



Faculty of Resource Science and Technology

**Taxonomic Diversity and Functional Ecology of Birds during Seasonal
Paddy Farming Practices in Southwestern Sarawak**

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Taxonomic Diversity and Functional Ecology of Birds during Seasonal Paddy
Farming Practices in Southwestern 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

The ecosystem of the paddy fields may be impacted by seasonal paddy farming, which is also expected to impact the birds inhabiting it. Relatively little research has been done worldwide on how paddy stages affect birds, and there is currently a dearth of research on the taxonomic diversity of birds in paddy fields caused by habitat heterogeneity on a landscape scale in Malaysia. Likewise, functional traits and groups of birds have been the subject of most research, but these studies were rarely carried out in paddy fields. This research investigated the taxonomic and functional groups of birds as well as the effects of habitat modification during three different paddy stages (planting, harvest and land preparation) in paddy fields of southwestern Sarawak and the objectives are as follows: (i) to compare the taxonomic diversity of birds; (ii) to classify and compare functional groups of birds; and (iii) to evaluate the effects of landscape-scale habitat modifications on bird taxonomic groups. Paddy fields of Kampung Skuduk, Kampung Baru and Kampung Pueh-Siru Dayak were sampled thrice during each paddy stage for 12 months from December 2021 to November 2022, with a cumulative effort for line transects and mist netting of 90 hours and 10,800 net hours. This study demonstrated the response of birds to continuous habitat modification in a paddy field ecosystem. Wholly, seasonal variations caused by paddy farming did not necessarily affect the bird community. There was no significant difference in bird taxonomic diversity, where paddy stages shared high numbers of bird species. Additionally, the functional groups of birds vary, indicating evolving feeding and foraging strategies in response to changing landscapes. Lastly, bird taxonomic groups had clustered distribution with weak associations of changing microhabitats and stages. This research contributes to developing management plans for birds in paddy fields and provides a method for assessing the ecosystem.

Keywords: Bird diversity, functional groups, paddy stages, paddy fields, taxonomic groups

Kepelbagaian Taksonomi dan Ekologi Fungsian Burung semasa Amalan Penanaman Padi Bermusim di Barat Daya Sarawak

ABSTRAK

Ekosistem sawah padi mungkin terjejas oleh penanaman padi bermusim, yang juga dijangka memberi kesan kepada burung yang mendiaminya. Penyelidikan yang agak sedikit telah dilakukan di seluruh dunia tentang bagaimana peringkat padi mempengaruhi burung. Selain itu, terdapat kekurangan penyelidikan mengenai kepelbagaian taksonomi burung di sawah padi yang disebabkan oleh heterogeniti habitat pada skala landskap di Malaysia. Begitu juga, ciri-ciri fungsian dan kumpulan burung telah menjadi subjek kajian kebanyakan, tetapi kajian ini jarang dijalankan di sawah padi. Penyelidikan ini meneliti kumpulan taksonomi dan fungsi burung serta kesan pengubahsuaian habitat semasa tiga peringkat tanaman padi yang berbeza (penanaman, penuaian, dan penyediaan tanah) di kawasan sawah padi di barat daya Sarawak dan objektifnya adalah seperti berikut: (i) membandingkan kepelbagaian taksonomi burung; (ii) untuk mengelas dan membandingkan kumpulan berfungsi burung; dan (iii) untuk menilai kesan pengubahsuaian habitat berskala landskap ke atas kumpulan taksonomi burung. Kerja lapangan telah dijalankan sebanyak tiga kali di sawah padi Kampung Skuduk, Kampung Baru dan Kampung Pueh-Siru Dayak pada setiap peringkat padi selama 12 bulan dari Disember 2021 hingga November 2022, dengan usaha kumulatif untuk transek garisan dan jaring kabus selama 90 jam dan 10,800 jaring-jam. Kajian ini menunjukkan bagaimana burung memberi tindak balas terhadap pengubahsuaian habitat secara berterusan dalam ekosistem sawah padi. Secara keseluruhan, perubahan bermusim akibat pertanian padi tidak semestinya memberi kesan besar terhadap komuniti burung. Tiada perbezaan ketara dalam kepelbagaian taksonomi burung, di mana setiap peringkat penanaman padi menampung bilangan spesies burung yang tinggi dan hampir

serupa. Namun begitu, kumpulan fungsi burung menunjukkan variasi, mencerminkan strategi pemakanan dan pencarian makanan yang berubah-ubah selaras dengan perubahan landskap. Akhir sekali, kumpulan taksonomi burung mempunyai pengedaran berkelompok dengan persatuan yang lemah dalam perubahan mikrohabitat dan peringkat. Penemuan ini menyumbang kepada pembangunan pelan pengurusan burung di kawasan sawah padi serta menyediakan kaedah penilaian terhadap fungsi ekosistem secara keseluruhan.

Kata kunci: *Kepelbagaian burung, kumpulan berfungsi, peringkat padi, sawah, kumpulan taksonomi*

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LIST OF ABBREVIATIONS

APT	antimony potassium tartrate
Cmax	level of coverage reached by the sample that attained the lowest coverage when all samples were extrapolated to twice the reference sample size
FG	Functional Group
g	gram
GLMM	Generalized Linear Mixed Model
IndVal	Indicator values
IUCN	International Union for Conservation of Nature
km	kilometre
m	metre
ml	millilitre
mm	millimetre
MRPP	Multi-Response Permutation Procedure
One-way ANOVA	One-way Analysis of Variance
SWLPO 1998	Sarawak Wild Life Protection Ordinance of 1998
SOM	Self Organizing Map
Tukey HSD	Tukey honestly significant difference
U-matrix	unified distance matrix

CHAPTER 1

INTRODUCTION

1.1 Paddy Fields Birds

Paddy fields are home to various birds, especially waterbirds (Elphick, 2015; Gunathilaka, 2019). These waterbirds include shorebirds (families Scolopacidae and Charadriidae), rails (family Rallidae), and the majority of species in the Ardeidae family (egrets, herons, and bitterns). The egrets (e.g., Great Egret *Ardea alba*, Intermediate Egret *Ardea intermedia*, Little Egret *Egretta garzetta*, and Cattle Egret *Bubulcus ibis*), bitterns (e.g., Yellow Bittern *Ixobrychus sinensis* and the Cinnamon Bittern *Ixobrychus cinnamomeus*), and herons (e.g., Grey Heron *Ardea cinerea*, Purple Heron *Ardea purpurea*, and the Chinese Pond Heron *Ardeola bacchus*) are commonly found in paddy fields across Borneo (Phillipps and Phillipps, 2014). Rails include the Eurasian Moorhen *Gallinula chloropus* and the White-breasted Waterhen *Amaurornis phoenicurus*. Additionally, several shorebird species include Wood Sandpiper *Tringa glareola*, Long-toed Stint *Calidris subminuta*, White-winged Black Tern *Chlidonias leucopterus*, and Whiskered Tern *Chlidonias hybrida*. Winter visitors who may overwinter in Borneo, like the Common Sandpiper *Actitis hypoleucos*, Pacific Golden Plover *Pluvialis fulva*, Little-ringed Plover *Charadrius dubius*, Green Sandpiper *Tringa ochropus*, Wood Sandpiper *Tringa glareola*, and Long-toed Stint *Calidris subminuta* are migrants that stay after November (Phillipps and Phillipps, 2014). Most of these migrants chose open rural areas, forests, and coastal regions, whilst also using paddy fields for staging (Phillipps and Phillipps, 2014; Gogoi et al., 2023). Paddy fields may serve as alternative wetlands and

provide important stopover sites for long-distance migratory waterbirds (Choi et al., 2022).

While the majority of studies have concentrated on waterbirds in paddy fields, land bird species may also be present in the fields (Gunathilaka, 2019). Munias (family Estrildidae) are recognised bird pests in paddy fields and commonly associated with the paddy harvest, particularly as the paddy begins to produce grains (Kurnianto et al., 2024; Reddy et al., 2024). Paddy fields are also beneficial to other land birds that live near humans, including mynas, starlings (family Sturnidae), doves, and pigeons (family Columbidae). Birds of prey such as Black-shouldered Kite *Elanus caeruleus*, including migratory raptors (e.g., Chinese Sparrowhawk *Accipiter soloensis*, Pied Harrier *Circus melanoleucos*, Black Kite *Milvus migrans* and Oriental Honey Buzzard *Pernis ptilorhynchus*) are commonly found in paddy fields (Eng et al., 2014; Ramli & Fauzi, 2018), especially during land preparation when the plots are exposed, which provides access to prey such as rodents and insects (Azman et al., 2019; Zhang et al., 2024). Migratory raptors utilise paddy fields as staging areas during their migrations. These fields provide crucial stopover sites for them to rest and refuel, especially in regions where natural wetlands are scarce (Blount et al., 2021). While migratory raptors used paddy fields as staging locations throughout their migration routes, the Black-shouldered Kite *Elanus caeruleus* typically used mango and coconut trees as their nesting sites in paddy fields (Ramli & Fauzi, 2018).

1.2 Changing Landscape of Paddy Fields Due to Paddy Farming

Paddy fields are frequently perceived as monotypic plant environments (Chen et al., 2006), even if different vegetation may be interspersed across the paddy matrices (Horgan et al., 2023). However, several paddy farming practices including the irrigation

level and paddy growth can seasonally alter the appearance of paddy fields (Bouman et al., 2007; Kotera et al., 2014). Paddy fields are typically flooded with small, verdant paddy plants that have just been transplanted into the paddy plot during planting (Abdullah, 2004). Following planting, paddy height has greatly increased during the paddy growing stage and the inundation has been drained, leading to eventual harvest (Chapagain et al., 2011; International Rice Research Institute, 2024a). During the harvest, the green paddy fields are replaced by yellowish-ripened paddy. Additionally, no paddy plant occupies the paddy field during land preparation. The soil of paddy fields (such as rain-fed or irrigated paddy fields) is usually exposed, inundated with water, and prepared for the next cycle (Bouman et al., 2007; Azman et al., 2019).

1.3 Problem Statement

Bird taxonomic diversity in paddy fields has been studied extensively in Peninsular Malaysia (Azman et al., 2011, 2014, 2019; Amira et al., 2018; Mohd-Taib and Kamaruddin, 2018; Gunathilaka, 2019; Mohd-Taib et al., 2021). However, such studies are particularly scarce in Malaysian Borneo (Makbul and Wong, 2016; Karim et al., 2018). Although the effects of habitat modification caused by different paddy stages on the paddy field environment can be observed and are predicted to affect the composition and assemblage of birds, this area of research remains relatively understudied. Numerous studies on birds due to spatiotemporal variability have been conducted, but only a few were conducted in paddy fields (Maeda, 2001; Amano et al., 2008; Choi et al., 2021). Besides that, there is a lack of studies that scrutinise birds as bioindicators that can be used to measure biodiversity related to the different paddy stages in paddy fields (Bergmann et al., 2024), while other animals like insects, macroinvertebrates, amphibians and fish have been studied (Rizo-Patrón et al., 2013; Liu et al., 2020; Şişman et al., 2020;

Babbar et al., 2023; Kurnianto et al., 2024). Likewise, most research on bird functional groups and traits has focused on rainforests and agroecosystems such as oil palm plantations and cacao agroforestry, with relatively few studies conducted in paddy fields. A significant methodological gap was observed in the literature, as most studies conducted in Malaysian paddy fields have relied solely on point counts or line transect surveys, without incorporating mist netting. This approach may overlook secretive, small, or highly mobile bird species, potentially resulting in incomplete data and biased findings.

1.4 Objectives

This research aimed to conduct a comprehensive analysis of the taxonomic and functional groups of birds as well as the effects of habitat modification on them during three different paddy stages (planting, harvest, and land preparation) in paddy fields of southwestern Sarawak. This was achieved through the following set of objectives:

- i. To compare the taxonomic diversity of birds during three different paddy stages in paddy fields of southwestern Sarawak;
- ii. To classify and compare functional groups of birds in paddy fields during three different paddy stages in paddy fields of southwestern Sarawak;
- iii. To evaluate the effects of landscape-scale habitat modifications on bird taxonomic groups during three different paddy stages in paddy fields of southwestern Sarawak.

1.5 Chapter Summary

The first chapter is the introduction to the general outline of the thesis: study background, problem statement and objectives. Chapter 2 provides an overview of existing literature on paddy farming in Sarawak, covering its agroecosystem, cycles, and

stages. It also examines the local ecological calendar for paddy and birds in Borneo, reviews global studies on bird taxonomic diversity in paddy fields, discusses functional ecology concepts, explores potential microhabitats within paddy fields, and identifies knowledge gaps. Chapter 3 describes and compares the taxonomic diversity of birds during three different paddy stages whilst identifying potential indicator species, followed by a discussion of the findings and conclusion. In Chapter 4, the identified functional traits of birds were classified into functional groups and the assemblages were compared and discussed. Chapter 5 evaluated the effects of landscape-scale habitat modifications on bird taxonomic groups in paddy fields by identifying microhabitat structure and its usage patterns. Finally, Chapter 6 provides a general conclusion, acknowledges limitations, and suggests ideas for further research and conservation initiatives.

