451	4.762 - 9.728	95.5414
		Abaxial	26.674	10.382	21.464 - 31.884	8.468 - 12.296	119.4268
4	<i>Monochoria hastata</i>	Adaxial	41.732	16.862	39.180 - 44.283	15.556 - 18.167	199.0446
		Abaxial	35.409	17.309	28.333 - 42.485	15.583 - 19.034	270.7006
5	<i>Ipomoea aquatica</i>	Adaxial	26.604	15.047	22.968 - 30.240	13.100 - 16.994	143.3121
		Abaxial	26.617	18.325	23.708 - 29.526	15.531 - 21.118	246.8153
6	<i>Lasia spinosa</i>	Adaxial	30.201	9.313	29.612 - 30.789	7.311 - 11.314	63.6943
		Abaxial	31.900	10.052	28.236 - 35.563	9.378 - 10.725	135.3503
7	<i>Persicaria attenuata</i> subsp. <i>pulchra</i>	Adaxial	24.302	12.846	22.236 - 26.367	10.652 - 15.040	127.3885
		Abaxial	22.852	16.907	20.151- 25.552	14.869 - 18.944	222.9299
Submerged free-floating							
8	<i>Ludwigia repens</i>	Adaxial	27.888	15.388	23.947 - 31.828	13.487 - 17.288	79.6178
		Abaxial	23.544	14.713	19.048 - 28.039	13.715 - 15.710	135.3503

Table 4.9: Continued

9	<i>Hydrilla verticillata</i>	Adaxial	N/A	N/A	N/A	N/A	N/A
		Abaxial	N/A	N/A	N/A	N/A	N/A
Floating-leaved							
10	<i>Nymphaea nouchalli</i>	Adaxial	9.6905	4.864	8.781 - 10.600	3.487 - 6.242	286.6242
		Abaxial	N/A	N/A	N/A	N/A	N/A
Submerged							
11	<i>Barclaya motleyi</i>	Adaxial	31.550	26.850	30.300 - 32.800	20.300 - 33.400	31.8471
		Abaxial	35.471	12.835	33.750 - 37.192	7.000 - 18.669	7.9618
12	<i>Cryptocoryne auriculata</i>	Adaxial	35.456	20.179	32.917 - 37.995	18.417 - 21.940	47.7707
		Abaxial	32.281	14.396	29.667 - 34.895	13.625 - 15.167	47.7707
13	<i>Cryptocoryne lingua</i>	Adaxial	24.055	13.625	22.122 - 25.988	12.602 - 14.647	31.8471
		Abaxial	25.104	13.917	21.541 - 28.667	12.334 - 15.500	31.8471
14	<i>Cryptocoryne longicauda</i>	Adaxial	31.558	13.670	30.308 - 32.807	10.698 - 16.642	23.8854
		Abaxial	31.189	14.649	28.721 - 33.656	9.605 - 19.693	31.8471
15	<i>Cryptocoryne striolata</i>	Adaxial	N/A	N/A	N/A	N/A	N/A
		Abaxial	34.812	16.648	29.483 - 40.140	13.500 - 19.795	55.7325
16	<i>Cryptocoryne zadiana</i>	Adaxial	30.388	18.875	26.250 - 34.525	16.250 - 21.500	31.8471
		Abaxial	28.357	17.458	25.880 - 30.833	15.415 - 19.500	15.9236
Emergent free-floating							
17	<i>Lemna minor</i>	Adaxial	22.042	18.792	20.250 - 23.833	18.083 - 19.500	167.1975
		Abaxial	N/A	N/A	N/A	N/A	N/A

Table 4.9: Continued

18	<i>Salvinia molesta</i>	Adaxial	10.685	7.045	8.171 - 13.199	4.923 - 9.167	95.5414
		Abaxial	N/A	N/A	N/A	N/A	N/A
Aquatic marsh plant							
19	<i>Cyperus</i> sp.	Adaxial	N/A	N/A	N/A	N/A	N/A
		Abaxial	33.434	9.933	32.800 - 34.067	9.333 - 10.533	358.2803
20	<i>Drosera spatulata</i> var. <i>bakoensis</i>	Adaxial	16.667	10.758	12.251 - 21.082	8.105 - 13.411	79.6178
		Abaxial	20.920	9.286	19.087 - 22.753	8.166 - 10.406	71.6561
21	<i>Eriocaulon</i> sp.	Adaxial	11.945	64.450	11.389 - 12.500	63.083 - 65.817	135.3503
		Abaxial	14.875	44.583	13.750 - 16.000	39.833 - 49.333	143.3121
22	<i>Fimbristylis polytrichoides</i>	Adaxial	24.146	20.703	21.489 - 26.803	20.256 - 21.150	23.8854
		Abaxial	N/A	N/A	N/A	N/A	N/A
23	<i>Pandanus yvanii</i>	Adaxial	19.667	18.875	16.000 - 23.333	10.750 - 16.250	39.8089
		Abaxial	24.389	22.333	23.278 - 25.500	19.333 - 25.333	270.7006
24	<i>Xyris</i> sp.	Adaxial	52.202	31.952	45.987 - 58.417	29.208 - 34.696	71.6561
		Abaxial	92.333	25.389	89.333 - 95.333	24.333 - 26.444	39.8089
Rheophytes							
25	<i>Bucephalandra</i> sp.	Adaxial	N/A	N/A	N/A	N/A	N/A
		Abaxial	44.926	24.896	40.731 - 49.121	23.212 - 26.579	63.6943
26	<i>Neonauclea</i> sp.	Adaxial	N/A	N/A	N/A	N/A	N/A
		Abaxial	23.399	10.920	20.900 - 5.897	9.359 - 12.481	270.7006

Table 4.9: Continued

27	<i>Rhynchopyle</i> sp.	Adaxial	N/A	N/A	N/A	N/A	N/A
		Abaxial	44.514	29.056	41.361 - 47.667	27.278 - 30.833	55.7325

** Notes: No data applied = N/A

Adaxial of 27 stomata plant aquatic and marsh plant species:

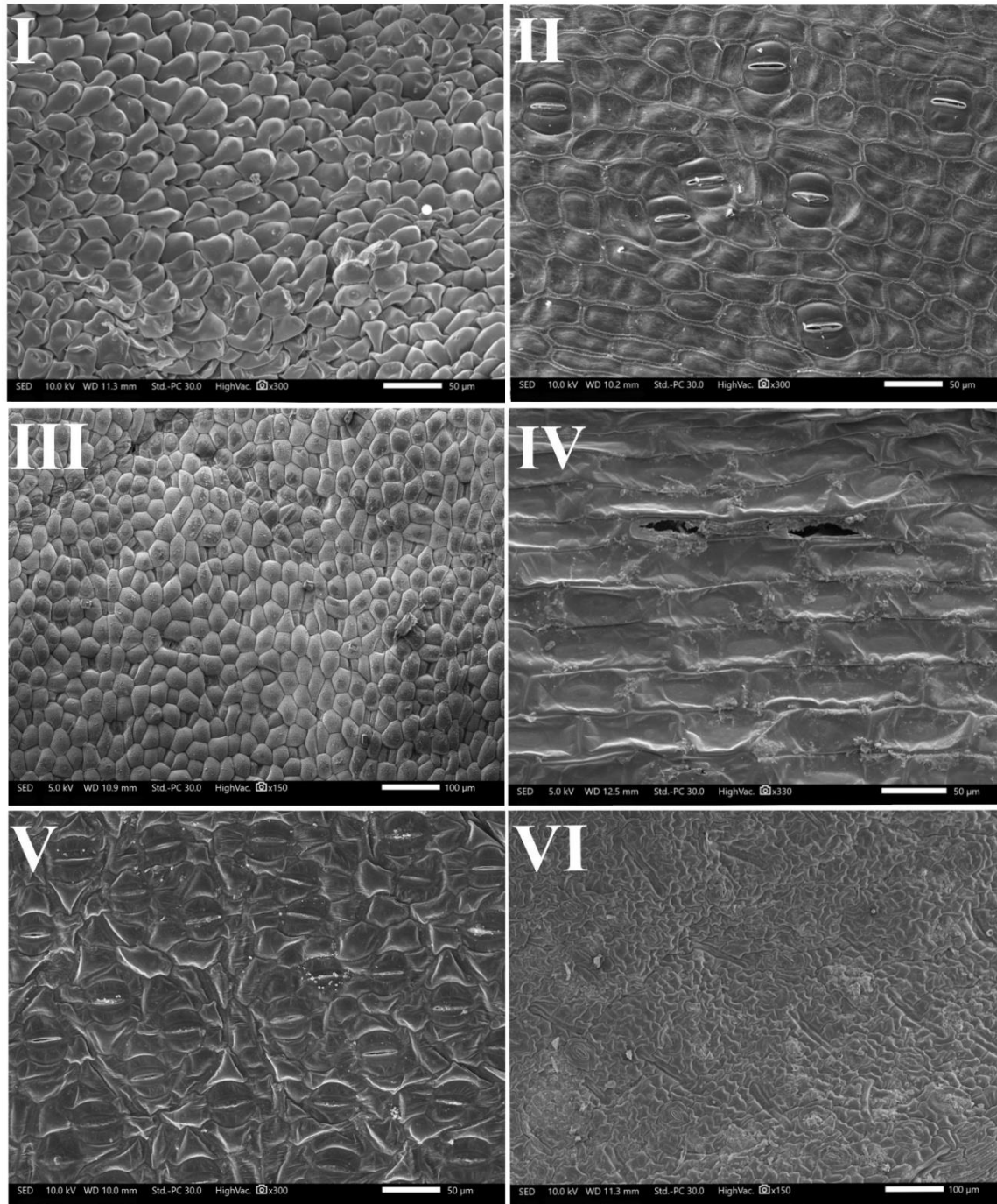


Figure 4.37: The adaxial of I. *Bacopa* sp., II. *Pontederia crassipes*, III. *Limnocharis flava*, IV. *Hydrilla verticillata*, V. *Monochoria hastata*, VI. *Ludwigia repens*. Magnification: 150x-300x. Type of stomata paracytic (II),(III), and (V); diacytic (VI).

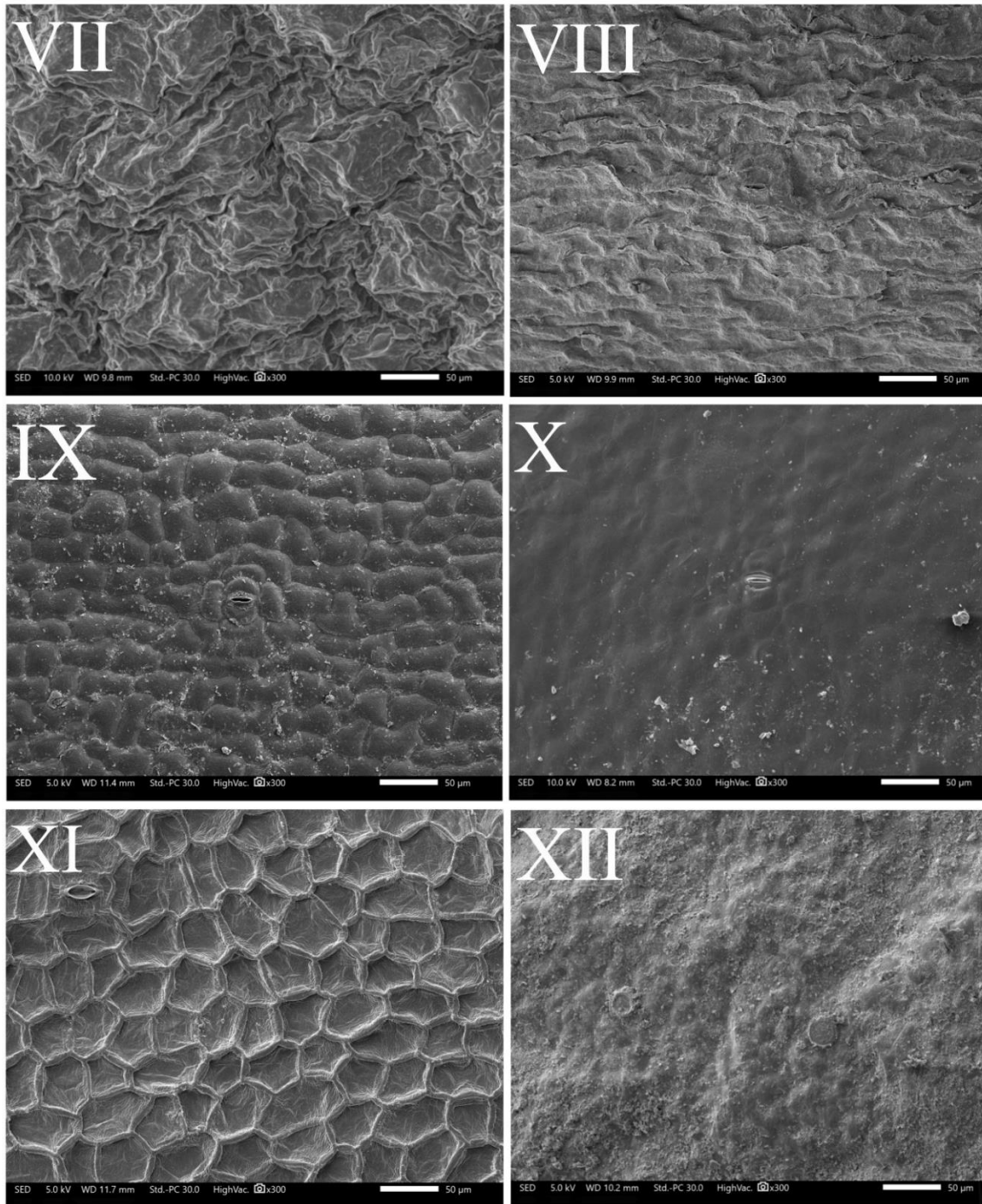


Figure 4.38: The adaxial of VII. *Nymphaea nouchalli*, VIII. *Barclaya motleyi*, IX. *Cryptocoryne auriculata*, X. *Cryptocoryne lingua*, XI. *Cryptocoryne longicauda*, XII. *Cryptocoryne striolata*. Magnification = 300x. Type of stomata stephanocytic (VIII); tetracytic (IX), (X), (XI), and (XII).