CHAPTER 2

LITERATURE REVIEW

2.1 Paddy in Sarawak

Paddy, also known as rice, is a semi-aquatic grass plant belonging to the Gramineae family. Only two of the 24 species in the genus *Oryza* (African rice *Oryza glaberrima* and Asian rice *Oryza sativa*) are grown for human consumption. *Oryza sativa* is the more commonly farmed species, whereas *O. glaberrima* is only farmed in Africa which is later supplanted by *O. sativa* (Śliwińska-Bartel et al., 2021). After years of farming and good adaptation to various soil types and climates, *O. sativa* has split into three subspecies: *O. sativa indica*, *O. sativa japonica*, and *O. sativa javanica* (Dunna and Roy, 2013). The slender-grained *O. sativa indica* variety is grown in India and all over tropical Asia. The short and roundish-grained *O. sativa japonica* is cultivated in subtropical and warm temperate regions such as Japan and northern China, while the broad and thick-grained *O. sativa javanica* grown in the Philippines and the mountainous areas of Madagascar and Indonesia (Dunna and Roy, 2013; Cordero-Lara, 2020).

With almost 1,900 paddy variations issued since 1961, India has been the most prolific variety developer, followed by South Korea (277 varieties) and Southeast Asia countries like the Philippines, Indonesia, Vietnam, Myanmar, and Thailand, which released more than 78 to 238 varieties (Omar et al., 2019). Seventy-three traditional and 19 improved paddy varieties from four Southeast Asian nations (Indonesia, Malaysia, Laos, and the Philippines) were gathered for a recent study on paddy genetic diversity (Sabran et al., 2023). Conversely, Malaysia has only published 49 varieties since 1964, led by the Malaysian Agricultural Research and Development Institute (MARDI) (Omar

et al., 2019). In Sarawak, the paddy varieties differ significantly from those recognised by MARDI and the exact number of paddy varieties is still unknown. Hence, this section compiled several varieties that have been identified by available literature.

Biris, Bario, Rotan, Bali, Katek Merah, Mamut, Bajong, Kanowit, Wangi and Bubok are known paddy varieties in Sarawak (Teo, 2024; Department Of Agriculture Sarawak, 2024). The most renowned fragrant paddy variety is Biris, which originates from Simunjan (Teo, 2024). Another popular variety is Bario, that particularly grown in the Bario Highlands (Naeg, 2012; New Straits Times, 2024). Other paddy varieties found within the Kelabits people are “Pade Adan” and “Pade Dari” (Janowski, 1991). Adan also can be found in Krayan Highlands in Kalimantan (Slow Food Foundation for Biodiversity, 2024).

Saratani is a paddy variety that can be found in Sarawak. First brought in from Thailand and made available in 1996, Saratani was planted by farmers in Tanjung Purun, Pueh, and Paloh (Department Of Agriculture Sarawak, 2024). Paddy farmers in this study also confirmed that the Saratani variety was the most they planted (Iran anak Sumbu, personal communication, March 21, 2022). This variety can be harvested 118 days after seeding during the main season and 116 days during the off-season. It was eventually cultivated on a larger scale when its short-term nature of appropriation for double cropping was widely regarded. Additionally, Saratani has medium-sized stems that range in length from 105 to 110 cm and are sturdy and difficult to lodge. Thriving in both rainfed and irrigated environments, both direct seeding and transplanting are acceptable for this variety. While Saratani has a good blast resistance, its long, thin, and shiny milled grains also do not clump together when cooked.

2.2 Cycle and Stages in Paddy Fields

Worldwide, there are five main types of paddy fields categorised based on water regimes, drainage, temperature, soil type, topography and habitat: irrigated, rain-fed, upland, deep water, and tidal marshes (Edirisinghe and Bambaradeniya, 2006). Paddy fields in Malaysia are usually lowland irrigated paddy fields, lowland rain-fed paddy fields or upland/hill paddy fields (Food and Agriculture Organization, 2004).

The paddy plant is a crop with a maturity period of 90 days to more than 150 days post-germination depending on the variety and the environment under which it is grown (Nelson et al., 2014). Short duration would be an average of 105 days, medium duration of 135 days and long duration of 150 days (International Rice Research Institute, 2024a). Malaysia applies double cropping for paddy annually, with a main season and an off-season. The main season is the period when paddy is grown without depending wholly on any irrigation system while the off-season is the dry period and paddy planting is normally dependent on an irrigation system (Dorairaj and Govender, 2023).

Agronomically, within this period, paddy also undergoes physically distinct life stages such as the vegetative stage (seedling, transplanting, or tillering), reproductive stage (panicle initiation, internode elongation, booting, heading and flowering), ripening stage (milky, dough and maturation) (Nelson et al., 2014). Synonymous terms for these paddy stages are usually planting, growing, and harvesting. However, the terms cannot be used interchangeably, such as vegetative or planting, reproductive or growing, ripening or harvest, because planting, growing, and harvest are paddy farming practices (Fiveable, 2024) that refer to paddy farming methods rather than paddy life stages.

The agricultural practice of paddy farming practices includes land preparation, planting, growing, harvesting, and post-harvest. Post-harvest and land preparation are two

paddy farming stages that are very close and often confusedly referred to as the same stages (Mohd-Taib and Kamaruddin, 2018). Post-harvest is usually the fallow period after the last harvest, followed by land preparation for the next paddy cycle. It is a series of processes in paddy farming (field-drying, threshing, shed-drying, cleaning, grading, storing, weighing, and milling) to change a freshly harvested paddy from the field into a form, state, or composition that adds value, increases its shelf life, and makes it usable, or edible (Department of Agriculture and Livestock, 2015). On the contrary, land preparation can be classified under pre-planting stages, consisting of preparing soil to provide the necessary conditions and seed selection (Ani et al., 2018; International Rice Research Institute, 2024b). Land preparation involves ploughing (to till or dig up, mix, and overturn the soil), harrowing (to break the soil clods into smaller masses and incorporate plant residue), levelling the field and making an irrigation system for the field (International Rice Research Institute, 2024c). The requirements for wet or dry land preparation vary depending on the paddy ecosystems. While upland/hill paddy fields do not always need to be puddled, lowland paddy fields are typically puddled to create a hard pan and minimise water loss (International Rice Research Institute, 2024c).

While the paddy plots are flooded in the land preparation stage for transplanting, paddy seeds are often put into seedbeds for germination. When the seeds have germinated, they are transplanted by hand to the inundated paddy fields during the planting stage. Throughout the growing stage, the fields continue to be irrigated and fertilized until the plants reach maturity and are ready for harvest. While irrigation is maintained during this period, the water level is gradually lowered over time, eventually leading to complete drainage by the harvest stage. Harvesting is the process of obtaining plant parts that have reached maturity and are often determined by changes in the form of visual appearance,

smell, colour, size, and moisture content (Department of Agriculture and Livestock, 2015). While harvesting can be accomplished using machinery, in many areas it is also carried out by hand in the traditional methods that have been used for generations such as picking, pulling, plucking, slashing, cutting, stripping and shaking (National Geographic Society, 2024).

2.3 Local Ecological Calendar

Traditional ecological knowledge by indigenous people often receives little attention despite its potential importance in how mother nature works (Hosen et al., 2020; Bakar and Franco, 2022). Local ecological calendars are more than just tools for measuring time; they are ecocultural frameworks that connect spatial and temporal scales, which help with managing landscapes and natural resources, forming important components of biocultural diversity (Franco, 2015; Armatas et al., 2016; Cochran et al., 2016). Local ecological calendars utilise the biological cycles of plants and animals, as well as changes in the skyscape and landscape, as temporal markers which are then associated with the social and cultural rhythms of the community (Bakar and Franco, 2022). Three Borneo local ecological calendars (Kedayan, Kelabit, and Kenyah Badeng) related to paddy and birds were compiled in this study.

Bakar and Franco (2022) described Kedayan Brunei's ecological calendar comprehensively (Figure 2.1) but only the paddy seasons and the significance of birds will be included in this section. Kedayan farmers back then understood it was time to scout for the rising of Pleiades in the east, which indicated the time for land preparation of paddy farming (June-July) when *angin punay*, an alternating strong and calm wind occurs from May to June, believed to bring the emerald doves *Chalcophaps indica* to the area where the Kedayan community lived. This period is known as the season of emerald

dove wind (*musim angin punay*) by the locals. *Mussaenda glabra* fruiting in August marks the start of the paddy planting season, which is followed by the harvesting season in January and February. Besides the emerald dove, another significant bird in the local ecological calendar is the Indian Cuckoo *Cuculus micropterus*. The Indian Cuckoo season (*musim burung sengkaput*) runs from March to April, signalling the arrival of the local fruit trees' blossom season in the next two to three months.

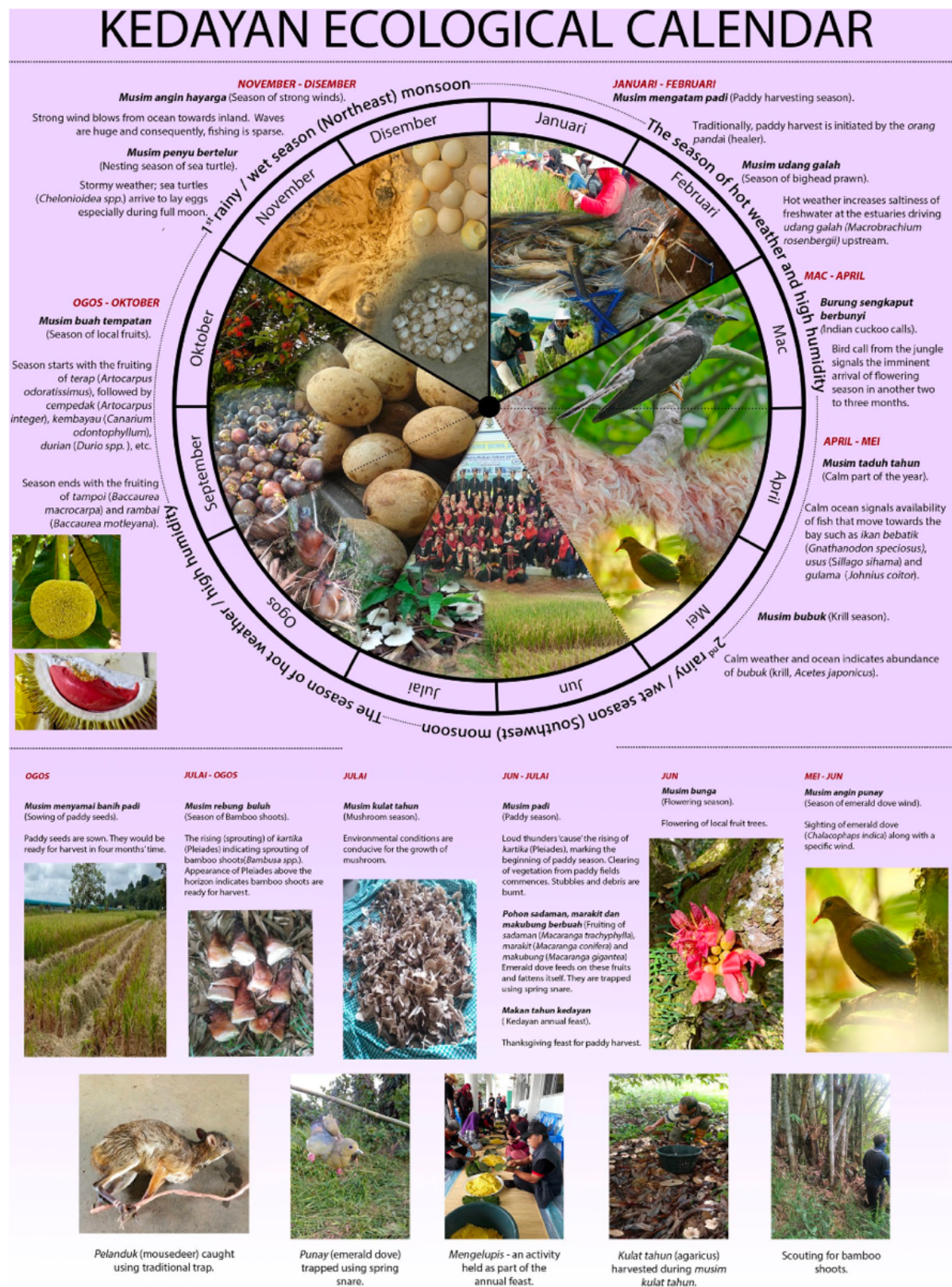


Figure 2.1: The pictogram of Kedayan Brunei's ecological calendar by Bakar and Franco (2022).

Janowski (1991) described the Kelabits obtain a single paddy cropping per year in irrigated paddy fields (*late baa*) and upland/hill paddy fields (*late luun*). Paddy seeds for irrigated paddy fields were planted in seedbeds in October and harvested in April. Paddy fields were reported to occur in several overlapping stages of growth at one time due to not all paddy fields being planted at the same time. Before the Second World War (1 September 1939 - 2 September 1945), the paddy calendar of the Kelabit people was timed by the arrival of various species of birds, though the species were unmentioned. The Gregorian calendar was adopted after 1955, yet it seems that the timing of events was almost the same as it was under the bird calendar. Beginning in 1968, the paddy year was advanced by roughly three months. Paddy fields are now harvested in late December after being planted in July or August.

Understanding weather patterns is crucial for the Kenyah Badeng to create an efficient calendar (Garay-Barayazarra et al., 2011) for their paddy farming. They keep track of rainy days per week while predicting short or long-term weather variations. Such extended dry spells in the earlier days of the dry season (February and March) put Kenyah Badeng on alert for a potentially wet August that could complicate their burning duties. The wet season, which typically lasts from September to February, has the most significant water from October to December, while the dry season, which lasts from March to August, has the least. To conclude one farming cycle and determine their next paddy fields, the Kenyah Badeng will celebrate the end of farming during post-harvest (*ramai o'o ajau*) after the dry season has reached halfway. Garay-Barayazarra et al. (2011) also discussed the traditional forecasting knowledge and practices related to Kenyah Badeng activities, including ornithomancy (the practice of reading omens from the actions of birds (Hamilton, 2007)) for Kenyah Badeng to predict the weather for paddy

farming. Bird sounds, in the case of the *bitucit* bird or sunbirds and spiderhunters (family: Nectariinidae), signalled the time that farmers needed to return from their fields to avoid the afternoon showers. Despite the appearance of continuous rains, it is believed to stop in a relatively short period when sparrows (family: Passeridae) begin to fly more quickly again and swallows (family: Hirundinidae) swoop low near the paddy fields.

Although birds have greatly inspired the culture of Sarawak natives, only three local ecological calendars were documented in Borneo, and these calendars are limited to eastern Borneo. In southwestern Sarawak, only the paddy community Kampung Sapit publicised the significance of bird omens in identifying suitable land for paddy farming (Bong, 2023). *Sasik* (cuckoos) and *Kusah* (tailorbirds) birds are believed to bring misfortune and difficult harvests.

2.4 Diversity Studies in Paddy Fields

Paddy fields, although anthropogenically constructed agricultural landscapes, exhibit remarkable animal biodiversity. These environments function as semi-aquatic ecosystems, providing crucial alternative habitats for a diverse array of aquatic and terrestrial species around the world. Research on the biodiversity of paddy fields commonly focuses on several prominent faunal groups such as insects, spiders, invertebrates, fish, frogs, including birds (Luo et al., 2014; Katayama et al., 2019; Thei et al., 2020; Mohamed et al., 2022; D'Souza et al., 2024; Peng et al., 2024; Wang et al., 2024).

Bird diversity in paddy fields has been extensively researched globally (Gunathilaka, 2019) but remains disproportionately low in Southeast Asia (Platt et al., 2021; Angkaew et al., 2023; Putri et al., 2023). In Malaysia, there are a few studies conducted in Peninsular Malaysia (Azman et al., 2011, 2019; Amira et al., 2018; Mohd-

Taib et al., 2021) but they are especially uncommon in Malaysian Borneo (Makbul and Wong, 2016; Karim et al., 2018). Table 2.1 consolidates bird diversity studies done in paddy field ecosystems in Asia.

A notably diverse paddy field bird community was described by Azman et al. (2019), where 83 paddy fields were sampled and secondary data were obtained from various databases and literature, resulting in 129 species from 50 families. Contrarily, most previous studies in Malaysia have shown a low number of bird species documented in the paddy fields (Table 2.1). These low records could result from data collection (point count or line transect) not being supplemented with secondary data or mist netting that can be effective for secretive, smaller or highly mobile birds that may be missed. Land birds were observed as dominant in Azman et al. (2019), whilst most studies have concentrated on studying waterbirds in paddy fields due to their conservation status. Paddy fields are also beneficial to other land birds such as mynas, starlings, doves, pigeons, munias, and birds of prey. They may be recognised as bird pests or biological control agents in paddy fields. Current data on Malaysian paddy field birds should be updated to address the evident disparity in studies conducted in Borneo and to fill existing methodological gaps.

Table 2.1: Diversity indices (Richness = number of bird species, $^1D / H'$ = Shannon, $^2D / D$ = Simpson, C = Simpson Dominance J' = Pielou's evenness) and sampling method employed in the paddy field and associated habitat based on available literature data.

Habitat	Location	Method	Richness	$^1D / H'$	$^2D / D / C$	J'	Reference
Multiple habitat	China	L	55, 98	-	-	-	Zhang et al. (2024)
Paddy field	Indonesia	P	14	1.24	0.42	-	Putri et al. (2023)
Paddy fields	Thailand	P	236	-	-	-	Angkaew et al. (2023)
Multiple habitat	Thailand	L, P	24, 43, 47	1.90, 2.25, 2.50	1.90, 2.25, 2.50	0.87, 0.81, 0.94	Supahan (2022)
Paddy field	Malaysia	P	40	2.474	-	-	Mohd-Taib et al. (2021)
Paddy field	Myanmar	L	85	-	-	-	Platt et al. (2021)
Paddy field	India	L	87	-	-	-	Jayasimhan and Padmanabhan (2019)
Multiple habitats	Malaysia	P, M	438, 129	-	-	-	*Azman et al. (2019)
Paddy field	Malaysia	P	11, 8, 17	-	-	-	Mohd-Taib and Kamaruddin (2018)
Multiple habitat	Malaysia	M	13, 21	3.045, 2.565	0.935, 0.7257	-	Karim et al. (2018)
Paddy field	Malaysia	P	46	-	-	-	Amira et al. (2018)
Paddy field	Philippines	P	59	-	-	-	Horgan et al. (2017)
Multiple habitat	Malaysia	P, L, M	37, 46, 18, 11	3.4664	-	-	Makbul and Wong (2016)
Paddy field	India	L	42	-	-	-	Rahalker and Patel (2015)
Paddy field	Malaysia	P	67	2.154 - 3.321	-	-	Azman et al. (2014)
Multiple habitat	Malaysia	P, M	72, 59, 49	3.561, 3.183, 1.042	-	-	Azman et al. (2011)

Abbreviation: Method: L = Line transect, P = Point count, M = mist netting. *data collection from primary and secondary sources.

2.5 Functional Ecology

Over the past two decades, the exponential increase of functional ecology studies across different spatial and temporal scales has now become routine (Mammola et al., 2021). Nonetheless, functional ecology in animals remains an emerging field (Luza et al., 2023) and is generally considered to be in its early stages, lagging behind the advancements made in plant functional ecology (Blaum et al., 2011; Luza et al., 2023). Regardless, birds have been the most studied taxonomic group given that measuring their traits is relatively straightforward (Mayani-Parás et al., 2023). Functional ecology studies of birds in tropical areas have been quite extensive (Tscharntke et al., 2008; Sekercioglu, 2012; Newbold et al., 2014; Sayer et al., 2017), although there relatively little research being done in Southeast Asia (Clough et al., 2009; Edwards et al., 2013; Hua et al., 2016). These studies were in rainforests and agroecosystems such as cacao agroforestry and oil palm plantations whilst never in paddy fields. Worldwide, functional ecology studies have been limited to open agroecosystems such as paddy fields (Sekercioglu, 2012; Horgan et al., 2017).

Functional ecology is a subfield of ecology that concerns the function or role of an individual, a species, a population, a community, a trophic level, or an evolutionary process in a trophic system (Calow, 1987; Russell, 2022). Other familiar terminologies in functional ecology are functional diversity, functional group and functional traits.

Functional diversity is defined as “a component of biological diversity that enumerates the different types of processes in a community that are important to its structure and dynamic stability” (Moore, 2013), which according to common understanding, refers to the significance and complexity of those species and organismal features that influence ecosystem function (Russell, 2022). The distinction between

functional diversity and taxonomic diversity is not always clearly delineated. Moore (2013) addressed this issue by examining the differing emphases and methodological approaches within various ecological subdisciplines, including autecology, community ecology, and ecosystem ecology. He concluded that taxonomic diversity is more appropriately applied within the context of autecology, which focuses on individual organisms or species, whereas functional diversity is more relevant to ecosystem ecology, where the emphasis lies on ecological processes and functions.

In the study of species-mediated interactions and processes, community and ecosystem ecology often classify species into broader categories, such as functional groups. Hooper et al. (2002) mentioned that the terms functional group, functional type, guild and ecological groups may be used synonymously. However, in animal ecology studies, mostly referred to as guilds, and the classification is based on the usage of food resources (i.e., resource-centred guild approaches) (Blondel, 2003; Blaum et al., 2011; González-Salazar et al., 2014). Although resources play a major role in determining the suitability of a habitat, several other traits such as dispersal capacity, demographic rates, competitive capacities, predator avoidance, etc., may influence how a species responds to changes in its environment (Blaum et al., 2011). Guilds emphasise similarities in resource use and competitive interactions among species, without directly considering the ecological processes or functions involved. Functional groups address this limitation by incorporating species roles in ecosystem functioning (Blondel, 2003; Moore, 2013). Therefore, a classification system that goes beyond the resource-centred guild approach using the functional linkages between habitats and the requirements of species with certain features is needed to assess how communities are responding to environmental changes.

Species can be categorised into functional groups by assigning their traits based on ecological similarities (i.e., functional traits), with the assumption that species within the same functional groups participate in similar roles in the processes and functioning of ecosystems (Bello et al., 2010). Functional traits are the morphological, physiological, anatomical, and behavioural aspects of their ecological role within an ecosystem, that strongly influence organismal performance, which impacts fitness indirectly via its effects on growth, reproduction and survival (Violle et al., 2007; Moore, 2013; Russell, 2022; Mayani-Parás et al., 2023). However, there is currently no standardised set of resource traits required to define functional groups, and the terminology used to label these groupings remains inconsistent across studies (Moore, 2013). Given that function in an ecosystem context is directly related to how species use resources, the schemes used to define functional groups have varied widely and are typically based on the resource requirements (i.e., food, habitat, and time) of species and their position in niche space relative to other species. Recent studies have developed classification schemes that measure the ecological importance of mammals and birds in an environment via their functional traits (González-Salazar et al., 2014; Mayani-Parás et al., 2023) while also helping to understand in depth how biodiversity affects particular ecosystem functions.

Environmental factors that could affect the functional traits of birds have been extensively studied including spatial, temporal, meteorological, seasonal, elevation, canopy height, canopy cover, and vegetation structure (Schütz and Schulze, 2015; de Arruda Almeida et al., 2019; Campos-Silva and Piratelli, 2020; Feng et al., 2020; Li et al., 2022; Remeš et al., 2021; Jarzyna and Stagge, 2023). Despite these insights, there is still little consensus on the impacts of changing habitat in paddy fields due to seasonal

paddy farming practices. More in-depth assessment can be done spatially and temporally in paddy fields by assessing their functional ecology.

2.6 Microhabitats in Paddy Fields

The structure of microhabitats within paddy fields is heavily influenced by human management practices. The timing and extent of flooding, the use of fertilisers and pesticides, and the methods of paddy planting and harvesting all shape the microhabitat characteristics. For example, the practice of intermittent flooding, where fields are flooded and drained at different stages, can create dynamic habitats that change throughout the growing season. This variability can support a diverse range of species adapted to different water levels and environmental conditions. However, intensive agricultural practices, including the use of chemical fertilisers and pesticides, can negatively impact the quality of these microhabitats (Choi et al., 2021). Pesticides, in particular, can reduce the abundance of beneficial invertebrates, disrupting food webs and affecting species that depend on these invertebrates. The impact of agricultural intensification on biodiversity in paddy fields remains a topic of active research, with several studies calling for more sustainable management practices that protect the integrity of these habitats while maintaining agricultural productivity (Abudulai et al., 2022; Schmid and Schöb, 2023).

The primary feature of paddy fields is the flooded environment (paddy plots, ditch and pond), which creates waterlogged zones crucial for various species, particularly aquatic organisms. Flooded paddy plots support a range of aquatic microhabitats, where water depth, duration, and water quality can vary. Shallow areas often host small invertebrates and amphibians, while deeper zones may be home to fish and other aquatic

species (Sekercioglu, 2012). Studies show that the water depth in paddy fields directly affects the species composition of both invertebrates and birds (Horgan et al., 2017). For example, smaller waterbirds (shorebirds and waterfowl) with relatively short legs foraged efficiently in lower water levels, whereas larger waterbirds (stork-like birds) typically inhabit or utilise deeper water levels for foraging (Tojo, 1996; Nam et al., 2015). In addition to water depth, the timing of flooding is also critical. The seasonality of flooding, especially during the paddy farming cycle, creates a dynamic environment in which species must adapt to changing conditions. Periodically flooded zones, particularly during dry-down periods, create mudflats that are vital feeding areas for wading birds (Ramli and Norazlimi, 2017; Mathot et al., 2018). These areas can also support numerous invertebrates, which form a crucial part of the food web in paddy ecosystems (Sekercioglu, 2012).