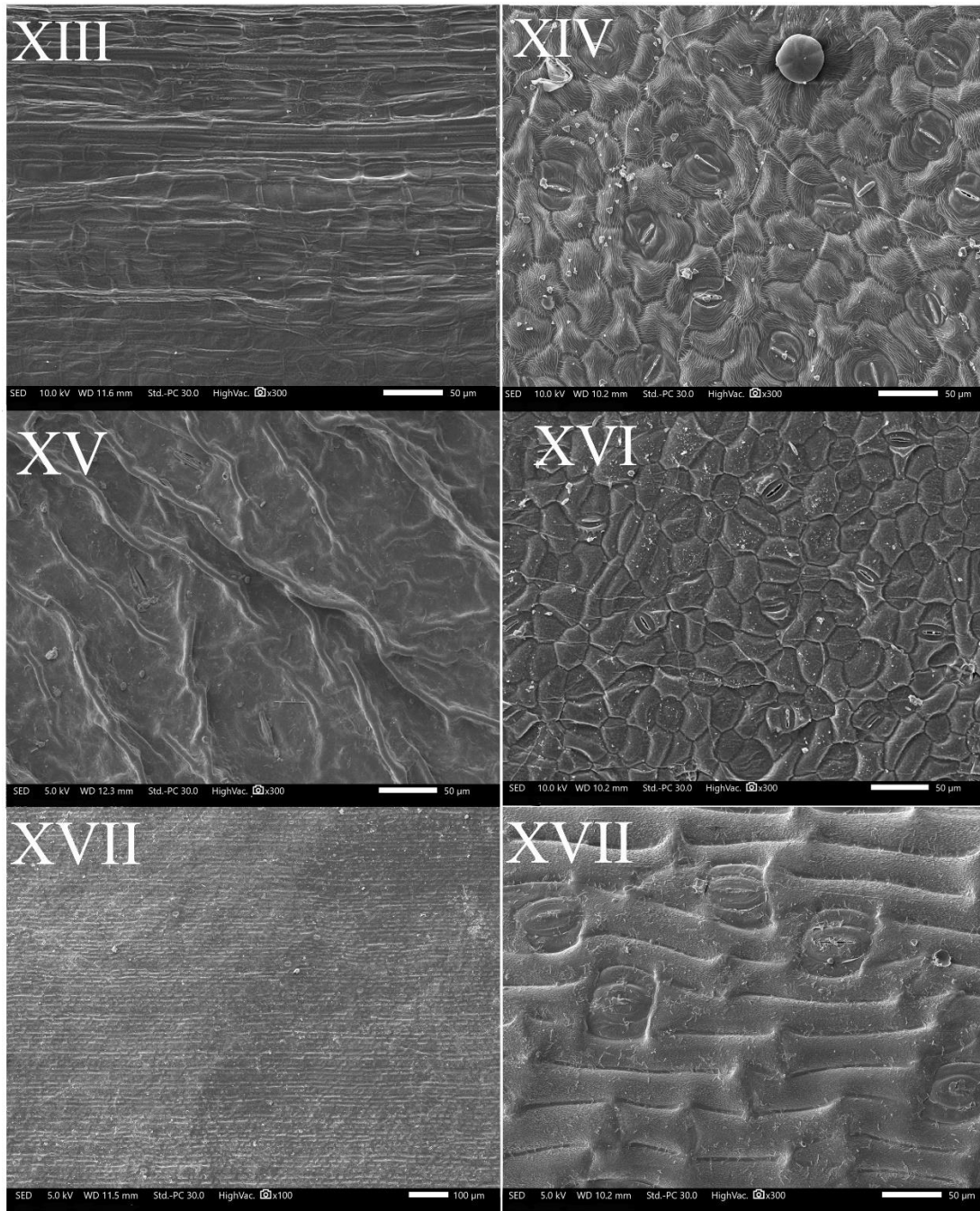


Figure 4.39: The adaxial of XIII. *Fimbristylis polytrichoides*, XIV. *Ipomoea aquatica*, XV. *Lasia spinosa*, XVI. *Persicaria attenuata* subsp. *pulchra*, XVII. *Pandanus yvanii*, XVIII. *Xyris* sp. Magnifications = 100x-300x. Type of stomata hemiparacytic (XIII); paracytic (XIV), (XVI), and (XVIII).

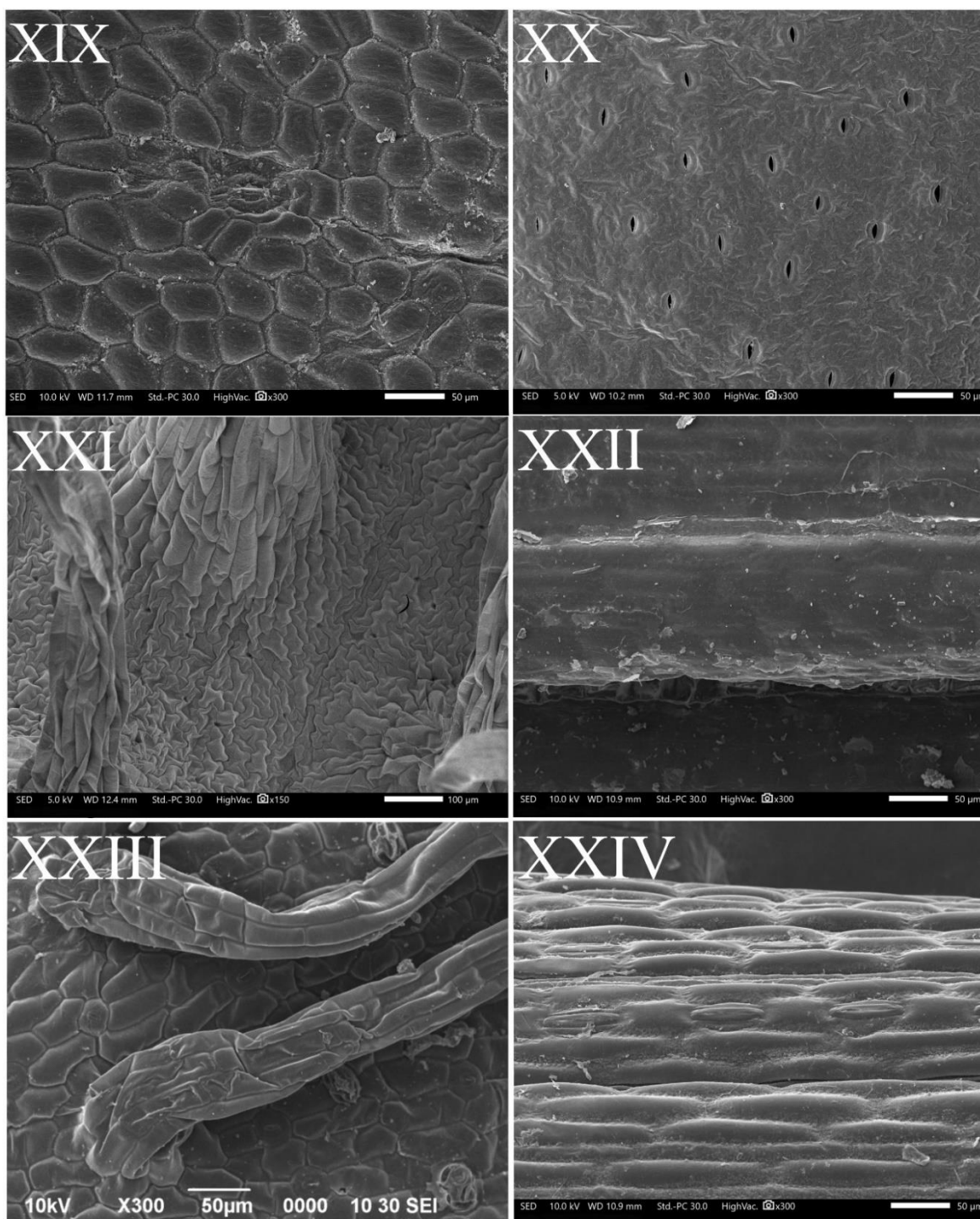


Figure 4.40: The adaxial of XIX. *Cryptocoryne zadiana*, XX. *Lemna minor*, XXI. *Salvinia molesta*, XXII. *Cyperus* sp., XXIII. *Drosera spatulata* var. *bakoensis*, XXIV. *Eriocaulon* sp. Magnification =150x – 300x. Type of stomata tetracytic (XIX); anisocytic (XXI); paracytic (XXII) and (XXIV); pericytic (XXIII).

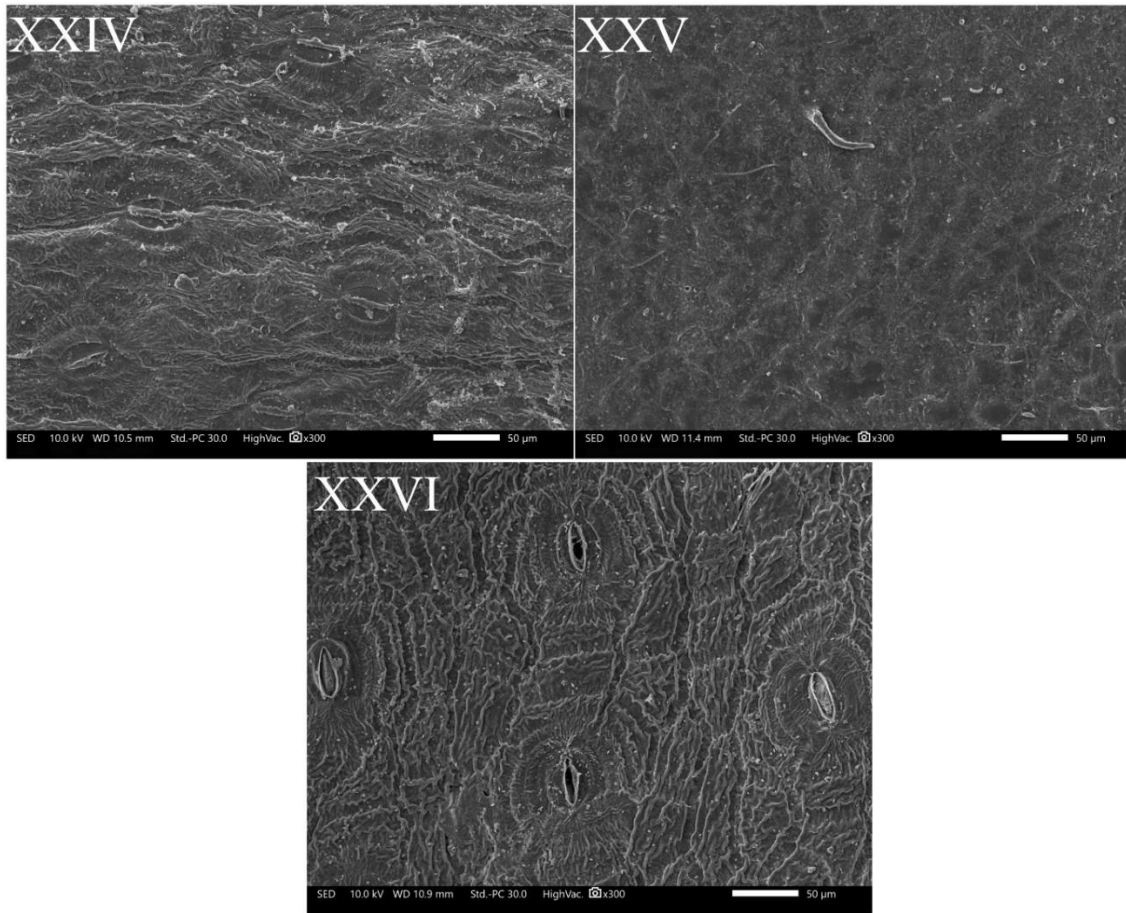


Figure 4.41: The adaxial of XXIV. *Bucephalandra* sp., XXV. *Neonauclea* sp., XXVI. *Rhynchopyle* sp. Magnification = 300x-330x. Type of stomata paracytic (XXIV) and (XXV); tetracytic (XXVI).