Vegetation in paddy fields, both aquatic and terrestrial, provides essential microhabitats for many species. Paddy plants themselves, along with associated grasses and wild plants, create vertical structures that offer shelter, food, and nesting sites. Insects, particularly herbivores, thrive on these plants, and their presence in turn supports higher trophic levels, including birds, amphibians, and small mammals (Hashimoto et al., 2019; Propper et al., 2023). Studies have shown that the density and type of vegetation can significantly influence species composition in paddy fields. For instance, dense paddy plots provide suitable habitat for small mammals like rodents, which feed on paddy seeds, while more open paddy plots may attract a higher abundance of birds, especially raptors (Azman et al., 2019). The edges of paddy fields, such as those adjoining forest patches, also host significant vegetation diversity. These areas support a variety of plant species that are not found in the main flooded zones, such as grasses, shrubs and trees. These

edge habitats are particularly important for birds and insects that prefer less disturbed areas for nesting and foraging (Terraube et al., 2016). Additionally, certain aquatic plants like duckweed and water lilies play crucial roles in providing both food and shelter for aquatic invertebrates, which in turn support higher trophic levels (Wersal and Madsen, 2012). However, this pattern is not consistent across all locations and is significantly shaped by local environmental factors, land management practices and disturbances, which can limit or alter vegetation diversity at these edges in paddy fields (Musters et al., 2009; Uchida & Ushimaru, 2015; Uchida et al., 2018).

The levees or dikes that separate paddy fields and the margins around fields represent significant non-flooded microhabitats. These elevated areas support vegetation that differs from the submerged environments. It typically hosts grasses, shrubs, and even trees, creating habitats for species that prefer drier conditions. Birds, in particular, utilise levees for perching, foraging, and nesting, with species like sparrows, doves, and geese commonly observed in these areas (Fujioka et al., 2010; Horgan et al., 2017). In terms of functionality, levees and field margins provide important corridors for species movement between paddy fields and adjacent habitats such as wetlands, forests, or grasslands (Choi et al., 2021). These corridors are vital for species that require both aquatic and terrestrial habitats throughout their life cycles. As such, these areas play a pivotal role in the overall connectivity of ecosystems within agricultural landscapes.

Such microhabitats like the flooded environment, vegetation and levees in paddy fields were commonly considered, but artificial substrates are less frequently included due to their high variability in composition, structure, and ecological roles across different sites, which complicates their categorisation and standardisation in ecological research

(Matikinca & Zondi, 2025). Artificial substrates can function as microhabitats in various ecosystems, providing essential resources like shelter, food, or breeding sites for a variety of species. These substrates, which are man-made or altered structures, can be critical in both aquatic and terrestrial environments where natural habitats may be limited or degraded (Seaman, 2007; Croak et al., 2010). In paddy fields, artificial dikes, irrigation channels, and constructed ponds serve as important microhabitats for various aquatic species. These man-made structures can host aquatic plants, algae, and invertebrates, providing essential food and shelter for insects, amphibians, and small fish. For instance, submerged materials like rocks or concrete structures can offer a surface for algae growth or shelter for invertebrates, which in turn attract predators, such as birds or fish (Croak et al., 2010). Such artificial substrates often function as stepping stones for biodiversity in human-modified landscapes. Artificial substrates like birdhouses, nest boxes, or man-made trees placed in agricultural or urban environments can serve as vital microhabitats for nesting birds (Dulisz et al., 2022). In areas where natural nesting sites (such as trees or cliffs) are scarce due to habitat degradation, artificial substrates can serve as alternative breeding sites, offering safe and stable conditions for bird species to reproduce. For example, artificial nest boxes are widely used to support cavity-nesting species, such as owls or sparrows, in agricultural landscapes or urban environments (Zhang et al., 2021). In agroecosystems, artificial substrates like piles of rocks, bamboo poles, or even discarded farm equipment can act as microhabitats for small mammals, reptiles, and insects. These structures often provide sheltered environments where species can escape predators, find food, or lay eggs. These substrates can thus increase the overall habitat complexity in agricultural landscapes.

Paddy fields as important agroecosystems, provide a complex array of microhabitats that support a rich diversity of species, including birds, insects, and plants (Sekercioglu, 2012; Tschardtke et al., 2012; Newbold et al., 2014). Microhabitats in paddy fields are small, localised areas that provide distinct environmental conditions within the broader paddy landscape (Shi et al., 2016). These microhabitats vary spatially and temporally depending on factors such as temperature, humidity, moisture, light exposure, or the presence of specific food sources (Denney et al., 2020; de Frenne et al., 2021; K rkjas et al., 2021; Bodineau et al., 2024). The significance of microhabitats within paddy fields, along with the organisms they support, underscores their role in shaping spatiotemporal diversity and contributing to functional ecological processes.

CHAPTER 3

TAXONOMIC DIVERSITY OF BIRDS DURING SEASONAL PADDY FARMING PRACTICES IN SOUTHWESTERN SARAWAK

3.1 Introduction

Taxonomic diversity of birds refers to the variety and complexity of avian species across different taxonomic ranks, including orders, families, genera, and species (Li et al., 2024). Birds represent a highly diverse group within the vertebrates, with over 10,000 species currently recognised, making them one of the most species-rich class of terrestrial vertebrates (Elphick, 2014; Chan et al., 2015). Birds are taxonomically grouped under the class Aves, which is further subdivided into several orders, such as Passeriformes (perching birds), Charadriiformes (shorebirds) and Gruiformes (waterfowl) (Elphick, 2014; Phillipps and Phillipps, 2014; Lim et al., 2020; Lepage, 2023). Among these orders, Passeriformes is the largest, encompassing over 6,000 species, or about 60% of all bird species (Gill et al., 2019). Within each order, birds are further classified into families, genera, and species, based on morphological, behavioural, and genetic characteristics (Brusatte et al., 2015).

The study of bird diversity has profound ecological implications, as species richness is closely linked to habitat stability and the ability of ecosystems to recover from disturbances. Birds play key roles in ecosystems, from pollinators and seed dispersers to predators and prey, and their diversity is often considered a marker of ecosystem health (Sekercioglu et al., 2008). However, understanding taxonomic diversity also requires attention to biogeography, as it shaped the distribution patterns of species (Britney, 2025). Bird species are found in nearly all habitats on Earth, from the Arctic to the Antarctic,

leading to significant geographical variation in bird families and genera (Schweizer et al., 2018). This includes the paddy fields, which can host a diverse range of bird species like munias and raptors, and especially waterbirds (Gunathilaka, 2019).

In Malaysia, there have been studies on the bird taxonomic diversity in paddy fields of Peninsular Malaysia (Azman et al., 2011, 2019; Amira et al., 2018; Mohd-Taib et al., 2021). However, paddy bird diversity studies are particularly scarce in Malaysian Borneo. This body of literature remains limited to brief reports by Makbul and Wong (2016) in Sabah and Karim et al. (2018) in Sarawak. The influence of paddy farming activities on the paddy field environment and its composition of birds could be visually observed during different paddy growth stages (Natuhara, 2013) but has yet to be systematically studied. A significant methodological gap in the literature is the limited use of mist netting in previous studies conducted in paddy fields (Azman et al., 2014; Azman et al., 2011; Makbul & Wong, 2016; Horgan et al., 2017; Amira et al., 2018; Karim et al., 2018; Mohd-Taib et al., 2018; Jayasimhan & Padmanabhan, 2019; Mohd-Taib et al., 2021; Platt et al., 2021; Supahan, 2022; Putri et al., 2023), which may have resulted in potentially incomplete data. The objective of this study is to compare the taxonomic diversity of birds during three different paddy stages (planting, harvest, and land preparation).

3.2 Methodology

3.2.1 Study Site

The study site encompassed three paddy fields located in southwestern Sarawak, including (i) Kampung Skuduk (1°14'57.8"N, 110°25'54.0"E) in Serian Division, (ii) Kampung Baru (1°28'12.5"N, 110°28'42.0"E) in Samarahan Division, and (iii) Kampung Pueh-Siru Dayak (1°49'54.3"N, 109°42'25.3"E) in Kuching Division. The estimated

distance from Kampung Skuduk to Kampung Pueh is 134 km, from Kampung Pueh to Kampung Baru is 120 km, and from Kampung Baru to Kampung Skuduk is 34 km (Figure 3.1). There are approximately 28.4 ha of paddy fields in Kampung Skuduk, 10.7 ha in Kampung Baru, and 85.0 ha in Kampung Pueh-Siru Dayak.

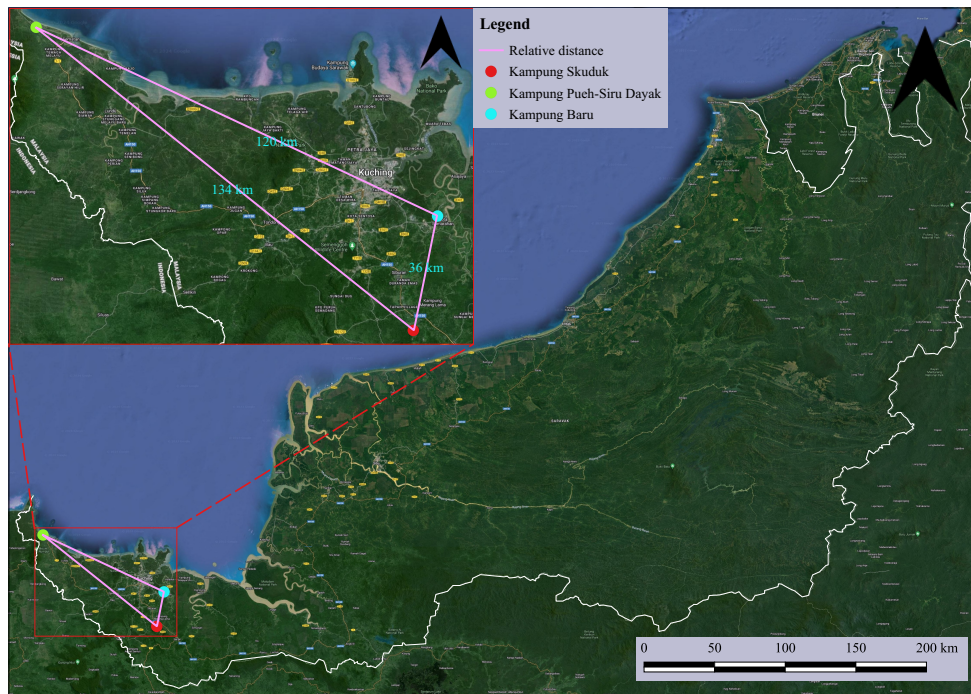


Figure 3.1: Map showing the three sampled paddy fields (inset) in southwestern Sarawak, Malaysia (generated using QGIS-LTR 3.22.11 ‘Białowieża’).

Kampung Skuduk is located in Siburan of Serian Division, 46 km to Kuching, Sarawak. Kampung Skuduk (1°14'57.8"N 110°25'54.0" E) is a small Bidayuh village, believed to be split of Kampung Chupak and Kampung Payang that migrated from Kampung Gayu after running out of farmland (Bombastic Borneo, 2022). Limestone caverns border the area; notable mention is the Gua Raya and a mountain, Gunung Payang. Most villagers are invested in paddy farming, with a total area of approximately 28.40 hectares of paddy fields just in front of their homes. Compared to another two locations, Kampung Skuduk has practised modern paddy farming technology such as owning their milling facility, harvesting machine (Kubota Harvester), and ploughing

tractors. The fields are irrigated with a water pump system, hence the ability to practice double-cropping a year without relying on the weather. The double-cropping seasons are referred to as *Padi Tahun* and *Padi Burung* (Zack, personal communication, December 8, 2021).

Kampung Baru in Kota Samarahan Division is a Malay village believed to be part of the lost Pegu community (Amir, 2015). People of Kampung Baru love farming and will usually utilise any unoccupied land for their farming activities, including paddy farming. The paddy fields (1°28'12.5"N 110°28'42.0" E) studied in Kampung Baru were initially unoccupied government land lots before being utilised by Kampung Baru's villagers to do paddy farming. The 10.68 hectares of paddy fields, a relatively small patch situated within an urban landscape are surrounded by major infrastructure including Jalan Datuk Mohamad Musa (a main road), Al-Muttaqin Mosque, The Summer Shopping Mall, and nearby residential areas. The site is located approximately 22 km from Kuching, the state capital of Sarawak. The paddy fields are naturally irrigated with water due to their peat swamp forest origin. Kampung Baru farmers practised single and double cropping per year.

Kampung Pueh and Kampung Siru Dayak are Bidayuh Selako's village. The villages share 85.04 hectares of paddy-farming land (1°49'54.3"N 109°42'25.3" E) in Sematan (ca. 144 km from Kuching). Geographically, the paddy fields are surrounded by beaches and mountains. The nearest mountain is Gunung Pueh, which is the highest mountain within the southwest exterior of Sarawak, with an elevation up to 1,550 m a.s.l. The people of Kampung Pueh-Siru Dayak practised double-cropping system yearly despite not having a water pump to irrigate the fields. They refer to the double cropping

as *Padi Tuha* or *Tahutn Basar* and *Padi Tahutn Lapis* (Iran anak Sumbu, personal communication, March 21, 2022).

3.2.2 Paddy Farming Scheme

The Northeast and Southwest monsoons cause wet season and dry seasons highly influencing the weather (Minggu, 2024; Malaysian Meteorology Department, 2025), thus also affecting the partitioning of the paddy stages in the southwestern part of Sarawak. Besides that, the willingness and agreement between the farmers to engage in agricultural activities significantly influence the paddy stages at each site. As a result, no exact date can be given for each season stage; only projected months are known. As overlapping paddy stages are common, only the current dominant paddy stage is chosen to indicate the paddy stage per sampling. According to local farmers, although the agricultural schedule mentioned here was based on a single-year survey during the present study, it is practically the same as that of succeeding years.

Figure 3.2 shows an ecological calendar illustrating the paddy farming scheme of the selected sites. The first planting stage of the annual cycle of the year 2021–2022 started in November 2021 and continued until February 2022. The harvest stage followed in March 2022 and land preparation began in April 2022. The second planting stage of the annual cycle was in May 2022, lasting until July 2022 and followed by harvest in August 2022 and land preparation in September and October 2022, when the cycle was about to start again.

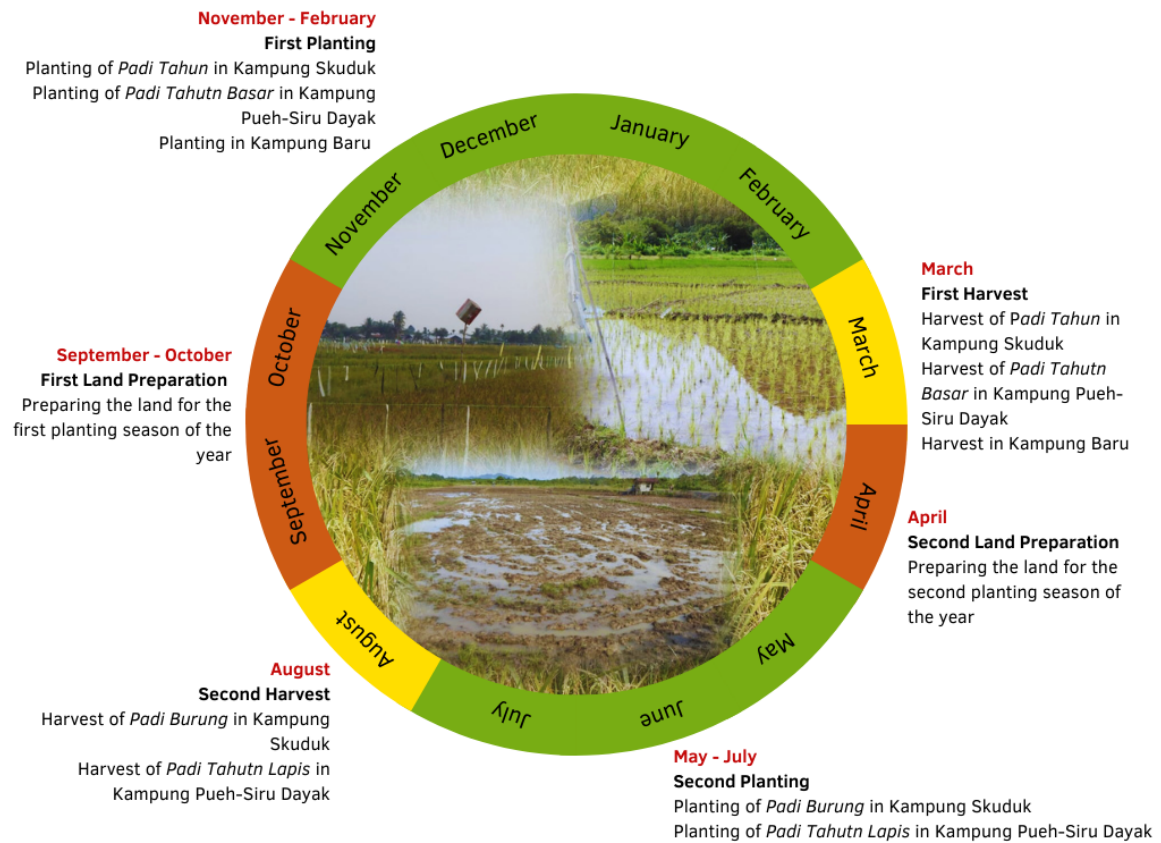


Figure 3.2: Ecological calendar illustrating the paddy farming scheme of the selected sites (Kampung Skuduk, Kampung Baru and Kampung Pueh-Siru Dayak).

3.2.3 Data Collection

Paddy fields were surveyed three times during each paddy stage for 12 months from December 2021 to November 2022. Active and passive surveys by line transect and mist netting were conducted for 5 days to survey birds in each paddy field (Figure 3.3). The cumulative effort for line transects and mist netting was 90 hours and 10,800 net hours, respectively.

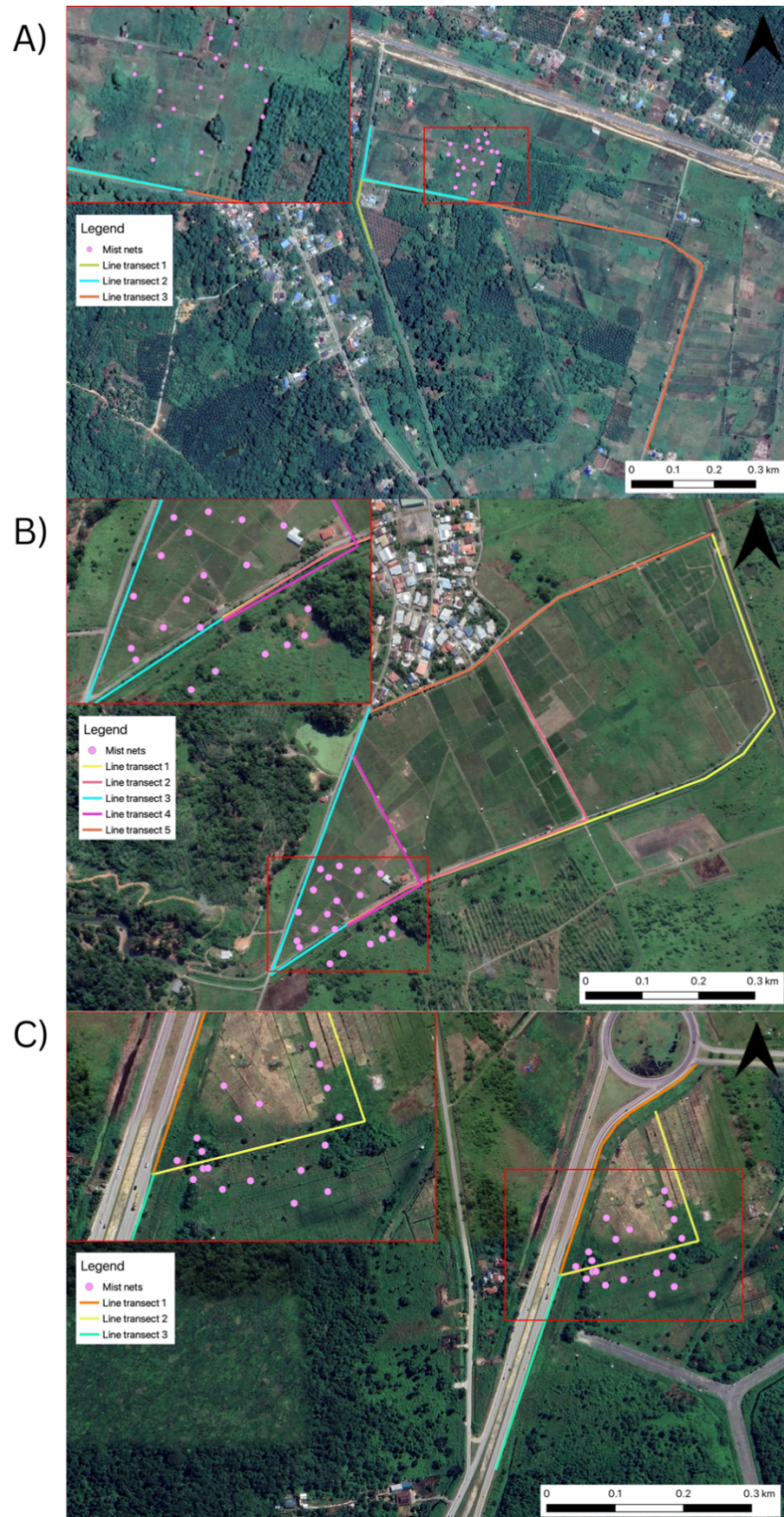


Figure 3.3: Map showing the placement of line transects and mist nets at (A) Kampung Pueh-Siru Dayak, (B) Kampung Skuduk and (C) Kampung Baru.

Eleven line transects of 1 km $\times$ 100 m were established in and around the paddy fields (Figure 3.3). Each transect was surveyed twice daily, once in the morning (0700–0930 hours) and once in the late evening (1600–1830 hours) with each session lasting approximately 2 hours and 30 minutes. Bird sightings and their coordinates were recorded using Nikon Monarch 5 (8 $\times$ 42) binoculars (Nikon Corporation, Tokyo, Japan) and the Garmin GPSMAP 78S device (Garmin Ltd., Olathe, KS, USA), respectively. Any birds found throughout the survey were noted and photographed for immediate identification and subsequent confirmation. The Zoom H6 Handy Recorder (Zoom Corporation, Tokyo, Japan), paired with the MKE 600 Shotgun Microphone (Sennheiser, Wedemark, Germany), TELINGA UNIVERSAL Parabolic Sound Dish (Telinga, Tobo, Sweden), and MDR-7506 dynamic stereo headphones (Sony Group Corporation, Tokyo, Japan), was used to identify and record bird songs and calls heard along the line transects. All species that vocalised within acoustic ranges (≤ 100 m) were recorded. Bird species identification by calls and songs was verified using the accessible global digital archives of Xeno-canto (Planque et al., 2005). The recorded audio samples were processed using Audacity (Version 3.4.2) and assessed using Raven Pro (Version 1.6).

Twenty mist nets (2.5 m $\times$ 12 m, mesh size 36 mm, three shelves, approximately 1.2 to 3.0 meters in height) were utilised per sampling (Figure 3.3). These nets were strategically positioned in and around the paddy fields to intercept birds moving through the area. To minimise overlap, the nets were spaced at intervals of 20 to 50 meters. The mist nets were left operational for 12 hours between 0600 and 1800 hours and were checked every 1 to 2 hours to ensure that the birds caught in the mist nets were disentangled quickly to avoid any casualties. Following extraction, birds were placed in individual cloth bags to be taken to a convenient area for processing (bird identification,

body measurement and marking using aluminium leg bands). Species identification was conducted on-site, referring to field guide books by Phillipps and Phillipps (2014), Lim et al. (2020), and the latest checklist of the birds of Borneo (Lepage, 2023).

3.2.4 Statistical Analysis

A Venn diagram was generated to visualise the species richness in paddy stages. To assess statistical differences in species richness among the planting, harvesting, and land preparation stages, the Friedman test was conducted using the ‘friedman.test’ functions from the R ‘stats’ package (R Core Team, 2024) to account for repeated measures. The results were hypothesised as follows:

H_0 - There is no significant difference in the species richness of birds during different paddy stages;

H_A - There is a significant difference in the species richness of birds during different paddy stages.

Biodiversity assessments were performed using the ‘iNEXT.4steps’ (Four Steps of Interpolation and Extrapolation) package (Chao and Hu, 2023). This package adopts the Hill number ($q = 0, 1, 2$) to quantify the species diversity of an assemblage, whereby diversity order 0 ($q = 0$) refers to species richness, diversity order 1 ($q = 1$) refers to the Shannon index, and diversity order 2 ($q = 2$) refers to the Simpson index. The assessment consists of four steps: Step 1, estimation of sample completeness; Step 2 (2a and 2b), empirical and asymptotic estimation of true diversity; Step 3, comparison of diversity for nonasymptotic sample coverage; and Step 4, estimation of evenness profiles across the bird assemblages of different paddy stages. In Step 1, for the estimation of sample completeness, the level of undetected diversity was assessed in the sample. In Step 2, the

true diversity of order q based on the reliability of the data was estimated to offer sufficient information. True diversity or the effective number of types is the number of equally abundant types needed for the average proportional abundance of the types to equal that observed in the dataset of interest (Supriatna, 2018). The following general equation was used (Jost, 2006):

$${}^qD \equiv \left(\sum_{i=1}^S p_i^q \right)^{1/(1-q)}, \quad \text{Equation 3.1}$$

indicating the q^{th} power sum of species relative abundances. The superscript and exponent of q represent the diversity order for all indices of the functions. In Step 2a, the pattern of each size-based rarefaction and extrapolation sampling curve up to twice the sample size was examined. If the curve stabilised, then the asymptotic estimate could be used to accurately infer the true diversity of the entire assemblage. Otherwise, the asymptotic diversity estimate represented only a lower bound. When the true diversity could be accurately inferred in Step 2a, the extent of undetected diversity within each dataset was obtained by comparing the estimated asymptotic diversity profile and empirical profile in Step 2b. Step 3 entailed nonasymptotic coverage-based rarefaction and extrapolation analysis. When the sampling data did not provide sufficient information to accurately infer true diversity in Step 2, fair comparisons of diversity across multiple assemblages could be made by standardising the sample coverage based on the integration of coverage-based rarefaction and extrapolation sampling curves up to a maximum coverage value of C_{max} (defined as the level of coverage reached by the sample that attained the lowest coverage when all samples were extrapolated to twice the reference sample size (Chao et al., 2020)). Step 4 assessed the evenness profiles at the coverage value of C_{max} among the compared samples. The Pielou J evenness index was computed for the same coverage value of C_{max} .