Abaxial of 26 species of aquatic and marsh plant:

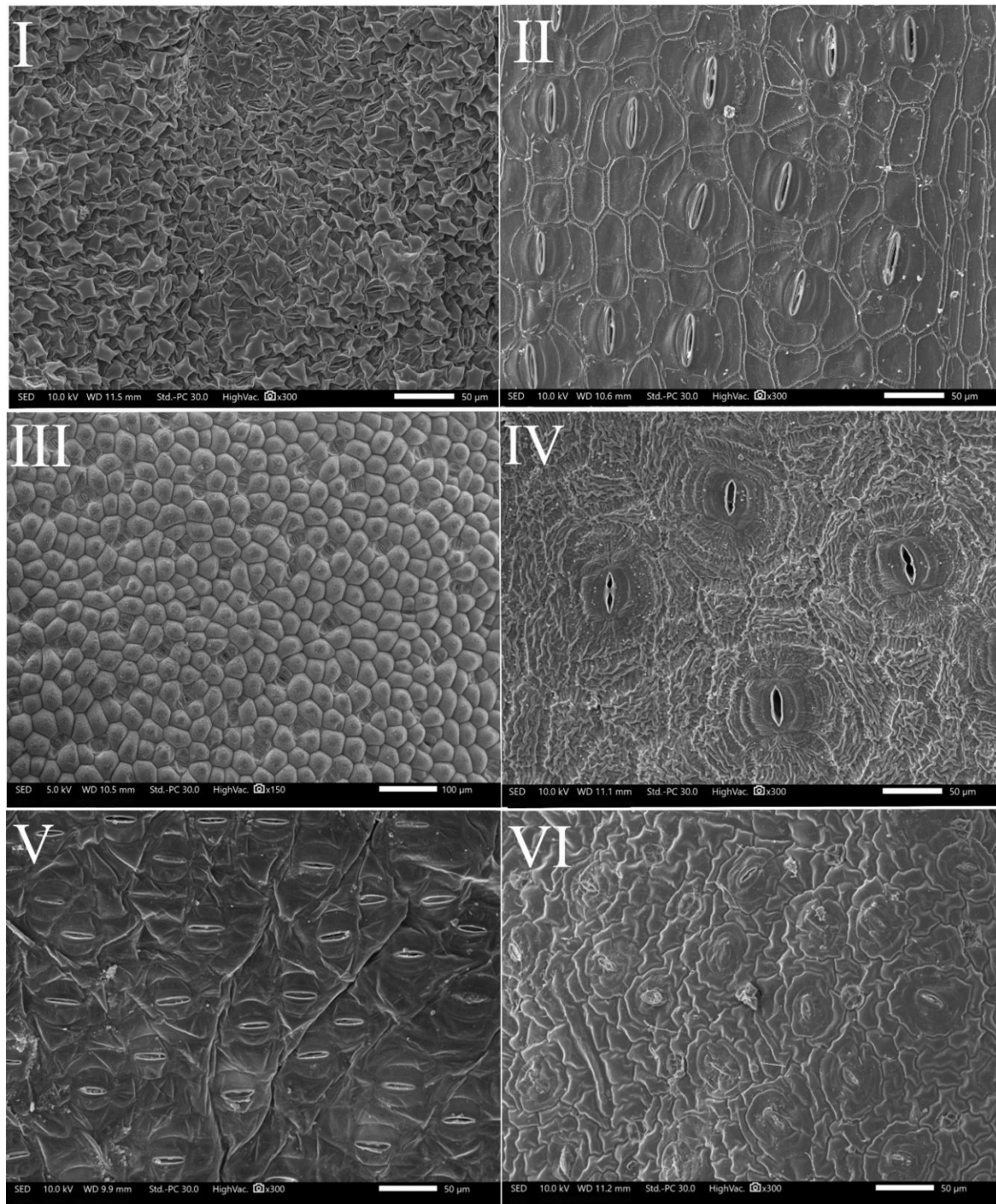


Figure 4.42: The abaxial of I. *Bacopa* sp., II. *Pontederia crassipes*, III. *Limnocharis flava*, IV. *Rhynchosyris* sp., V. *Monochoria hastata*, VI. *Ludwigia repens*. Magnification = 150x – 300x. Type of stomata (II), (II), and (V); tetracytic (IV); diacytic (VI).

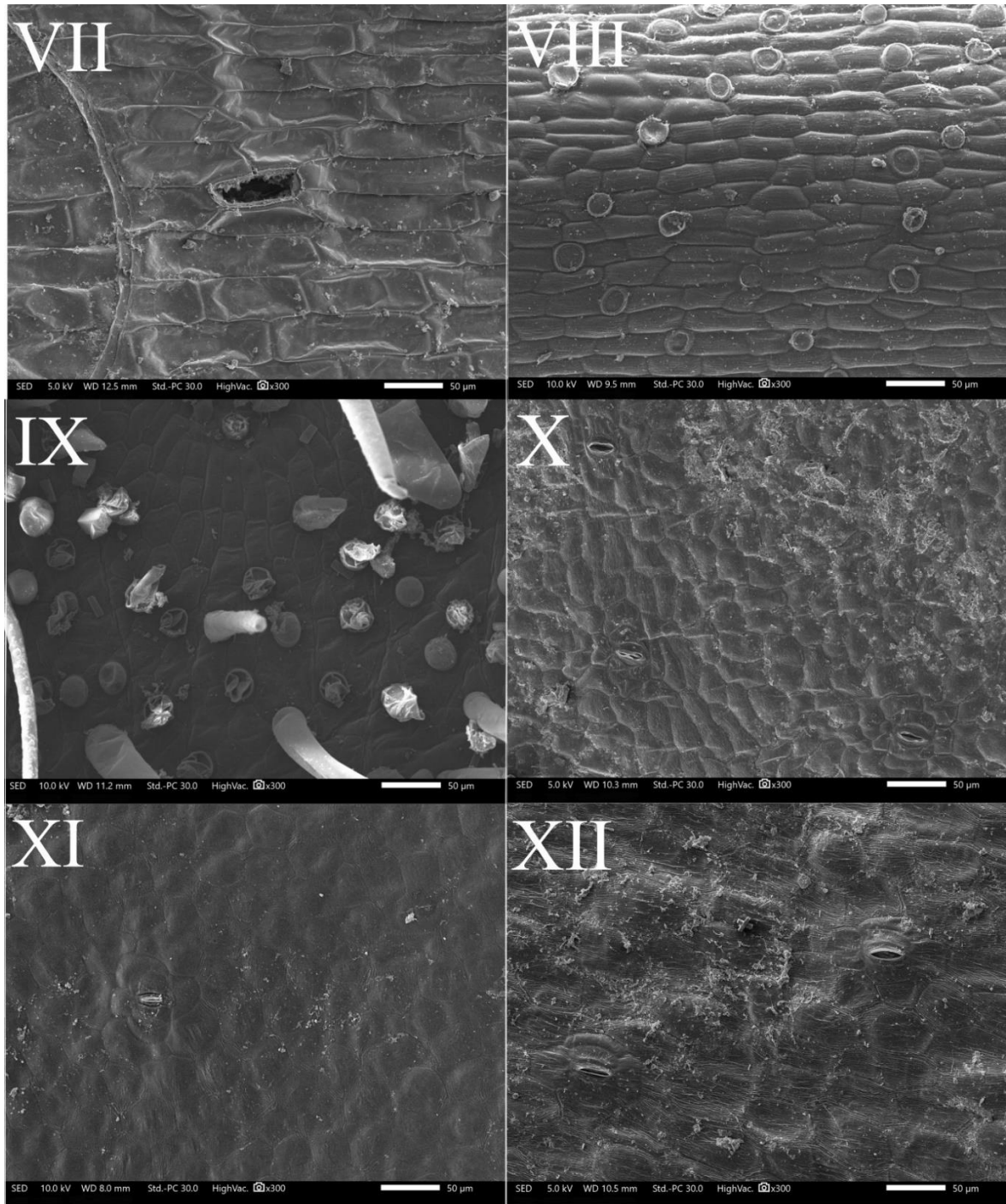


Figure 4.43: The abaxial of VII. *Hydrilla verticillata*, VIII. *Nymphaea nouchalli*, IX. *Barclaya motleyi*, X. *Cryptocoryne auriculata*, XI. *Cryptocoryne lingua*, XII. *Cryptocoryne longicauda*. Magnification = 300x. Type of stomata stephanocytic (IX); tetracytic (X), (XI), and (XII).

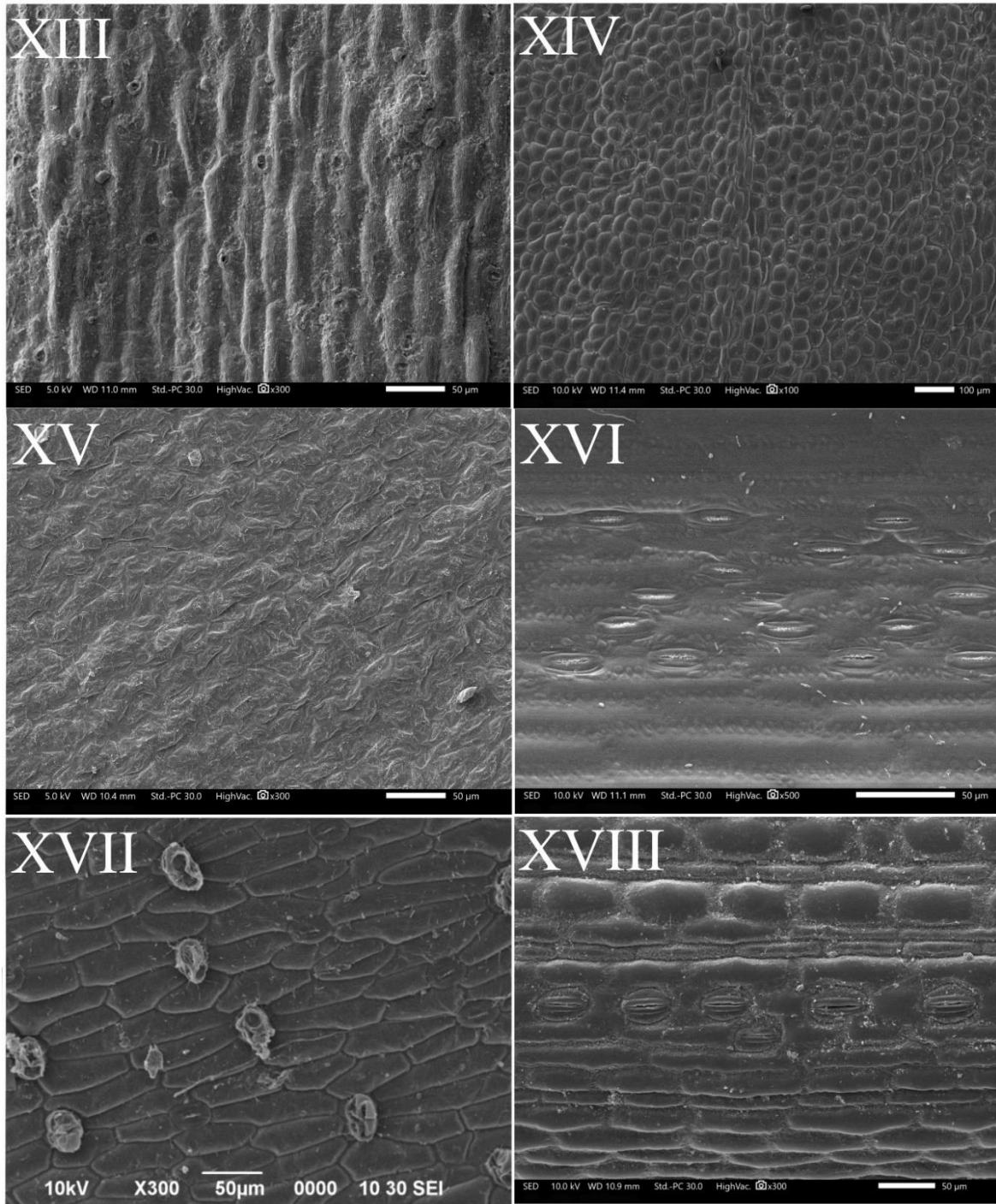


Figure 4.44: The abaxial of XIII. *Cryptocoryne striolata*, XIV. *Cryptocoryne zadiana*, XV. *Lemna minor*, XVI. *Cyperus* sp., XVII. *Drosera spatulata* var. *bakoensis*, XVIII. *Eriocaulon* sp. Magnification = 100x – 500x. Type of stomata tetracytic (XIII) and (XIV); paracytic (XVI) and (XVIII); pericytic (XVII).