Indicator values (IndVal) were generated using the ‘indicspecies’ package (de Cáceres and Legendre, 2009) to determine which species could potentially be used as bioindicators corresponding to the highest association value between a species and a site group. The statistical significance of this relationship was tested by permutation and assessed with the significance level of $\alpha = 1$ to include all potential indicator species in the paddy fields.

All calculations were performed using the R program (Version 4.3.2) (R Core Team, 2024).

3.3 Results

A total of 2,552 birds were recorded, including 94 species from 43 families, 88.30% (83 species) of which were residents while 20.21% (19 species) were migratory birds. While 75.53% (71 species) were land birds, 24.47% (23 species) were waterbirds, including seven shorebird species (8.51%). Two nocturnal species (Sunda Scops Owl *Otus lempiji* and Large-tailed Nightjar *Caprimulgus macrurus*) and three crepuscular species were recorded. The crepuscular species included one nocturnal-crepuscular species, the Greater Painted Snipe *Rostratula benghalensis* and two diurnal-crepuscular swiftlets: the White-nest Swiftlet *Aerodramus fuciphagus* and the Glossy Swiftlet *Collocalia esculenta*. Additionally, 27.66% (26 species) were classified as “Protected” under the Sarawak Wild Life Protection Ordinance of 1998 (SWLPO 1998). These include taxa of the families Alcedinidae, Apodidae, Ardeidae, Charadriidae, Picidae, Psittacidae, Rostratulidae, Scolopacidae, and Strigidae and songbird species such as Common Hill Myna *Gracula religiosa* and White-rumped Shama *Copsychus malabaricus*, which are highly sought in the songbird trade. Moreover, eight species (8.51%) are listed in the 2016 - 2022 Red List of the International Union for Conservation

of Nature (IUCN) as “Near Threatened” or “Vulnerable.” Among the taxa found in the paddy fields were two species endemic to Borneo, the Dusky Munia *Lonchura fuscans* and Bold-striped Tit-babbler *Mixornis bornensis*. The families Ardeidae and Nectariniidae were the most represented, with eight and six species, respectively. Scaly-breasted Munia *Lonchura punctulata* was the most abundant species in this study (310 individuals). Kampung Skuduk (70 species) has the highest species richness, followed by Kampung Pueh-Siru Dayak (56 species) and Kampung Baru (50 species). Furthermore, 58 species were identified by IndVal as potential indicators for each stage and combination of stages in paddy fields. Table 3.1 summarises the assemblages of birds from the selected sites according to families and species.

Table 3.1: Bird species recorded and their distribution, protection status, abundance, paddy stages, site and feeding guild. Endemic and potential indicator species were highlighted with symbols.

Family/Common Name	Scientific Name	Distribution	IUCN (2016-2022)	SWLPO	Abundance	Paddy Stage	Sampling Method		Site
							Mist netting (Number of individual)	Line transect (Number of sightings)	
ACCIPITRIDAE									
**Brahminy Kite	<i>Haliastur indus</i>	CR	LC ¹	-	2	L	0	2	P
**Crested Serpent Eagle	<i>Spilornis cheela</i>	CR	LC ¹	-	1	H	0	1	B
**Grey-headed Fish Eagle	<i>Haliaeetus ichthyaetus</i>	UR	NT ¹	-	2	P, L	0	2	P
**White-bellied Sea Eagle	<i>Haliaeetus leucogaster</i>	CR	LC ⁴	-	1	L	0	1	S
ACROCEPHALIDAE									
**Oriental Reed Warbler	<i>Acrocephalus orientalis</i>	CWV, M	LC ¹	-	1	H	1	0	B
ALCEDINIDAE									
**Blue-eared Kingfisher	<i>Alcedo meninting</i>	CR	LC ¹	P	4	H	4	0	S
**Collared Kingfisher	<i>Todiramphus chloris</i>	CR	LC ¹	P	2	L, P	1	1	S, B
APODIDAE									
**White-nest Swiftlet	<i>Aerodramus fuciphagus</i>	CR	LC ¹	P	72	L	0	72	P
**Glossy Swiftlet	<i>Collocalia esculenta</i>	CR	LC ⁴	P	102	P, H, L	0	102	S, B, P
ARDEIDAE									
**Cattle Egret	<i>Bubulcus ibis</i>	CR, CWV	LC ¹	P	1	P	0	1	P
Great Egret	<i>Ardea alba</i>	CNBV	LC ¹	P	100	P, H, L	1	99	S, B, P
Intermediate Egret	<i>Ardea intermedia</i>	CWV	LC ⁴	P	60	P, H, L	0	60	S, B, P
Little Egret	<i>Egretta garzetta</i>	CR, M	LC ¹	P	67	P, H, L	0	67	S, B, P

Table 3.1 continued

Cinnamon Bittern	<i>Ixobrychus cinnamomeus</i>	CR	LC ¹	P	27	P, H, L	3	24	S, B, P
**Yellow Bittern	<i>Ixobrychus sinensis</i>	UR, UWV	LC ¹	P	4	P, H	1	3	S, B
**Chinese Pond-Heron	<i>Ardeola bacchus</i>	CWV, M	LC ¹	P	2	P	0	2	P
**Striated Heron	<i>Butorides striata</i>	CR, M	LC ³	P	1	P	0	1	S
ARTAMIDAE									
White-breasted Wood Swallow	<i>Artamus leucorhynchus</i>	CR	LC ¹	-	26	P, H, L	2	24	S, B
CAMPEPHAGIDAE									
**Pied Triller	<i>Lalage nigra</i>	CR	LC ²	-	1	H	1	0	P
CAPRIMULGIDAE									
**Large-tailed Nightjar	<i>Caprimulgus macrurus</i>	VCR	LC ¹	-	2	P	0	2	S
CHARADRIIDAE									
**Little-ringed Plover	<i>Charadrius dubius</i>	CWV, M	LC ¹	P	8	P, L	1	7	S
Pacific Golden Plover	<i>Pluvialis fulva</i>	CWV, M	LC ¹	P	36	P, L	1	35	S, B, P
CISTICOLIDAE									
Ashy Tailorbird	<i>Orthotomus ruficeps</i>	CR	LC ¹	-	46	P, H, L	5	41	S, B, P
Rufous-tailed Tailorbird	<i>Orthotomus sericeus</i>	CR	LC ¹	-	38	P, H, L	2	36	S, B, P
Yellow-bellied Prinia	<i>Prinia flaviventris</i>	CR	LC ¹	-	120	P, H, L	17	103	S, B, P
COLUMBIDAE									
**Little Green-Pigeon	<i>Treron olax</i>	CR	LC ²	-	1	P	1	0	S
Pink-necked Green-Pigeon	<i>Treron vernans</i>	CR	LC ¹	-	32	P, H, L	6	26	S, B, P
Spotted Dove	<i>Spilopelia chinensis</i>	CR	LC ¹	-	150	P, H, L	4	146	S, B, P
Zebra Dove	<i>Geopelia striata</i>	CR, LCIR	LC ¹	-	19	P, H, L	9	10	S, B, P
CORACIIDAE									
**Dollarbird	<i>Eurystomus orientalis</i>	CR, CWV	LC ¹	-	1	H	0	1	P

Table 3.1 continued

CORVIDAE									
Black Magpie	<i>Platysmurus leucopterus</i>	CR	LC ¹	-	7	P, H, L	0	7	B, P
CUCULIDAE									
**Chestnut-breasted Malkoha	<i>Phaenicophaeus curvirostris</i>	CR	LC ¹	-	1	P	0	1	P
**Greater Coucal	<i>Centropus sinensis</i>	CR	LC ¹	-	14	P, L	0	14	S, P
Lesser Coucal	<i>Centropus bengalensis</i>	CR	LC ¹	-	55	P, H, L	4	51	S, B, P
**Moustache Hawk-Cuckoo	<i>Hierococcyx vagans</i>	UR	NT ⁶	-	1	P	0	1	S
Plaintive Cuckoo	<i>Cacomantis merulinus</i>	CR	LC ¹	-	22	P, H, L	2	20	S, B, P
DICAEIDAE									
**Orange-bellied Flowerpecker	<i>Dicaeum trigonostigma</i>	CR	LC ¹	-	3	P, H	1	2	S, P
**Scarlet-backed Flowerpecker	<i>Dicaeum cruentatum</i>	CR	LC ¹	-	1	P	0	1	S
**Yellow-breasted Flowerpecker	<i>Prionochilus maculatus</i>	CR	LC ¹	-	2	P	0	2	S, B
DICRURIDAE									
**Greater Racket-tailed Drongo	<i>Dicrurus paradiseus</i>	CR	LC ¹	-	4	P	0	4	S, B
ESTRILDIDAE									
Chestnut Munia	<i>Lonchura atricapilla</i>	CR	LC ¹	-	271	P, H, L	56	215	S, B, P
* **Dusky Munia	<i>Lonchura fuscans</i>	CR	LC ¹	-	138	P, H, L	92	46	S, B, P
Scaly-breasted Munia	<i>Lonchura punctulata</i>	AB	LC ¹	-	301	P, H, L	68	233	S, B, P
**Pin-tailed Parrotfinch	<i>Erythrura prasina</i>	RAR	LC ¹	-	1	L	1	0	P
EURLAMIDAE									
**Black-and-red Broadbill	<i>Cymbirhynchus macrorhynchos</i>	CR	LC ¹	-	2	P	1	1	S, B
**Green Broadbill	<i>Calptomena viridis</i>	CR	NT ⁶	-	1	P	0	1	S
GLAREOLIDAE									
**Oriental Pratincole	<i>Glareola maldivarum</i>	UR, UWV	LC ¹	-	1	L	0	1	S

Table 3.1 continued

HIRUNDINIDAE									
**Barn Swallow	<i>Hirundo rustica</i>	CWV, M	LC ²	-	9	L	2	7	S
**Pacific Swallow	<i>Hirundo tahitica</i>	VCR	LC ¹	-	19	P, H	5	14	S, B, P
LANIIDAE									
Long-tailed Shrike	<i>Lanius schach nasutus</i>	RNBV	LC ¹	-	36	P, H, L	18	18	S, B, P
MEGALAIMIDAE									
Red-throated Barbet	<i>Psilopogon mystacophanos</i>	CR	NT ⁶	-	34	P, H, L	0	34	S, B, P
MEROPIDAE									
**Blue-throated Bee-eater	<i>Merops viridis</i>	CR	LC ¹	-	5	H, L	0	5	P
MUSCICAPIDAE									
Oriental Magpie Robin	<i>Copsychus saularis</i>	CR	LC ⁴	-	20	P, H, L	3	17	S, B, P
**White-rumped Shama	<i>Copsychus malabaricus</i>	CR	LC ⁴	P	2	P, L	0	6	S
NECTARINIIDAE									
Brown-throated Sunbird	<i>Anthreptes malacensis</i>	CR	LC ¹	-	6	P, H, L	1	5	S, P
**Crimson Sunbird	<i>Aethopyga siparaja</i>	CR	LC ¹	-	13	P, L	1	12	S, B, P
**Olive-backed Sunbird	<i>Cinnyris jugularis</i>	CR	LC ¹	-	6	P, H	2	4	B, P
**Plain Sunbird	<i>Anthreptes simplex</i>	CR	LC ¹	-	10	P, L	0	10	S
**Little Spiderhunter	<i>Arachnothera longirostra</i>	CR	LC ¹	-	4	P, H	2	2	S, B
**Purple-naped Spiderhunter	<i>Kurochkinogramma hypogrammicum</i>	CR	LC ¹	-	14	P, H	0	14	S, B, P
PACHYCEPHALIDAE									
**Mangrove Whistler	<i>Pachycephala cinereal</i>	UR	LC ¹	-	1	L	0	1	S
PASSERIDAE									
Eurasian Tree Sparrow	<i>Passer montanus</i>	VCR	LC ¹	-	57	P, H, L	1	56	S, B, P
PICIDAE									

Table 3.1 continued

**Banded Woodpecker	<i>Chrysophlegma miniaceum</i>	CR	LC ¹	P	5	P, H	3	2	B, P
**Maroon Woodpecker	<i>Blythipicus rubiginosus</i>	FCR	LC ¹	P	2	P	0	2	S
**Rufous Piculet	<i>Sasia abnormis</i>	FCR	LC ¹	P	1	H	1	0	S
PLOCEIDAE									
Baya Weaver	<i>Ploceus philippinus</i>	LCIR	LC ¹	-	37	P, H, L	5	32	S
PSITTACIDAE									
**Long-tailed Parakeet	<i>Psittacula longicauda</i>	CR	VU ²	P	3	L	0	3	P
PYCNONOTIDAE									
**Buff-vented Bulbul	<i>Iole crypta</i>	CR	NT ¹	-	1	P	0	1	B
Olive-winged Bulbul	<i>Pycnonotus plumosus</i>	CR	LC ¹	-	17	P, H, L	5	12	S, B, P
Yellow-vented Bulbul	<i>Pycnonotus goiavier</i>	VCR	LC ¹	-	65	P, H, L	20	45	S, B, P
RALLIDAE									
Buff-banded Rail	<i>Gallirallus philippensis</i>	RA	LC ¹	-	18	P, H, L	0	18	S, B
Slaty-breasted Rail	<i>Lewinia striatus</i>	UR	LC ¹	-	3	P, H, L	2	1	B, P
Eurasian Moorhen	<i>Gallinula chloropus</i>	UR, UWV	LC ¹	-	14	P, H, L	1	13	S, P
White-breasted Waterhen	<i>Amaurornis phoenicurus</i>	VCR, VCWV	LC ¹	-	115	P, H, L	4	111	S, B, P
**White-browed Crane	<i>Porzana cinerea</i>	CR	LC ¹	-	7	P, H	1	6	S, B
RHIPIDURIDAE									
Malaysian Pied-fantail	<i>Rhipidura javanica</i>	CR	LC ¹	-	8	P, H, L	2	6	S, P
ROSTRATULIDAE									
**Greater Painted Snipe	<i>Rostratula benghalensis</i>	CR	LC ¹	P	1	P	1	0	5
SCOLOPACIDAE									
**Pin-tailed Snipe	<i>Gallinago stenura</i>	CWV	LC ⁴	P	4	H, L	2	2	B, P
**Swimhoe's Snipe	<i>Gallinago megala</i>	UWV	LC ¹	P	8	P, L	4	4	B

Table 3.1 continued

**Common Sandpiper	<i>Actitis hypoleucos</i>	VCWV, M	LC ¹	P	23	P, L	0	23	S
Wood Sandpiper	<i>Tringa glareola</i>	VCWV, M	LC ¹	P	67	P, H, L	16	51	S, B
SITTIDAE									
**Velvet-fronted Nuthatch	<i>Sitta frontalis</i>	CR	LC ¹	-	1	P	0	1	S
STRIGIDAE									
**Sunda Scops Owl	<i>Otus lempiji</i>	CR	LC ¹	P	1	L	1	0	P
STURNIDAE									
Asian Glossy Starling	<i>Aplonis panayensis</i>	VCR	LC ¹	-	68	P, H, L	16	52	S, B, P
Common Hill Myna	<i>Gracula religiosa</i>	CR	LC ¹	P	26	P, H, L	0	26	S, P
Common Myna	<i>Acridotheres tristis</i>	CR	LC ¹	-	34	P, H, L	0	34	S, B, P
TEPHRODORNITHIDAE									
Rufous-winged Philentoma	<i>Philentoma pyrrhopterum</i>	FCR	LC ¹	-	20	P, H, L	0	20	S, P
TIMALIIDAE									
**Chestnut-winged Babbler	<i>Cyanoderma erythropterum</i>	CR	LC ¹	-	3	P	0	3	S, B
**Scaly-crowned Babbler	<i>Malacopteron magnum</i>	CR	LC ¹	-	1	P	0	1	B
**Short-tailed Babbler	<i>Pellorneum malaccense</i>	CR	NT ⁵	-	1	P	0	1	S
* **Bold-Striped Tit-Babbler	<i>Mixornis bornensis</i>	CR	LC ²	-	3	P, H	1	2	P
**Fluffy-backed Tit-babbler	<i>Macronous ptilosus</i>	CR	NT ¹	-	3	P	0	3	S
TURDIDAE									
**Eyebrowed Thrush	<i>Turdus obscurus</i>	UWV, M	LC ¹	-	1	P	0	1	P
VIREONIDAE									
**White-bellied Erpornis	<i>Erpornis zantholeuca</i>	UR	LC ¹	-	1	P	1	0	S
					2,552	406 (51 sp)	2,150 (84 sp)		

Notes: Distribution: VCWV = Very Common Winter Visitor, VCR = Very Common Resident, CR = Common Resident, UR = Uncommon Resident, FCR = Fairly Common Resident, RAR = Rare Resident, SR = Scarce Resident, AB = Absent, CWV = Common Winter Visitor, UWV = Uncommon Winter Visitor, RWV = Rare Winter Visitor, CNBV = Common Nonbreeding Visitor, UNBV = Uncommon Nonbreeding Visitor, RNBV = Rare Nonbreeding Visitor, M = Migrant, N = Native, RA = Rare, VA = Vagrant, LCIR = Locally Common Introduced Resident; IUCN = IUCN Red List: LC = Least Concern, NT = Near Threatened, EN = Endangered, VU =

Vulnerable, Year = 2016¹, 2018², 2019³, 2020⁴, 2021⁵, 2022⁶; SWLPO 1998 = Sarawak Wildlife Protection Ordinance 1998: P = Protected, - = Not listed; Paddy stage: P = Planting, H = Harvest, L = Land preparation; Site: P = Kampung Pueh-Siru Dayak, B = Kampung Baru, S = Kampung Skuduk; * = Endemic; ** = Indicator species; Feeding Guild^s = Specialist

Figure 3.4 shows a Venn diagram visualising the species richness in paddy stages in this study. This includes 23 species recorded solely during the planting stage, nine species observed during the land preparation stage, and six species detected during the harvest stage. A total of 35 species are shared by all paddy stages, 11 species are shared by planting and harvest, eight species are shared by planting and land preparation, and two species are shared by harvest and land preparation.

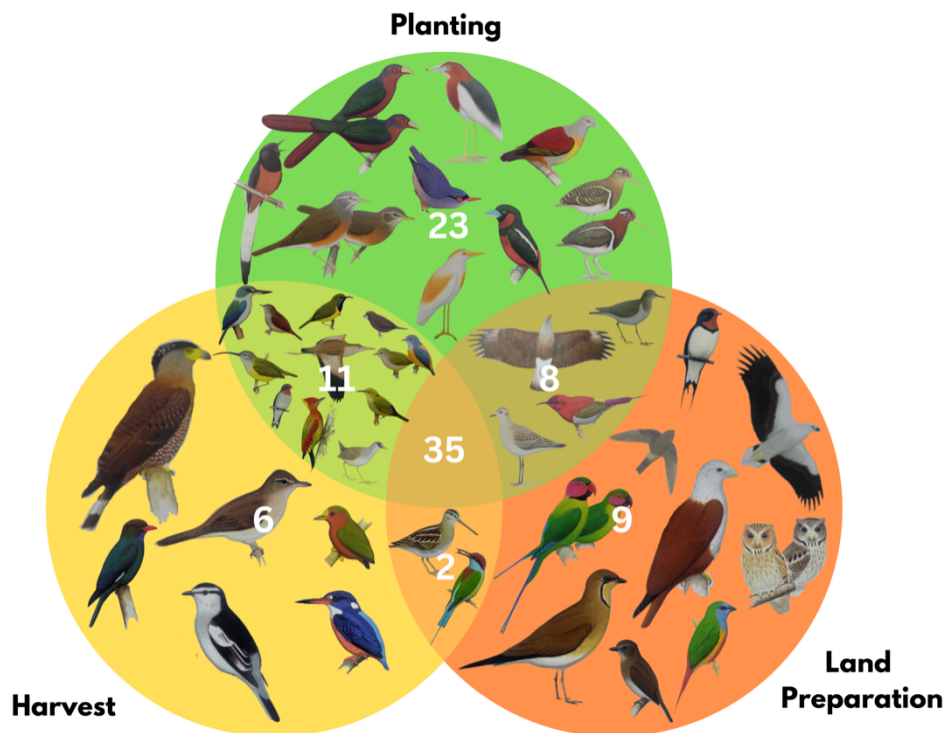


Figure 3.4: The Venn diagram shows that 35 species are shared by all stages, planting has the most exclusive species (23 species), and harvest has the least exclusive species (six species).

Friedman test ($\chi^2 = 0.6667$, $df = 2$, $P = 0.7165$) suggested no statistically significant difference in species richness across the three paddy stages (planting, land preparation, and harvest).

Figure 3.5 shows the diversity assessment performed using 'iNEXT.4steps.' Numerical values for the procedures are provided in Appendix B. Figure 3.5 (a) shows that the estimated sample completeness profiles increase with diversity order ($q = 0, 1, 2$), implying undetected

diversity within the dataset. The estimated sample completeness for $q = 0$ for the overall assemblage is 75.0%, with the land preparation stage having the highest completion of species richness and the planting stage having the highest number of undetected species. In contrast, the estimated sample completeness for $q = 1$ and $q = 2$ for the overall data is 99.0% and 100.0%, respectively, indicating that almost all species in the studied sites were sampled and detected. Figure 3.5 (b) reveals that, for each stage, the size-based rarefaction and extrapolation sampling curves for $q = 1$ and $q = 2$ stabilise, implying that asymptotic diversity estimates for these two measures work satisfactorily to infer true diversities. The planting stage is significantly more diverse than the other stages for any fraction up to entire assemblages. However, neither of the sampling curves for $q = 0$ stabilised, extrapolated up to twice the reference sample size, suggesting that the data do not provide sufficient information to accurately estimate true species richness within each assemblage. The asymptotic estimate of species richness (i.e., the Chao1 estimate) thus represents a minimum estimate (lower bound) of species richness. Based on Figure 3.5 (c), the undetected species richness ($q = 0$) within the stages is moderate. However, Figure 3.5 (b) shows that the degree of difference in true species richness of the entire assemblages cannot be precisely assessed since these estimates are lower bounds. In contrast, the undetected $q = 1$ and $q = 2$ within the different paddy stages are small, implying that nearly all highly abundant species were detected. In Figure 3.5 (d), for $q = 0$, although the data are insufficient for inferring the true richness of the entire assemblage, inference and significance testing can be performed up to a standardised coverage value of $C_{\max} = 98.8\%$. The planting stage shows the highest diversity and all differences in each stage are significant. The diversity value of $q = 1$ and $q = 2$ for a standardised coverage value of 98.8% differs very little from that of the entire assemblage. Figure 3.5 (e) shows the evenness profile for $q = 0, 1, 2$. Under the coverage value of 98.8%, the Pielou J evenness index shows that the evenness among species occurrences in every stage is relatively similar. Nonetheless, all measures consistently show

that the evenness among species abundances in land preparation is higher than that in the planting and harvest stages for a standardised coverage value of 98.8%. Altogether, only true diversities for order $q = 1$ and $q = 2$ were achieved with planting observed to have the highest true diversities (${}^1D = 42.75$, ${}^2D = 30.25$). The highest diversity was still observed during planting (${}^0D = 92.01$, ${}^1D = 41.61$, ${}^2D = 29.73$) in nonasymptotic coverage-based rarefaction and extrapolation. However, evenness was observed to be highest during land preparation ($J' = 0.83$). In short, the data revealed that the planting stage and land preparation respectively harbour more diverse birds and more even bird communities in the paddy fields of southwestern Sarawak.