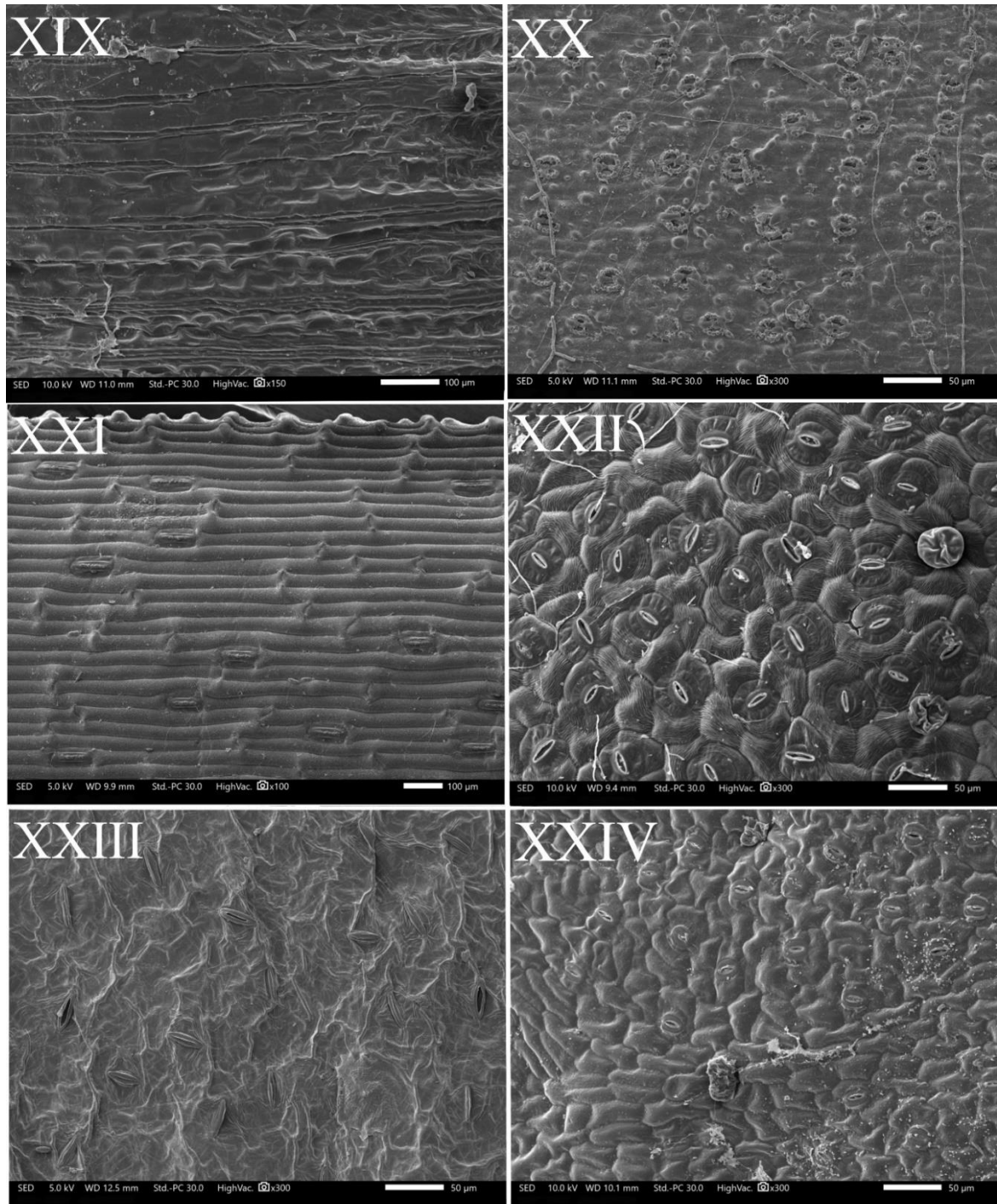


Figure 4.45: The abaxial of XIX. *Fimbristylis polytrichoides*, XX. *Pandanus yvanii*, XXI. *Xyris* sp., XXII. *Ipomoea aquatica*, XXIII. *Lasia spinosa*, XXIV. *Persicaria attenuata* subsp. *pulchra*. Magnification = 100x – 300x. Type of stomata hemiparacytic (XIX); paracytic (XXI), (XXII), and (XXIV).

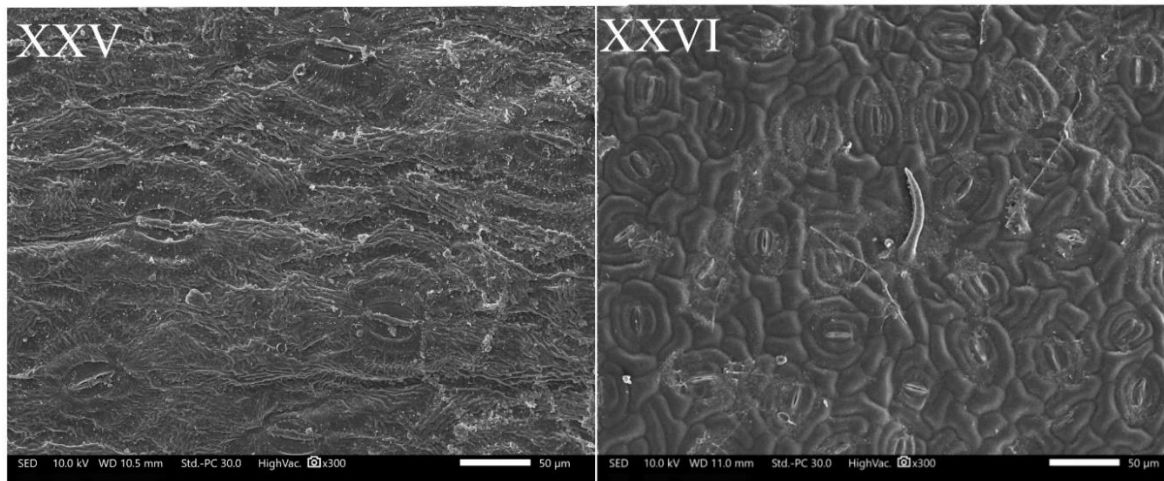


Figure 4.46: The abaxial of XXV. *Bucephalandra* sp., XXVI. *Neonauclea* sp., Magnification = 300x. Type of stomata paracytic (XXV) and (XXVI).

4.3.2.3 Trichome

Plants usually have an epidermis-derived cover such as hairs or trichomes that are the individual components, while an indumentum is the collective cover. The indumentum has adaptive significance, playing a function in plant defense and sometimes in transpiration control (Hewson, 2019). According to Table 4.8, there are eight species of aquatic and marsh plants in Sarawak that have trichomes on the leaf surface. There are five different types of trichome characteristics discovered: unicellular, hydropotes (trichome for aquatic plants), multi-celled glandular, glandular hair, and multicellular uniseriate (molesta type). Figure 4.47 shows the types of trichome presence on eight species.

The eight species that has trichomes are *Barclaya motleyi*, *Cryptocoryne lingua*, *Drosera spatulata* var. *bakoensis*, *Ipomoea aquatica*, *Nymphaea nouchali*, *Ludwigia repens*, *Neonauclea* sp., and *Salvinia molesta*. In the emergent group, *Ipomoea aquatica* are species had trichomes, which was a multi-celled glandular trichome on both the leaf surface. Submerged free floating plant that has trichome on both the leaf surface is *Ludwigia repens* and the type that was found was multi-celled glandular. Next, *Nymphaea nouchali* in the floating leaved group where trichome was only found on the abaxial of the leaf and the type of trichome found was unicellular. *Barclaya motleyi*, same family as *Nymphaea nouchali* but belongs in different group of aquatic lifeform which is in the submerged group. This species has trichome on both sides of the leaves, the type of trichome found was unicellular and hydropotes. Other than *Barclaya motleyi*, species that was found to have trichome on both sides of the leaf from the submerged group lifeform was *Cryptocoryne lingua* where the type of trichome found was unicellular.

Salvinia molesta (emergent free-floating) only has trichomes on the adaxial surface only, which was a multicellular uniserate type of trichome. As for aquatic marsh, only *Drosera spatulata* var. *bakoensis* has presence of trichomes on both sides of leaf surface amongst the six species found in the lifeform. The type of trichomes found was multi-celled glandular and glandular hair, although glandular hair only present on the adaxial surface. Lastly, from the rheophytes group is *Neonauclea* sp. where the type of trichome found was unicellular on both side of the leaf surface.

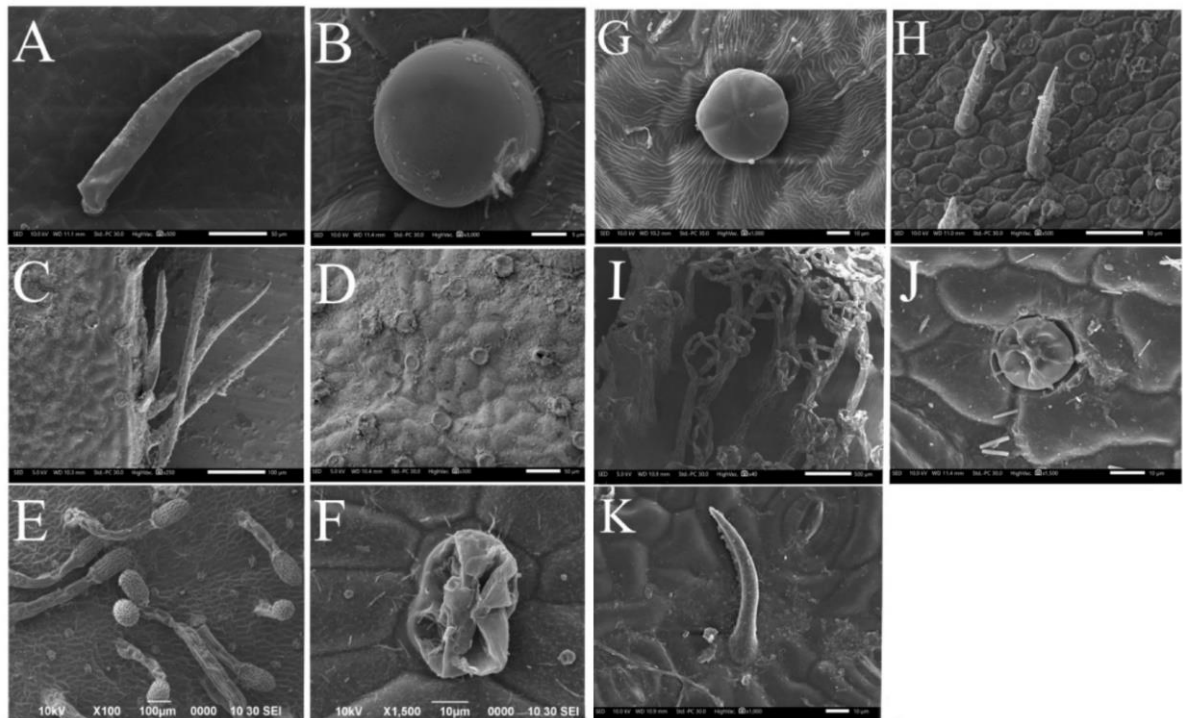


Figure 4.47: Scanning Electron Microscope (SEM) trichome of A. and B. *Barclaya motleyi*, C. and D. *Cryptocoryne striolata*, E and F. *Drosera spatulata* var. *bakoensis*, G. *Ipomoea aquatica*, H. *Nymphaea nouchali*, I. *Salvinia molesta*., J. *Ludwigia repens*, K. *Neonauclea* sp. Magnification = 100x – 3000x. Type of trichome unicellular (A), (H), (C), and (K); hydropotes (B); multicelled glandular (G), (J), and (F); multicellular uniserate (I); glandular hair (E).

4.3.3 Palynology

In the study, 14 species from seven genera and families were identified and were examined. The species are *Ceratopteris thalichoides* var. *thalichoides*, *Cryptocoryne auriculata*, *Cryptocoryne longicauda*, *Drosera spatula* var. *bakoensis*, *Ipomea aquatica*, *Monochoria hastata*, *Limnocharis flava*, *Utricularia aurea*, *U. gibba*, *U. nivea*, *U. subulata*, *U. hirta*, *U. minutissima*, and *U. bifida*. As shown in Table 4.1 (List of studied species collected from western Sarawak and their common or vernacular name)

4.3.3.1 Pollen Characteristics.

In this research the main characters that were described are the aperture type, shape, size, pollen ratio, pollen length (equatorial and polar view), unit, and sculpturing pattern of exine were used to categorise the morphology shown in Table 4.10 and Figure 4.48 showed the pollen found.

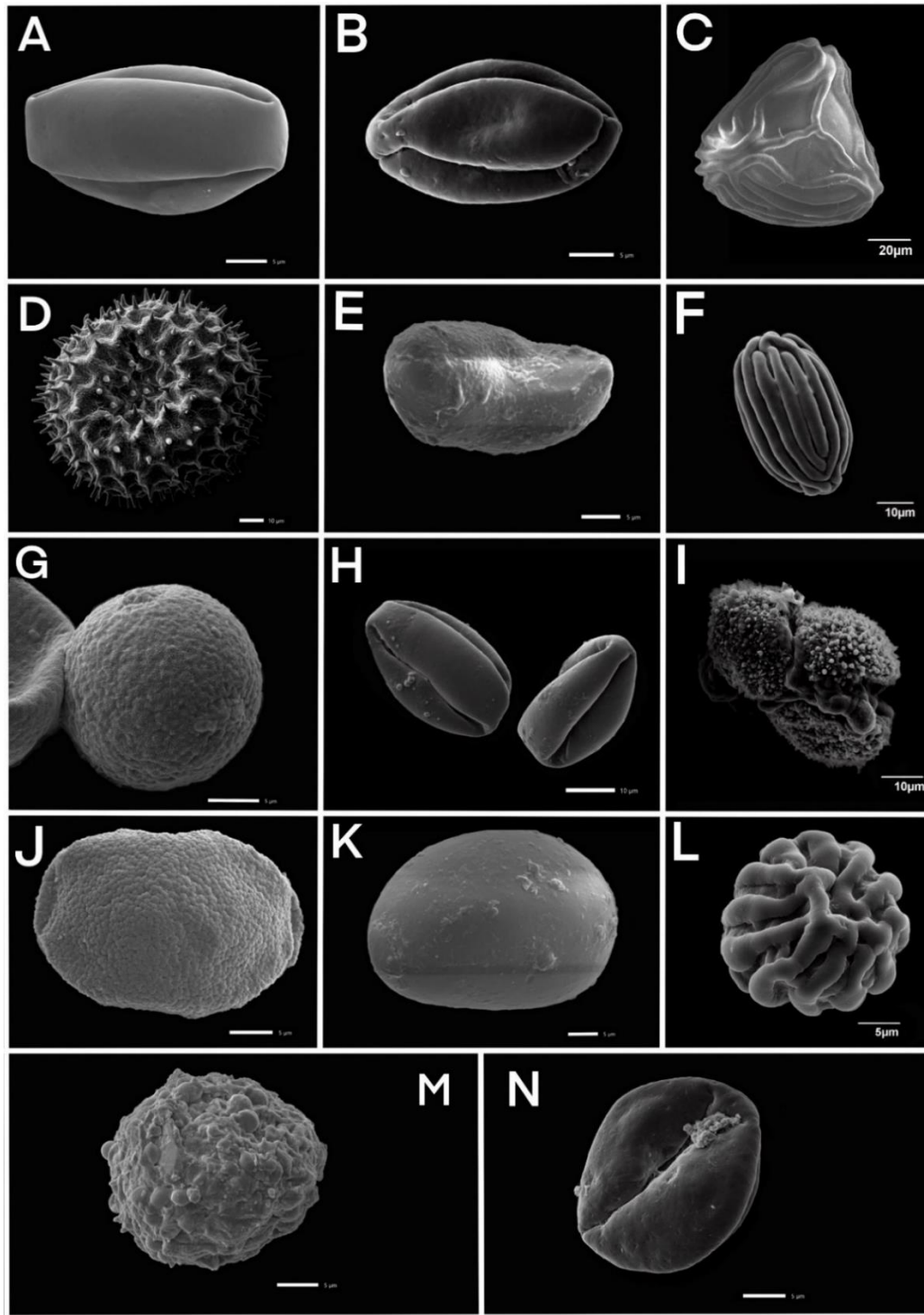


Figure 4.48: Scanning Electron Microscope (SEM) A. Equatorial view, *Utricularia nivea*. B. Equatorial view, *Utricularia minutissima*. C. Polar view, *Ceratopteris thalichoides* var. *thalichoides*. D. Polar view, *Ipomoea aquatica*. E. Equatorial view, *Cryptocoryne longicauda*. F. Equatorial view, *Utricularia aurea*. G. Equatorial view, *Cryptocoryne auriculata*. H. Equatorial view, *Utricularia bifida*. I. Polar view, *Drosera spatulata* var. *bakoensis*. J. Equatorial view, *Monochoria hastata*. K. Equatorial view, *Utricularia hirta*. L. Polar view, *Utricularia gibba*. M. Polar view, *Utricularia subulata*. N. Equatorial view, *Limnocharis flava*.

Table 4.10: Pollen characteristics of 14 species of aquatic and marsh plant from western of Sarawak arranged by alphabetically species.

Species	Size	Shape	Unit	Polar view (µm)		Equatorial view (µm)		Pollen ratio	Aperture	Exine sculpturing
				length	breadth	length	breadth			
<i>Ceratopteris thalictroides</i> var. <i>thalichoides</i>	L	Triangular straight-shell shape	Monad	87.81-94.63	81.27-91.97	84.71-92.27	84.20-93.53	1.03	Inaperture	Rugose
<i>Cryptocoryne auriculata</i>	M	Subprolate	Monad	29.94-42.44	24.37-34.34	30.10-37.42	26.00-31.94	0.61	Inaperture	Psilate and slightly granulate/scabrate
<i>Cryptocoryne longicauda</i>	M	Suboblate	Monad	15.42-25.88	12.83-23.11	26.54-29.52	16.64-19.07	0.74	Inaperture	Psilate and slightly granulate/scabrate
<i>Drosera spatulata</i> var. <i>bakoensis</i>	L	n.d	Monad	59.04-63.03	55.23-62.23	40.29-52.26	41.69-45.78	1.32	n.d	Granulum and nanoclavate
<i>Ipomea aquatica</i>	L	Oblate-spheroidal	Monad	67.88-85.97	64.02-80.63	77.45-97.23	58.08-84.65	0.88	Pantoporate	Echinate
<i>Limnocharis flava</i>	S	Prolate – spheroidal	Dyad	18.29-19.50	18.55-19.96	17.40-19.82	18.35-20.49	1.02	Triporate	Granulate
<i>Monochoria hastata</i>	M	Suboblate	Monad	22.73-24.57	28.33-32.03	28.90-34.60	21.13-25.71	0.75	Monocolpate	Gemmate and clavate
<i>Utricularia aurea</i>	S	Prolate	Monad	21.76-36.23	21.50-35.98	41.66-48.46	20.27-25.98	1.95	Stephanocolpate	Psilate

Table 4.10: Continued

<i>Utricularia bifida</i>	S	Subprolate	Monad	25.88- 27.46	22.13- 25.95	29.90- 34.40	17.90- 21.20	0.83	Tetracolpate	Psilate and slightly perforate
<i>Utricularia gibba</i>	S	Suboblate	Monad	21.69- 21.88	20.18- 24.41	23.11- 31.81	16.36- 26.74	0.79	Stephanocolpate	Psilate
<i>Utricularia hirta</i>	M	Subprolate	Monad	19.65- 23.66	19.40- 32.00	19.40- 32.90	20.35- 30.00	0.83	Tetracolpate	Psilate and slightly perforate
<i>Utricularia minutissima</i>	M	Subprolate	Monad	17.39- 20.61	14.72- 16.33	16.20- 25.33	28.60- 35.40	0.92	Tetracolpate	Psilate and slightly faveolate
<i>Utricularia nivea</i>	M	Subprolate	Monad	19.65- 28.00	16.03- 23.34	31.60- 34.56	17.88- 22.56	0.72	Tricolpate	Psilate and slightly perforate
<i>Utricularia subulata</i>	S	Suboblate	Monad	14.90- 20.27	13.50- 14.86	17.24- 23.97	13.68- 26.36	0.85	Tricolpate	Granulum

4.3.3.2 Pollen Morphology

A pollen key to the studied species by structure of pollen characters

- 1a. Pollen unit Monad ----- 2
- 1b. Pollen unit Dyad----- *Limnocharis flava*
- 2a. Pollen aperture absent, inaperture-----3
- 2b. Pollen aperture present, aperture more than one-----5
- 3a. Pollen sculpture rugose-----*Ceratopteris thalichoides*
- 3b. Pollen sculpture psilate and slightly grabulate/ scabate-----4
- 4a. Pollen shape subprolate----- *Cryptocoryne auriculata*
- 4b. Pollen shape suboblate----- *Cryptocoryne longicauda*
- 5a. Aperture one, monocolpate ----- *Monochoria hastata*
- 5b. Aperture more than one, other than monocolpate----- 6
- 6a. Aperture three, ----- 7
- 6b. Aperture more than 3, ----- 8
- 7a. Pollen sculpture granulum ----- *Utricularia subulata*
- 7b. Pollen sculpture psilate and slightly perforate ----- *Utricularia nivea*
- 8a. Pollen aperture porate, pantoporate----- *Ipomea aquatica*
- 8b. Aperture colpate, stephanocolpate or tetracolpate-----9
- 9a. Number of colpi four, tetracolpate-----10

- 9b. Number of colpi more than four, stephanocolpate-----12
- 10a. Pollen sculpture psilate and slightly faveolate ----- *Utricularia minutissima*
- 10b. Pollen sculpture psilate and slightly perforate ----- 11
- 11a. Pollen size of pollen more than 25 μm -----*Utricularia hirta*
- 11b. Pollen size of pollen less than 20 μm ----- *Utricularia bifida*
- 12a. Pollen shape prolate, size more than 23 μm ----- *Utricularia aurea*
- 12b. Pollen shape suboblate, size less than 23 μm ----- *Utricularia gibba*

*Exclude *Drosera spatulata* var. *bakoensis* due to lack of data

4.3.3.3 Pollen description

1. *Ceratopteris thalictroides* var. *thalictroides*

Inaperture, triangular straight-shell shape, large, monad, 87.81-94.63 x 81.27-91.97 μm in length and breadth, 84.71-92.27 x 84.20-93.53 μm in length and breadth, pollen ratio 1.95, sculpturing rugose.

2. *Cryptocoryne auriculata*

Inaperture, subprolate, medium, monad, 29.94-42.44 x 24.37-34.34 μm in length and breadth, amb bean shape, 30.10-37.42 x 26.00-31.94 μm in length and breadth, pollen ratio 0.61, sculpturing psilate and slightly granulate/ scabrate.

3. *Cryptocoryne longicauda*

Inaperture, suboblate, medium, monad, 15.42-25.88 x 12.83-23.11 μm in length and breadth, amb bean shape, 26.54-29.52 x 16.64-19.07 μm in length and breadth, pollen ratio 0.74, sculpturing psilate and slightly granulate/scabrate.

4. *Drosera spatulata* var. *bakoensis*

Not define, suboblate, medium, monad, 27.64-30.33 x 23.38-27.53 μm in length and breadth, 31.50-34.22 x 24.89-25.91 μm in length and breadth, pollen ratio 0.88, sculpturing clavate and baculite.

5. *Ipomea aquatica*

Pantoporate, oblate-spheroidal, large, monad, 67.88-85.97 x 64.02-80.63 μm in length and breadth, amb circular; equidistantly distributed, pori circular; 3.40-4.65 μm in diam, 77.45-97.23 x 58.08-84.65 μm in length and breadth, spine is 3.9-6.0 μm long, sculpturing echinate, spine is 3.9-6.0 μm in length, slender, pollen ratio 0.88.

6. *Limnocharis flava*

Triporate, prolate-spheroidal, small, dyad, 18.29-19.50 x 18.55-19.96 µm in length and breadth, amb rounded triangular, 18.61-19.42 µm in length and breadth, pollen ratio 1.02, sculpturing granulates.

7. *Monochoria hastata*

Monocolpate, suboblate, medium, monad, 22.73-24.57 x 28.33-32.03 µm in length and bread, colpi $\frac{3}{4}$ way up to the pole, 28.90-34.60 µm in length and breadth, pollen ratio 0.75, sculpturing gemmates and clavate.

8. *Utricularia aurea*

Stephanocolpate, prolate, medium, monad, 21.76-36.23 x 21.51-35.98 µm in length and breadth, amb circular, colpi long and narrow; the ends of colpi are anastomosed, 41.66-48.46 µm x 20.27-25.98 µm in length and breadth, pollen ratio 1.95, sculpturing psilate.

9. *Utricularia bifida*

Tetracolpate, subprolate, small-medium, monad, 25.88-27.46 x 22.13-25.95 µm in length and breadth, amb circular; colpi $\frac{3}{4}$ way up to the pole, 29.9-34.4 x 17.9-21.2 µm in length and breadth, pollen ratio 0.83, sculpturing psilate and slightly perforate.

10. *Utricularia gibba*

Stephanocolpate, suboblate, small, monad, 21.69-21.88 µm length and breadth, amb circular, colpi long and narrow; the ends of colpi are anastomased, 23.11-31.81 µm in length and breadth, pollen ratio 0.79, sculpturing psilate.

11. *Utricularia hirta*

Tetracolpate, subprolate, small-medium, 19.65-23.66 x 21.73-32.00 μm in length and breadth, amb circular; colpi $\frac{3}{4}$ way up to the pole, 19.40-32.90 x 20.35-30.00 μm in length and breadth, pollen ratio 0.83, sculpturing psilate and slightly perforate.

12. *Utricularia minutissima*

Tetracolpate, subprolate, small, 17.39-20.61 x 14.72-16.33 μm length and breadth, amb circular; colpi $\frac{3}{4}$ way up to the pole, 16.20-25.33 x 28.60-35.40 μm in length and breadth, pollen ratio 0.92, sculpturing psilate and slightly foveolate.

13. *Utricularia nivea*

Tricolpate, subprolate, small-medium, monad, 19.65-28.00 x 16.03-23.34 μm in length and breadth, amb circular; colpi $\frac{3}{4}$ way up to the pole, 31.60-34.56 x 17.88 – 22.56 μm in length and breadth, pollen ratio 0.72, sculpturing psilate and slightly perforate.

14. *Utricularia subulata*

Tricolpate, suboblate, small, monad, 14.90-20.27 x 13.50-14.86 μm in length and breadth, amb circular, 17.24-23.97 x 13.68-26.36 μm in length and breadth, pollen ratio 0.85, sculpturing granulum.

CHAPTER 5

DISCUSSIONS

5.1 Diversity and Distribution of Aquatic and Marsh Plant Western Sarawak

The results that are presented here reveal information about several important characteristics of the aquatic plant ecosystems in western Sarawak. A total of 50 taxa was found in western Sarawak, whereas according to Malaysia Biodiversity Information System (MyBIS) (<https://www.mybis.gov.my/one/>) by Malaysia Biodiversity Centre (MBC) et al. (2023) total of 36 species are native all of which developed and adapted to their natural habitat which exhibiting distinctive ecological trait that support the overall health and equilibrium of the surrounding aquatic ecosystems. As for native species, most occur only in a relatively small area. However, *Barclaya motleyi* is one of the native species that are often found in western Sarawak. This species is considered rare (other than *Cryptocoryne*) due to the plants having typical habitat, which is clear, shallow waters with slow-moving currents, such as streams.

There are 10 species are non-native and the remaining four species are unknown according to MyBIS. Among the 10 non-native species, three species are invasive (*Pontederia crassipes*, *Ludwigia leptocarpa*, and *Salvinia molesta*) and two are introduced or exotic species (*Limnocharis flava* and *Typha angustifolia*). Grace College (2021) mentioned that a native species is one that evolved in its natural environment and has adapted to living in that environment (it has the potential to become aggressive, much like an invasive species). While invasive plants outcompete other species. Inflicting ecosystem damage, non-native plants originated somewhere other than their current site and were introduced to the area where they now exist (also called exotic species). An alien species has been

unintentionally or deliberately introduced by man into regions outside of its normal geographic distribution. In this situation, any organism species that have been unintentionally or knowingly introduced into Malaysia is classified as an alien species (Faridah-Hanum & Latiff, 2021).

Globally, biological invasions are regarded as risks to native biodiversity and ecological function (Kolar & Lodge, 2001). Yet, the management of exotic species is frequently impeded by a lack of knowledge about their life cycle traits. Vegetative or sexual reproduction is an important step in the spread and maintenance of imported plants (Richardson et al., 2000). To handle biological invasions effectively, significant information of the invading species' reproduction and propagation strategies is required (Forman & Kesseli, 2003).

During the field survey, the invasive plants *Pontederia crassipes*, *Ludwigia leptocarpa*, and *Salvinia molesta* were observed to be aggressive and successfully conquering the aquatic ecosystem. Figure 5.1 depicts an invasive plant found in western Sarawak taking over an ecosystem. *Salvinia molesta* has taken over the UNIMAS lake and drainage system, which were previously inhabited by *Nymphaea lotus*, *Ludwigia repens*, and *Hydrilla verticillata*. After *Salvinia molesta* was introduced and established in the environment, the other species were no longer detected growing in the lake. According to Luque et al. (2014) *Salvinia molesta* is the world's fastest-colonising weed. When *Salvinia* invades a waterbody, it quickly covers it from bank to bank, edging out all other free-floating aquatic plants and cutting off sunlight from benthic vegetation. This limits the photosynthetic and aerial replenishment of oxygen in the water lying beneath the *Salvinia* carpet, wreaking havoc on the water's physicochemical quality (Hussain et al., 2016).

Pontederia crassipes and *Ludwigia leptocarpa*, on the other hand, is expected to become an issue. Figure 5.1 (A) showed the *Pontederia crassipes* in ditches beside paddy fields, situated at the Kota Samarahan wayside, and this will cause limits to the water flow and quality in the agricultural areas. Center (1994) mentioned that *Pontederia crassipes* is one of the world's most invasive aquatic plants, with serious ecological and socioeconomic implications. According to Denny (2012), this is because, due of its high reproduction rate and complicated root structure, it frequently produces dense, interconnecting mats. Meanwhile, *Ludwigia leptocarpa* has taken over the UNIMAS drainage system, causing water flow to be restricted. According to Thouvenot et al. (2013) certain water primroses, which occur in both aquatic and riparian habitats in various geographic regions, are among the most problematic invasive aquatic plants. It is critical to eliminate these invasive aquatic species before they establish themselves and to ensure that they are not introduced into new areas. These species spreads rapidly, forming dense mats on water surfaces, causing significant ecological damage while it also out-competing native species and reducing the biodiversity of freshwater habitats.

An in-depth understanding of the life cycle features, reproductive strategy, and ecological impact of these invasive species is necessary for their management. To protect native species, contain invasive alien species is crucial for their management, and re-establish the ecological equilibrium of the area, conservation programmes and action plans become crucial. According to Hussner et al. (2017) there has no single technique that works in every condition, despite the fact that many have developed to control invasive aquatic plants. Also, the study delves deeply into the morphological and palynological traits of these species, providing important resources for identifying the species and reaching conclusions regarding their diversity. This study greatly advances the understanding of aquatic plant

communities by addressing these diverse aspects. It also fosters a more thorough understanding of the ecological attributes of these communities, providing a foundation for conservation initiatives to protect and preserve the important ecosystems.

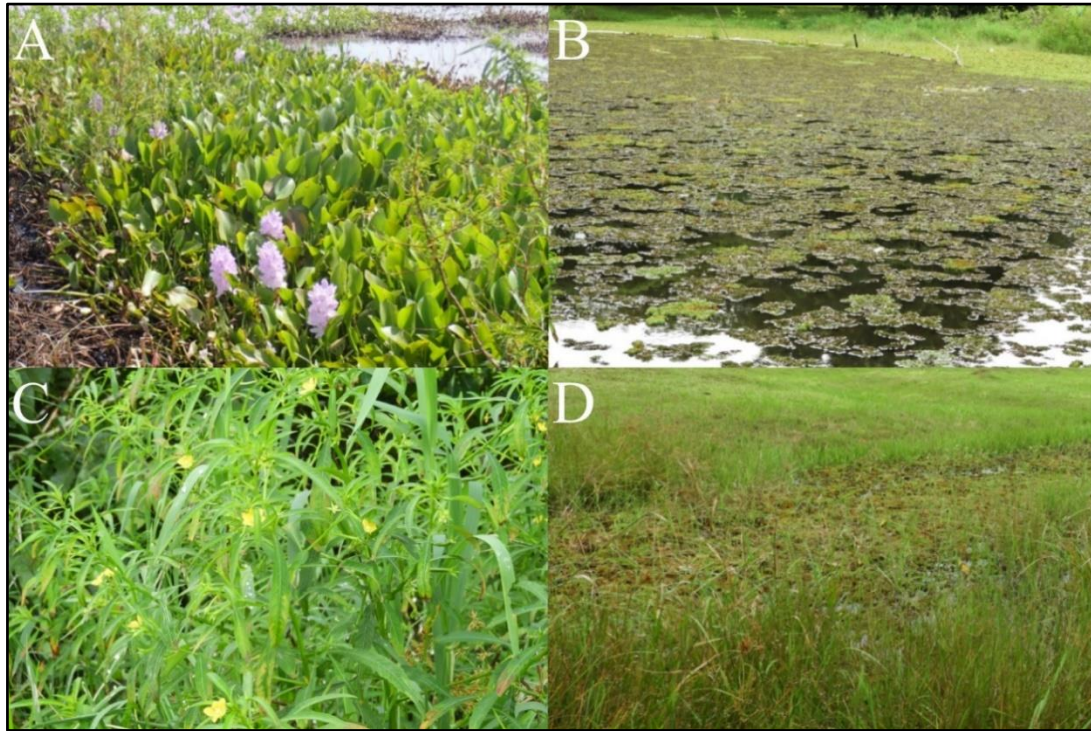


Figure 5.1: Invasive plant found in western Sarawak. A. habit of *Pontederia crassipes* dominating at Kota Samarahan roadside. B. *Salvinia molesta* and *Ludwigia leptocarpa* dominates the lake of UNIMAS. C. *Ludwigia leptocarpa* at UNIMAS lake. D. *Salvinia molesta* dominating lake and drainage system in UNIMAS.

Topography plays an important role in aquatic plants. The majority of aquatic macrophytes are common and well-suited to their environment (Srivastava et al., 2008). Results showed that the species diversity in the Samarahan division is the highest with 32 taxa, indicating significant species richness, which correlates to the topography where the elevation of Samarahan is the lowest compared to the other two divisions (Kuching and Serian). Species richness, representing the number of different species present, is a key

metric used to measure diversity. As the result shown in Table 4.2, the species found in the Samarahan area mostly ranged from 5 to 65 metres in elevation. Figure 5.2 shows the topographic map of Sarawak; about the map, it is observed that the majority of the Samarahan area's elevations are below 96 metres. Based on the results in Table 4.2, the highest altitude of aquatic species found in Samarahan was 65 metres. Meanwhile, the topography in the Kuching division was a mixture of both high and low altitudes. The lowest altitude of aquatic and marsh species found in Kuching was 10 metres and situated at Bako National Park, while the highest aquatic species found were in Santubong National Park with an elevation of 816 metres.

According to the map in Figure 5.2, the geography of Serian is primarily high elevation, up to 1300 meters, and there are fewer waterbodies than in Samarahan and Kuching. The species recorded in Serian, on the other hand, were largely found in man-made lakes and ditches at an elevation of 14 metres. The majority of aquatic and marsh plants discovered in Samarahan were located in coastal vegetation, ditches, and artificial lakes. Kuching could be found largely in rivers, streams, and ditches. Based on the findings, Collin III and Likens (1969) predicted that as altitude increases, the number of genera and species decreases. According to the Clarke (1955), aquatic species adapt and adjust inclimatic extremes; consequently, environmetal circumstances deteriorated as altitude increased. However, the effects of lower temperatures, as altitude rose had a considerable impact on the distribution of plants and animals. Based on the species found it is agreeable to the statement given by authors.

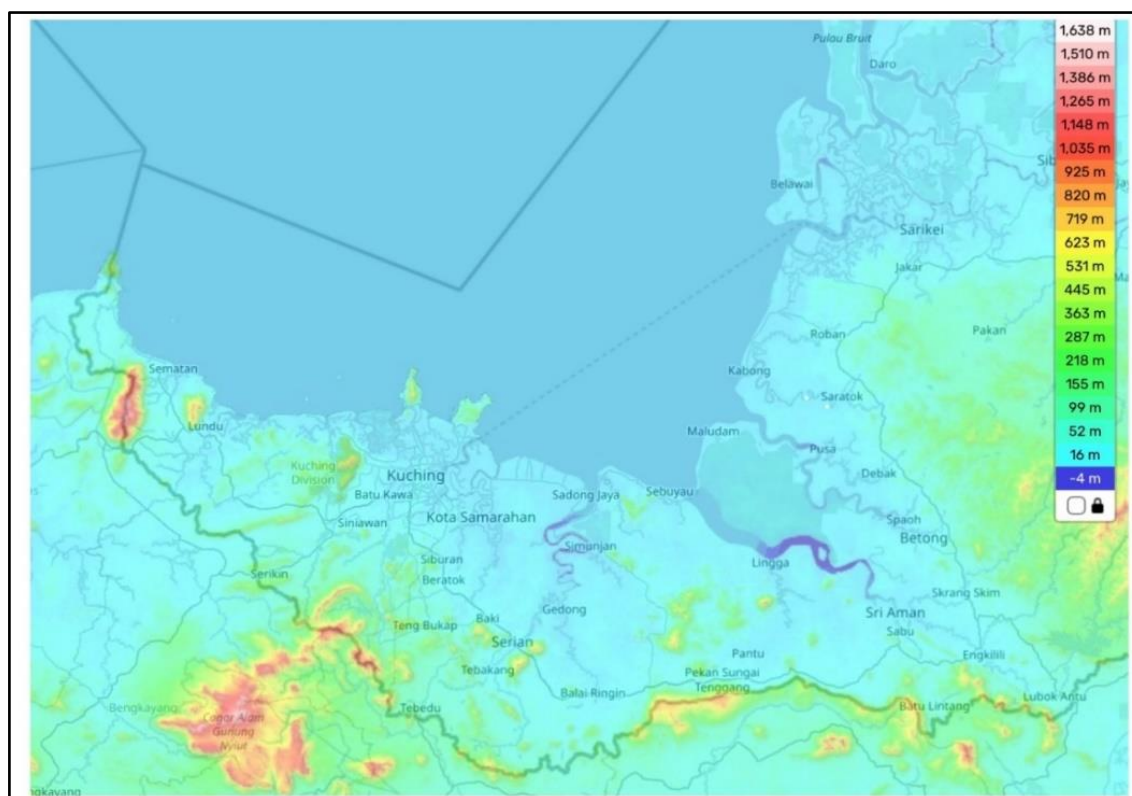


Figure 5.2: The Sarawak topographic map, elevation, terrain. Note: The data for Sarawak topography are from “Sarawak topographic map”, by topographic-map.com, World topographic map.

The pH and temperature of water also have an impact on the distribution and diversity of aquatic and marsh plants. For optimal growth, different plant species have distinct pH requirements, and changes in pH might impact their distribution. Based on the results, generally the temperature of aquatic and marsh plant found in western Sarawak ranges between 26 °C to 33.0 °C. This data was agreed with Kasselmann (2003), who stated that studies on terrestrial plants have revealed that the ideal temperature for tropical or subtropical plants is between 30 and 40 °C, and for all other species it is between 15-30 °C mentioned by Larcher in 1984. He also discovered that plants had adapted to temperature changes between night and day in their natural environments. Therefore, based on the results in Table 4.5, the temperatures of aquatic and marsh species found were all within their

optimum range. Temperature can also influence aquatic plant growth and distribution, as many species have specific temperature requirements for optimal growth. According to Kirk (1994), water temperature regulates aquatic plant productivity by influencing the pace at which chemical reactions occur. For example, the invasive plant *Salvinia molesta* prefers temperatures between 27 and 30 °C, while Cary and Weerts (1983) prefer temperatures between 24 and 28 °C. This explains the invasive growth within the lake at UNIMAS.

The concentration of hydrogen ions in solution is measured by pH, which is regarded as a master variable due to its influence on chemical processes and aquatic life. The pH of neutral water is 7, pH values less than 7 are acidic, and pH values more than 7 are alkaline. The majority of aquatic life enjoys pH levels between 6.5 and 8. (Laxson & Kelting, 2013). With the exception of two *Cryptocoryne* species, the pH of the aquatic and marsh species discovered ranged from acidic to neutral. According to Hutchison (2005), Sarawak is divided into two geological zones: the Sunda Shield, which extends southwest from the Batang Lupar River (near Sri Aman) and forms the state's southern tip, and the geosyncline region, which extends northeast to the Batang Lupar River and forms the state's central and northern regions.

Up to 60 per cent of the soil in Sarawak consists of lithosols and 12 per cent consists of podsols, while the coastal and riverine regions are replete with alluvial soil. 12 per cent of Sarawak consists of peat swamp forests. Limestone with well-developed karst topography and cave systems is dispersed from the west to the east of Sarawak but concentrated in some locations, such as the Bau district in the west and the region south of Kalimantan. Based on the geological zones described by Hutchison, this explains how *Cryptocoryne auriculata* can survive in an alkalinity environment due to the locality found in the Bau district in a limestone forest, where the pH of the water gives off an alkalinity result. According to

Omernik et al. (2018), if the landscape is in a region with limestone-containing rocks, then runoff compounds like calcium carbonate (CaCO_3), which increases the pH and alkalinity of the water, will be present. Thus, among all the species of aquatic plants found, *C. auriculata* has the highest pH of water due to its habitat in a limestone forest. According to Laxson and Kelting (2013), a high-alkalinity lake has a more consistent pH than a low-alkalinity lake, and a more stable pH is less stressful to aquatic life.

Alkalinity is determined by the concentration of calcium carbonate in the water, and lakes with fewer than 10 ppm of calcium carbonate are more prone to acidification, but lakes with more than 20 ppm of calcium carbonate are not. *Cryptocoryne cordata* var. *zonnata* was also discovered in alkaline pH water. The rest of the *Cryptocoryne* species were discovered in water with an acidic pH. This locality distinguished the *Cryptocoryne* species found in alkaline and acidic water. The Kuching division had both *Cryptocoryne* species (*C. auriculata* and *C. cordata* var. *zonnata*), while the remainder of the *Cryptocoryne* species (excluding *C. lingua* and *C. zadiana*) were discovered in the acidic pH and Samarahan divisions. However, *C. cordata* var. *zonnata* was found in alkaline water, which contradicts Kasselman's statement.

5.2 Morphological Characteristics of Aquatic and Marsh Plant in Western Sarawak

Aquatic and marsh plant has a broad range of lifeform where it is widely discussed and categorized by researchers. Some divided their lifeforms or habits into categories such as de Moura-Junior et al. (2013) where there categorized aquatic plant into seven lifeforms (amphibious, emergent, epiphyte, free-floating, free-submerged, rooted-floating and rooted submerged) while Muhlberg (1982) categorized aquatic lifeform into four habitats which were alder swamp, reed-belt, zone of floating plants and some of submerged plants. However

Hu et al. (2021), had categorized the life form into three types which were emergent plants, floating-leaved and submerged plants in various aquatic habitats in northeastern China. Schuyler (1984) had categorized the life forms and growth of aquatic plant into two habit which was (I) pleustophytes (floating free from substrate) while there are two types for the first category which is vegetative plant body underwater and on water surface. Next type (II) is plant's root system in or on substrate which is either submergents, planmergents or emergents. Based on this research, aquatic plants were categorized into seven types of lifeform which were emergent, floating leaved, emergent free floating, submerged, submerged free floating, rheophytes and aquatic marsh plant.

Rheophytes are aquatic plants found in tropical rainforests with swift water currents, where few other species can thrive. Van Stennis (1981, 1987) introduced the word 'rheophytic' in an ecological context, focusing on vascular plants growing in the water column of riparian habitats, where the plants are impacted by flood to seasonal submersion. He classified rheophytic plants as "species that are naturally restricted to the beds of swift-moving water and rivers and flourish there up to the flood level, but not beyond the reach of frequent flash floods". As a potential habitat type for colonisation, riparian systems are by nature highly disturbed environments. It is believed that the fluctuating variability of disturbances is one of the key elements influencing rheophyte colonisation. After rainfall, many plants that grow on rocks or trees near streams, rivers, and waterfalls may be submerged in quickly moving water for as little as a few hours. These plants are known as "rheophytes", which are not considered aquatic plants due to their terrestrial vegetative growth and reproduction (Khan, 1990). Although some experts are still debating whether or not rheophytes belong to the aquatic category, it is generally accepted that they are. In this study, we classified rheophytes as aquatic plants based on the habits. While the species that

are in the marsh category are still controversial; according to Mulhberg (1982) it is impossible to create a clear distinction between the plants of the water and those of the land water interface. According to Parlan et al. (2021) the classification system for wetland type generally identifies five primaries categorise: palustrine (marshes, swamps, and bogs); marine (coastal wetlands including coastal lagoons, rocky shores, and coral reefs); estuarine (including deltas, tidal marshes, and mangrove swamps); lacustrine (wetland associated with lake); and riverine (wetlands along rivers and streams).

The flower features serve as vital identifiers. In this research majority of the flower type is actinomorphic and zygomorphic, there are 16 species of aquatic plant that is actinomorphic, and 15 species was zygomorphic while the rest of the species is not defined. Paleontological and phylogenetic research have demonstrated that floral zygomorphy (bilateral symmetry) has separately evolved in multiple plant groups from the actinomorphic (radially symmetric) ancestors because of severe selection applied by specialised pollinators (Gomez et al., 2006). They also mentioned that the result demonstrated that the plants with zygomorphic flowers have attracted more pollinators and had the highest fitness, as determined not just by the number of seeds generated per plant but also by the number of seeds generated per plant but also by the number of seeds that survived to the juvenile stage. The number of emergent plants Table 4.6 showed that majority of the plants in the emergent lifeform are actinomorphic type of flower. Most aquatic and marsh plants have their flowers or inflorescences formed above water. According to Kasselman (2003) pollination happens via insects and/or wind in the most of aquarium plants, the majority of which are marsh plants and flowers or inflorescences that are created outside the water.

5.3 Stomata and Trichome Characteristics of Aquatic and Marsh Plant in Western Sarawak

Small pores which are found on the surfaces of leaves, stems, and are surrounded by a pair of guard cells are called stomata, they regulate the flow of gases, mainly CO₂ and water vapor between the inside of leaves and atmosphere (Hetherington & Woodward, 2003). For plants to perform photosynthesis, the process of gases exchange will go through the stomata. Aquatic plants with floating leaves, like waterlilies, have stomata on the upper surface of the leaves, epistomatic. Additionally, in some aquatic plants, the stomata are only present on the upper surface of floating leaves such as water fern, but aerial leaves have stomata on both surfaces. Most submerged aquatic plants lack stomata, and gas transport between the water and plant tissues happens over a thin cuticle (Willmer & Fricker, 1996).

The stomata distribution of aquatic plants was agreeing with the result as Willmer and Fricker findings, the *Nymphaea nouchalli*, *Lemna minor* and *Salvinia molesta* stomata observed was present with stomata on the adaxial. These species are grouped into floating-leaved and emergent free-floating. They also mentioned that most submerged aquatic plants, do not possessed stomata and sometimes the aerial leaves have stomata on both leaf surfaces, it has proven based on Table 4.6, the results showed that two species from the submerged group; *Ludwigia repens* and *Hydrilla verticillata* where one had stomata on both sides of the leaf while the other with no stomata. *Ludwigia repens* has an amphistomatic character, while *Hydrilla verticillata* has no stomata presence on either side of leaves. The outcome of *Hydrilla verticillata* was in line with previous research and validated by Begam and Choudi (1993). However, for *Barclaya motleyi* the present of stomata were found on both sides of the leaf. These results found were opposite from the findings by Kordyum et al. (2021) where they stated that a homogenous mesophyll that is not differentiated into palisade and spongy

parenchyma that are characterized into floating leaves, submerged leaves, and aggregated in a rosette on the sediment; the adaxial and abaxial have no stomata on the leaf surface.

The genus *Cryptocoryne* were understudied on their stomata characteristics. A total of five *Cryptocoryne* species were found in western Sarawak (*C. auriculata*, *C. lingua*, *C. longicauda*, *C. striolata*, and *C. zadiana*). Thus, this study showed that most *Cryptocoryne* found in western Sarawak have paracytic type of stomata though one species is slightly different upon the others. *Cryptocoryne striolata* stomata occurrence was different from the other species where this species has a hypostomatic occurrence while the other four species were amphistomatic. Though previous research by Vaidya (2016) found that *Cryptocoryne spiralis* had a paracytic type of stomata while the ones found in western Sarawak are all tetracytic type of stomata.

The density and distribution of stomata varies with the structure of the leaf surface (epidermal cell density) among plants with distinct life-history strategies under varying environmental conditions. Developing leaves change their stomatal density based on leaf area (SD) (Salisbury, 1928). The stomata density results showed that *Cyperus* sp. had the highest density which was 358.2803 mm⁻² while *Barclaya motleyi* had the lowest 7.7618 mm⁻². These two species have different lifeforms where *Cyperus* sp. was on transitional regions between land and water bodies thus only the roots were embedded to the soil and immersed in water. However, for *Barclaya motleyi* the whole plant form was immersed in water, only the flowers sometimes emerged on the water surface or slightly above water surface. This is due to different lifeforms and the conditions of their habitats. The aquatic marsh plants have drier habitats which makes the stomatal density higher. Those from coastal (presumably drier) areas had a higher ratio of adaxial to abaxial stomatal density than species from inland, however they concluded plant plasticity among species is likely due to

changes in species' intrinsic traits in relation to their life/growth forms and the environmental circumstances of their primary habitats (Tay & Furukawa, 2008).

Trichome

The trichome comes in a wide variety of shapes and structures, such as unicellular, multicellular and glands. Most authors concur that hair is an epidermal protrusion that may be unicellular or multicellular and is elongated. Some authors consider hair and trichome to be synonymous (Hewson, 2019). As mentioned before there are seven types of trichome found in the aquatic plant in western Sarawak. *Drosera spatulata* var. *bakoensis* had two types of stomata found on the leaves which were multi-celled glandular and glandular hair though the glandular hair only present on the adaxial side of the leaves. However, Langer et al. (1995) found in his results for *Drosera spatulata* 3 types of trichome found on the leaf surface. In *Salvinia molesta* the adaxial surfaces of the floating leaves are thickly coated with unique trichomes, and their surface is highly water repellent (Barthlott et al., 1994). The trichomes on the adaxial side of the floating leaves of *Salvinia* species has various in size, shape, and content which can also be key identification to species. The *Salvinia* species found in western was *Salvinia molesta* this data was agreeable with Barthlott et al. (2009) where they described and categorized the *Salvinia* trichome into a few group and *Molesta* trichomes consist of four multicellular, uniseriate trichomes united by the second-to-last apical cells. The trichomes on the abaxial surface of aquatic plant leaves are known as hydropotes (water drinkers), and their form, size, and density vary among aquatic plants (Carpenter, 2006). Specifically the hydropotes were described or reported in species of the family Nymphaeaceae and the functional of the hydropotes relevance has been debated for decades, but there is no consensus. The hydropotes are believed to have a significant role in the movement of chemicals during separation and absorption processes, particularly in the

transfer of ions and water into plants (Kordyum et al., 2021). The hydropotes were found in *Barclaya motleyi* species on the abaxial surface along with a unicellular trichome, though there were no hydropotes found in the *Nymphaea nouchalli*.

5.4 Palynology Characteristics of Aquatic and Marsh Plant in Western Sarawak

The 13 species of flowering plants were all Angiosperm, with only one species from the Pteridophyta group, *Ceratopteris thalichoides* (L.) Brongn. Amongst the 13 species the four species were monocots (*Cryptocoryne auriculata*, *Cryptocoryne longicauda*, *Monochoria hastata*, and *Limnocharis flava*), two species were eudicots (*Drosera spatulata* var. *bakoensis* and *Ipomea aquatica*) and the other seven species were dicots (*Utricularia aurea*, *U. gibba*, *U. nivea*, *U. subulata*, *U. hirta*, *U. minutissima*, and *U. bifida*). As mentioned before the aperture type, shape, size, and exine sculpting pattern, the pollen morphology was categorised.

The type of apertures that was observed and found in the aquatic and marsh plants western Sarawak were inaperture, pantoporate, triporate, tricolpate, monocolpate, tetracolpate, and stephanocolpate. Apertures are one of the crucial physical characteristics to determine and differentiate between the pollen. Moore et al. (1991) asserts that apertures are the primary identifiers for prehistoric pollen grains and spores. The apertures found in *Cryptocoryne auriculata* and *C. longicauda* were both inaperturate, and the pollen unit was monad. This result was aligned with Grayum (1993) morphology description on the pollen of *Cryptocoryne* where the specimen examined were on *C. affinis* and *C. albida*.

As for *Utricularia*, based on Cruz et al. (2018) the pollen types listed were based mostly on morphological differences in the apertures of the pollen grains which were type I: (3)-porated; the species found in western Sarawak with this characteristic was *U. nivea* and

U. subulata. Type II: 4(5)-colporate, the species were *U. minutissima*, *U. bifida*, and *U. hirta*. Lastly, type III: (6)7-18- colporate the species found with this characteristics was both from an aquatic emergent free-floating lifeform which were *U. aurea* and *U.gibba*. Thus, the categorization for *Utricularia* aperture number was agreeable.

The pollen size categorization was based on Halbritter et al. (2018) where the aquatic plant comes in various size. Sizes of the grains ranged from very small, small, medium, large, and extremely large but apparently none of the pollen grain observed are at the ranged of very small and very large. The smallest pollen grains were (18.29-19.50 x 18.55-19.96 μm) in *Limnocharis flava* and the largest were (87.81-94.63 x 81.27- 91.97 μm) in *Ceratopteris thalichoides* var. *thalichoides*. However, in the results there was no very small and very large size found in aquatic and marsh plant. For *Cryptocoryne* there were slightly difference in size between *C. auriculata* (29.94-42.44 x 24.37-34.34 μm) and *C. longicauda* (15.42-25.88 x 12.83-23.11 μm) where *C. longicauda* was slightly smaller than *C. auriculata*. However, pollen size is often unreliable as a taxonomic characteristic. Pollen grains are renowned for their capacity to expand and compress in response to varying environmental or laboratory circumstances (Wodehouse, 1935). Some pollens have more than one sculpture characteristics. The exterior of the exine is covered with a variety of sculptures and ornamentation. In this study, the sculpture patterns of exine were observed as rugose, psilate, granulate/scabate, granulum, nanoclavate, echinate, gemmate, perforate, and faveolate. (Linn et al., 2020).

Other than the aperture being an important characteristic, in this study the polar axis and equatorial diameter/ ratio are used in this work to define the equatorial view of pollen morphology. The pollen shape and ratio were based on Wronska-Pilarek et al. (2016). Pollen grains were examined, and their forms were discovered to be triangular straight-shell shape,

subprolate, suboblate, oblate-spheroidal, prolate-spheroidal, and prolate. As for, *Drosera spatulata* var. *bakoensis* no suitable terms were identified due to shrinkage in result. Thus, probably due to harmomegathic effect. Harmomegathy is the characteristic infolding of pollen grains to compensate for the volume reduction caused by water loss (Volkova et al., 2013). All living pollen grains are capable of absorbing and releasing water; hence, each living pollen grain exists in two morphologically distinct states: dry and hydrated (Hewson, 2019).

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The two goals of this study, which were to document the aquatic and marsh plant species in the western Sarawak divisions of Kuching, Samarahan, and Serian, as well as to evaluate the diversity of these plants based on morphological and palynological traits, were successfully met. Morphological comparisons among the 50 taxa reveal a diverse of unique characteristics at the family, genus, and species levels, enhancing our understanding of these plants' taxonomy and adaptations. The construction of a checklist and distribution maps, along with the development of field keys for aquatic and marsh identification based on family and palynology, represents a significant contribution to botanical research and conservation in Sarawak. The remarkable species diversity observed in the Samarahan Division underscores its significance as a biodiversity hotspot. Categorization of these plants based on lifeforms and their preference for disturbed habitats and slightly acidic waters adds valuable ecological context to these findings.

The discovery of three invasive species which were *Salvinia molesta*, *Pontederia crassipes*, and *Ludwigia leptocarpa* is an important result, this is due to the prevention of invasive species and the maintenance of the local ecosystems and flora are directly affected by these findings. Impact of this study knowledge gathered here can assist in the control of invasive species, conservation methods, and the sustainable use of aquatic and marsh plant resources. Ultimately, these findings promote a deeper understanding of the region's rich botanical diversity and provide a solid lay for the groundwork for evidence-based policy choices that will protect Sarawak's distinctive flora for future generations.

6.2 Recommendations

The study of aquatic and marsh plants is critical because it provides fundamental data for future researchers to understand that each habitat is distinguished by a unique and intricate physical environment that sustains its biological species. The current study has been completed. This number of valuable species may be underestimated due to the survey's small scale and the scarcity of the records for many species. Nonetheless, the research is not yet complete, and there was a time constraint in a study of this type to cover aquatic plants as thoroughly as is required to clarify their ecological and distributional data. Important data must be gathered before comprehending the effect of plants on aquatic ecosystems.

- Further studies needed to be done on distribution of aquatic and marsh plant in Serian and Kuching Division.
- Details on the ecological study of aquatic and marsh species in western Sarawak
- A study should be undertaken to examine the socioeconomic significance of aquatic and marsh plant in western Sarawak.

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APPENDICES

APPENDIX 1: PHOTOGRAPHS OF STUDIED TAXA



Figure 1: A. fruit, *Pandanus yvanii*. B. inflorescence, *Utricularia caerulea*. C. habitat of aquatic plant in UNIMAS lake. D. habitat of *Cryptocoryne cordata* var *zonnata*. E. inflorescence, *Cryptocoryne auriculata*. F. plant habit, *Monochoria hastata*.



Figure 2: A. Plant habit, *Utricularia minutissima*. B. Cataphyll, *Cryptocoryne auriculata*. C. inflorescence, *Bucephalandra* sp. D. inflorescence, *Drosera spatulata* var. *bakoensis*. E. plant habit, *Rhynchophyle* sp. F. Plant habit, *Utricularia bifida* and *Fimbristylis polytrichoides*.

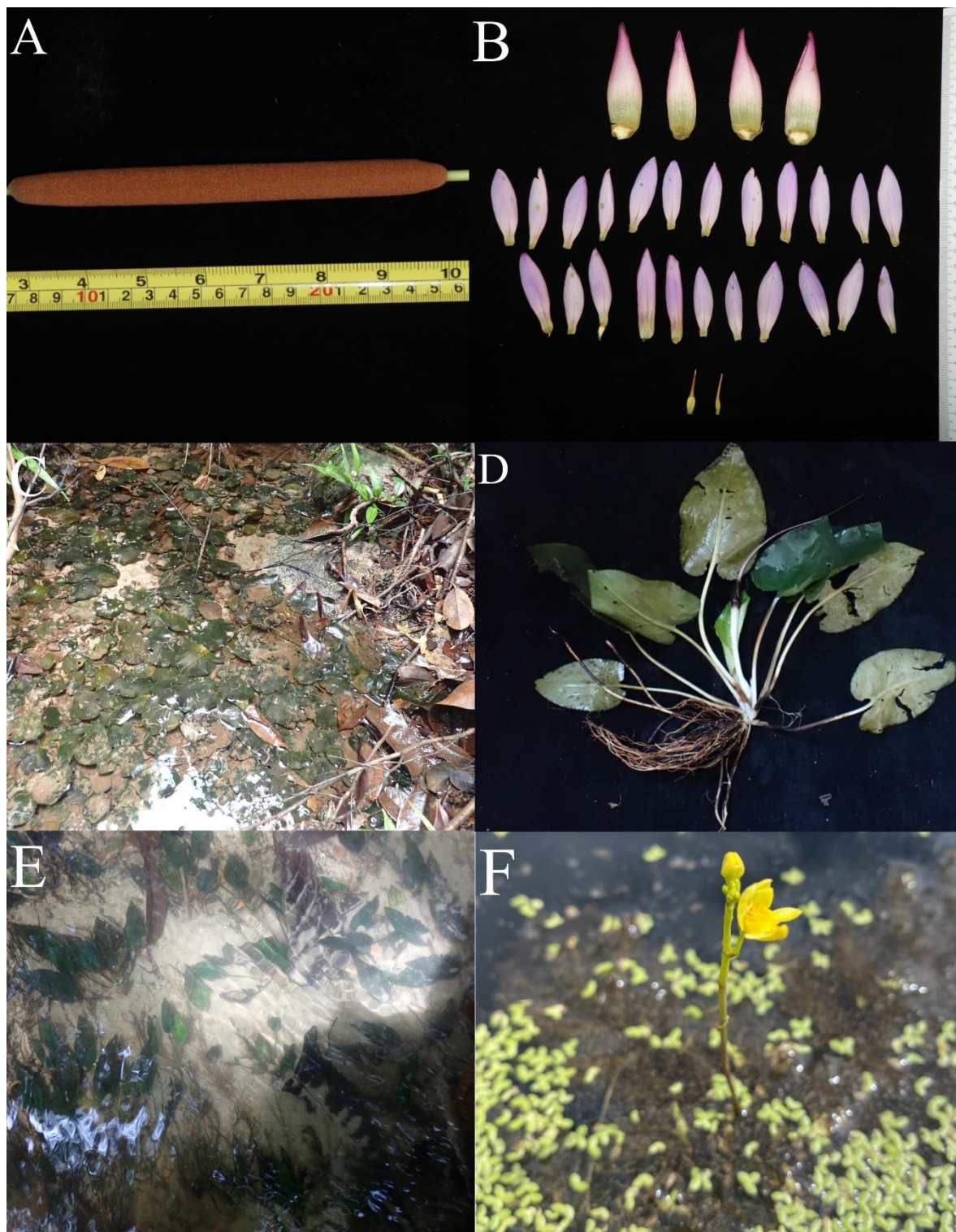


Figure 3: A. inflorescence, *Typha angustifolia*. B. corolla, *Nymphaea pubescens*. C. plant habit, *Barclaya motleyi*. D. plant habit, *Cryptocoryne longicauda*. E. plant habit, *Cryptocoryne striolata*. F. plant habits of *Utricularia aurea* and *Lemna minor*.

APPENDIX 2: FORESTRY PERMIT

Your Ref.: 2019067

Our Ref.: SFC.PL&RS/2020 – 004

6 August 2020



Ms. Umie Naylisa Binti Mohamad

Universiti Malaysia Sarawak

94300 Kota Samarahan

Sarawak

Dear Sir/Madam,

PERMISSION TO CONDUCT RESEARCH ON BIOLOGICAL RESOURCES/COLLECT SAMPLES OF BIOLOGICAL RESOURCES FOR RESEARCH:- SYSTEMATIC AND ECOLOGY STUDY OF AQUATIC PLANT IN WESTERN SARAWAK

The above subject matter refers.

2. With regards to your application for the above subject, I am glad to inform that permission is hereby granted for you and your team members to conduct research and collect samples of biological resources within the area as per table below:-

Species		Location	Quantity
Scientific Name	Type of Organism		
	Morphology, Anatomy (leaf stomata), Pollen and Water quality	Gunung Gading National Park, Santubong National Park, Bako National Park, Kubah National Park, Kubah National Park, Batang Ai National Park, Bungo Range National Park, Dered Krian National Park, Gunung Pueh National Park and Samunsam Wildlife Sanctuary	Quadrat sampling

../2

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STUDIES OF *UTRICULARIA* SPECIES IN WESTERN SARAWAK, MALAYSIA

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Abstract: *Utricularia* (Lentibulariaceae) is the second largest genus among the carnivorous plants that are also known as the bladderworts. This genus is cosmopolitan and it can be found in a variety of habitats, including subarctic environments, tropical rainforests, desert oases, and maritime islands. Generally, *Utricularia* has a few habits that they could survive in such as in freshwater aquatic, semi-aquatic, terrestrial, and lithophytic conditions. The genus can be found in Malesia, with ca. 30 species. So far, 14 species have been identified in Peninsular Malaysia. The objective of this study is to provide a checklist of *Utricularia* species in western Sarawak. The method used was convenience sampling where surveys were conducted throughout Western Sarawak. In this study, a total of nine species of *Utricularia* was found in the western part of Sarawak (Kuching, Sri Aman, Serian, and Samarahan Divisions). Three species are common, namely *U. bifida*, *U. minutissima*, and *U. aurea* and one species is fairly common *U. caerulea*. Bako National Park has five species, *U. minutissima*, *U. hirta*, *U. geoffrayi*, *U. subulata* and *U. uliginosa*.

Key words: Aquatic, Lentibulariaceae, terrestrial, *Utricularia*, Western Sarawak

INTRODUCTION

Lentibulariaceae is a family (order Lamiales) that comprises three genera, *Genlisea*, *Pinguicula* and *Utricularia*. Only about 1% of the approximately 250,00 species of angiosperm are carnivorous, with *Utricularia* accounting for about half of them (Juniper et al. 1989). This genus has a total of 215-275 species that are found around the world, with a greater percentage in the tropical zone (Poppinga et al. 2012, Taylor 1989). The genus is considered cosmopolitan and it can be found in subarctic region, tropical rainforests, desert oases, and on marine islands (Heywood et al. 2007). According to Fleischmann and Munchen (2015), *Utricularia* is the second largest genus of carnivorous plants, only being outnumbered by more than 250 species of *Drosera*. *Utricularia* is the only genus in Lentibulariaceae found in Malesia and there is a total of c. 30 species (Taylor 1974). In Peninsular Malaysia, there are approximately 14 species thus far and usually is found almost exclusively in nutrient-poor environments with low pH (Chew & Haron 2011).