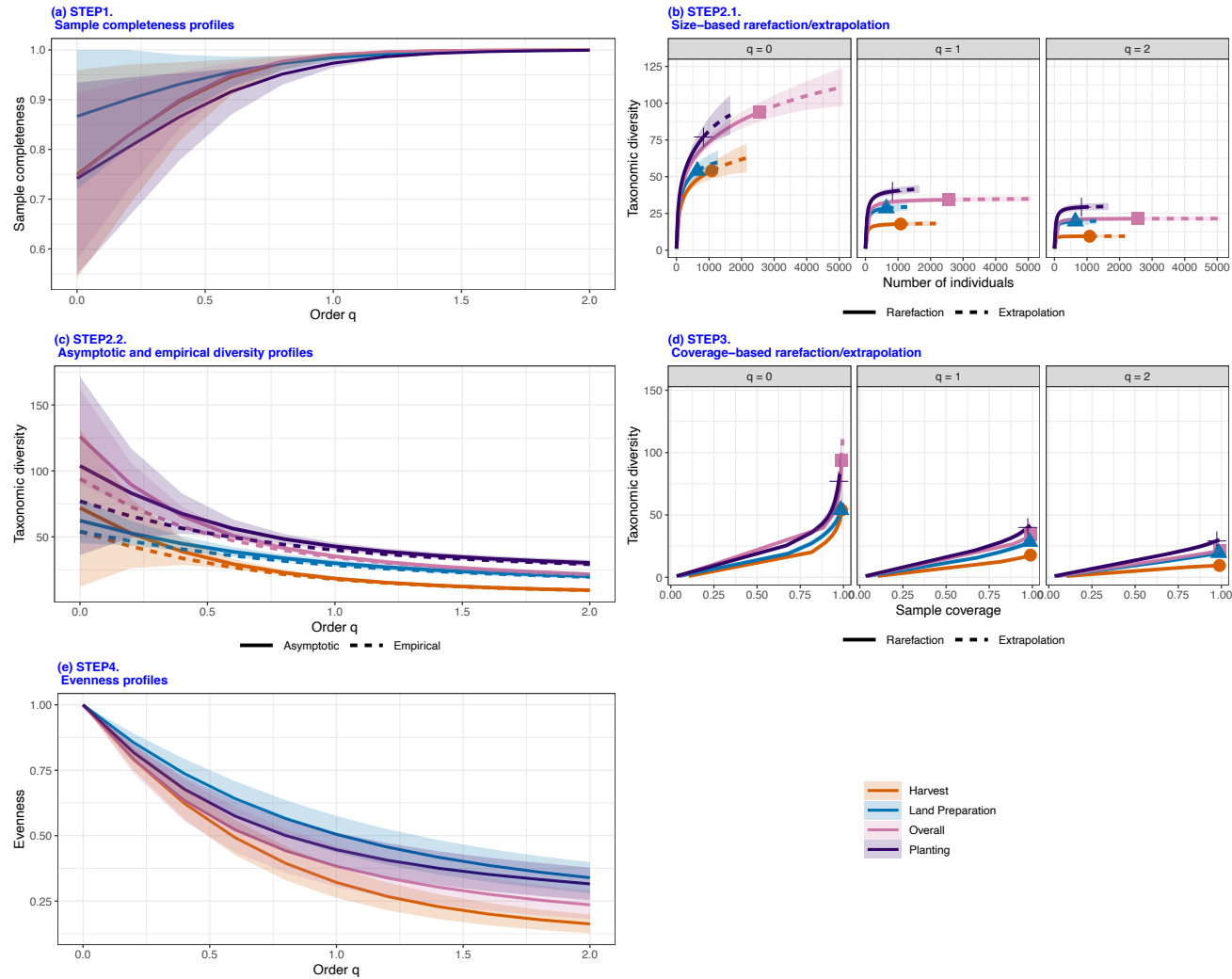


Figure 3.5: Overview of biodiversity assessments based on Hill numbers ($q = 0, 1, 2$): (a) estimated sample completeness curves; (b) size-based rarefaction and extrapolation; (c) asymptotic and empirical diversity profiles; (d) coverage-based rarefaction and extrapolation; and (e) evenness profile based on the normalised slope of Hill numbers. Coloured lines denote observed bird assemblages.

3.4 Discussion

This study recorded a higher number of species compared to most previous studies conducted in paddy fields (Azman et al., 2014; Azman et al., 2011; Makbul & Wong, 2016; Horgan et al., 2017; Amira et al., 2018; Karim et al., 2018; Mohd-Taib et al., 2018; Jayasimhan & Padmanabhan, 2019; Mohd-Taib et al., 2021; Platt et al., 2021; Supahan, 2022; Putri et al., 2023). Higher bird diversity can be expected in paddy fields if data are sampled using multiple survey methods. Line transects were adopted in this study because that approach offers more practicality in open areas with less dense vegetation that can obstruct vision, like paddy fields (Egli, 2014; Morrison and Peitz, 2021). Conducting point counts in open areas increases the possibility of double-counting the same bird individuals and underestimates the species richness (Egli, 2014; Morrison and Peitz, 2021). Line transects can be supported with bioacoustics equipment and camera capabilities to record more bird species (Carvalho et al., 2023). Some forest birds (e.g., Velvet-fronted Nuthatch *Sitta frontalis*, and family Timaliidae) were detected along the line transects using bioacoustic equipment consisting of an omnidirectional or shotgun microphone combined with a parabolic reflector. This setup significantly enhances sound capture over long distances by extending the pickup range beyond 30 meters and increasing directionality (Pavan, 2011; Penar et al., 2020; Cornell University, 2025; Terpstra, 2025). The parabolic reflector focuses sound waves toward the microphone, which helps isolate target vocalisations and reduce background noise. Moreover, the data collection includes the possibility of detecting secretive, smaller birds, highly mobile, nocturnal or crepuscular species when complemented with mist netting (Viquerat et al., 2012; Egli, 2014). Most previous studies relied solely on active surveys and did not incorporate mist netting, as it was often deemed unnecessary in monoculture agroecosystems like paddy fields, where open landscapes present minimal visual obstruction for bird detection (Azman et al.,

2011; 2012; 2019). However, this approach may have resulted in incomplete data due to the omission of less detectable or cryptic species. For species that are difficult to observe or count visually in open areas, mist nets can be an effective way to confirm their presence (Estades et al., 2006; Tattoni and LaBarbera, 2022; Carvalho et al., 2023). In this study, the Pin-tailed Parrotfinch *Erythrura prasine* and Bold-Striped Tit-Babbler *Mixornis bornensis*, both small and secretive species, were captured using mist nets set up around paddy fields located adjacent to a secondary forest patch (regenerated from abandoned paddy plots) and intermixed with agroforestry systems including rubber plantations. Additionally, mist netting was effective in capturing the cryptic and crepuscular Greater Painted Snipe *Rostratula benghalensis* and the nocturnal Sunda Scops Owl *Otus lempiji* within the paddy field environment. Their elusive behaviour and activity during low-light periods greatly limit visual detection and accurate identification, making mist netting (particularly when conducted at appropriate times) one of the few viable options.

Incomplete diversity detection during the planting stage explains the highest percentage of undetected diversity of singletons recorded over time (Chiu and Chao, 2016). Complete diversity could be achieved if the sampling duration for each of the paddy stages were increased (Grey et al., 2018; Hoffmann et al., 2019). Additionally, flawed partitioning of paddy stages whereby early growing and seedling stages are merged into one stage (planting stage) should be addressed. The northeast monsoon (November to March) and southwest monsoon (May to September) significantly affect the partitioning of paddy stages in southwestern Sarawak, especially for paddy fields without irrigation aid. The northeast monsoon causes substantial rainfall to the west of Sarawak while the southwest monsoon brings drier weather (Minggu, 2024; Malaysian Meteorology Department, 2025). Local farmers usually engage in planting or land preparation during the northeast monsoon and harvest during the southwest monsoon. Furthermore, the willingness and agreement among farmers to engage

in paddy farming practices also affect the partitioning of the stages (Garay-Barayazarra and Puri, 2011). The active paddy stage was identified based on dominant paddy features to avoid common misclassifications due to overlapping paddy stages (Wang et al., 2022).

No significant differences in species richness were detected across the paddy stages, likely due to the high proportion of species occurring consistently throughout all stages. Resident species from families such as Ardeidae and Estrildidae were abundantly recorded during each paddy stage, indicating a stable community presence. Their persistence across the agricultural cycle can be attributed to the heterogeneous landscape structure, where paddy fields are interspersed with houses and patches of secondary forest. This spatial mosaic likely contributed to the habitat complexity and continuous resource availability (Amira et al., 2018) by offering a range of microhabitats, thereby maintaining a relatively constant bird assemblage across stages (Halim & Norazlimi, 2024; Feng et al., 2025). Moreover, studies have shown that heterogeneous agricultural landscapes tend to support higher species richness and more resilient bird communities by reducing habitat fragmentation and facilitating movement across habitat types (Devictor & Jiguet, 2007; Mallet et al., 2022). In this context, the consistent presence of these resident species across all stages likely reflects the buffering effect of landscape complexity (Paulino et al., 2025), which mitigates the temporal habitat fluctuations associated with different paddy stages. Temporal water fluctuations in the irrigation of paddy fields create microhabitats with various water levels that provide different foraging opportunities for opportunistic feeders (Nam et al., 2015). Additionally, birds may utilise ditches where the drained water concentrates aquatic organisms with a variety of vegetation (Townsend et al., 2006) and may forage on levees rather than in the paddy field matrices (Choi et al., 2022). Other food resources such as insects, were continuously available regardless of the paddy stage (Mohd-Taib et al., 2018; Oo et al., 2020; Supahan, 2022). Munias were observed opportunistically consuming seeds of various kinds of grass, most notably the leftover

paddy that was not harvested, and the nutrient-rich filamentous alga *Spirogyra*, which supplies adequate protein to prepare for breeding (Avery, 1980; Amar-Singh, 2009).

Most indicator species during planting stages belong to Ardeidae and Timaliidae. Ardeidae is synonymous with the paddy fields, especially during planting (Azman et al., 2019). These taxa were observed utilising most portions of the paddy field, such as flooded paddy, levees, and ditches, to forage for food; they even sought shelter in trees (Pinto et al., 2013). Their habitat use depends on the magnitude of disturbance or contamination in their surrounding environment, thus making Ardeidae taxa useful as bioindicators of the health of an ecosystem (Pinto et al., 2013). Timaliidae feeds on insects and these taxa were observed to dwell in the adjacent forest and grasses to forage for food. These birds can be used as bioindicators as they are particularly sensitive to disturbances related to varying land uses (Sreekar et al., 2015). During harvest, most of the indicator species are carnivorous birds. The water irrigating the paddy matrices is usually drained but these birds can still be seen utilising the ditches. Ditches are valuable habitats for aquatic and terrestrial animals, supplying food resources and performing connectivity functions within the ecosystem (Herzon and Helenius, 2008). The extensive use of ditches by carnivorous birds suggests that these birds are bioindicators of pollution in aquatic and terrestrial environments. Migratory birds and raptors are indicator species during the land preparation stage. Paddy fields are suitable staging habitats along the route of migratory birds (Masero et al., 2011). Oriental pratincole *Glareola maldivarum* is an uncommon winter visitor that travels through Borneo to Australia and was observed foraging in open land in Kampung Skuduk during land preparation in October (Phillipps and Phillipps, 2014). The response of migratory birds in paddy fields can be used to monitor the carrying capacity of an artificial wetland habitat (Li et al., 2013). Meanwhile, the number of hunting raptors increased during land preparation. Taxa of Strigidae and Accipitridae use paddy fields as their preferred sites for hunting prey such as exposed

invertebrates, rodents, frogs, and snakes (Fujioka et al., 2010). Migratory raptors make excellent bioindicators and meet most of the criteria for ideal indicators, such as symbiotic associations with other species, connectivity in trophic levels as apex predators, sensitivity to disturbances that become indicative of the cause, and potential for being keystone and umbrella species (Natsukawa and Sergio, 2022).

Paddy fields are important as a refuge for many species of birds, including threatened species (Elphick, 2010; Natuhara, 2013) as an alternative to habitat loss (Yoon, 2009; Tadashi et al., 2014). The Grey-headed Fish Eagle *Haliaeetus ichthyaetus* shows an apparent population decline regionally in Southeast Asia due to habitat and food source disturbances (Tingay et al., 2006; 2010). This species is typically found near streams, lagoons, lakes, and dams in lowland areas, particularly close to coastal zones or estuaries, though it may also occur inland up to elevations of 3,500 feet, including areas near paddy fields (Planet of Birds, 2025). While a vast and dry paddy field might not be their ideal primary habitat, a paddy field system interconnected with other water sources or paddy plots that experience temporal inundation can offer suitable foraging conditions and attract the species. Despite its vulnerability, this species has been reported to persist in human-modified landscapes, provided that adequate food resources and tall nesting trees are present (Miron and Chowdhury, 2019). In this study, its occurrence in the paddy fields of Kampung Pueh–Siru Dayak (an area situated near the coastal beach) during planting and land preparation suggests that the surrounding water bodies and habitat structure provide suitable conditions for foraging and nesting (Tingay et al., 2010). Its regular presence in paddy fields may suggest its ecological role as a predator of small animals inhabiting these landscapes.

3.5 Conclusion

This study documented the bird assemblages present in the paddy fields of southwestern Sarawak, revealing higher species richness than reported in most previous studies. The findings

suggest that seasonal paddy practices do not necessarily alter paddy field bird diversity and assemblages due to habitat complexity and continuous resource availability. However, a complete bird diversity was not entirely captured. Greater sampling effort across longer durations within each paddy stage could improve detection rates and provide a more comprehensive picture of community dynamics. A more refined partitioning of these paddy stages (planting, growing, harvest and land preparation) is recommended to enhance resolution in future ecological assessments. Several potential indicator species were identified, offering valuable tools for monitoring the ecological condition and integrity of paddy field environments. Given their role in supporting both threatened resident species and migratory waterbirds, small-scale paddy fields should be recognised for their conservation value, irrespective of their farming practices.

CHAPTER 4

FUNCTIONAL GROUP CLASSIFICATION OF PADDY FIELD BIRDS IN SOUTHWESTERN SARAWAK

4.1 Introduction

Functional ecology is a subfield of ecology that studies the role of individuals, species, populations, communities, trophic levels, or evolutionary processes in a trophic system (Russell, 2022). It includes terms like functional diversity, functional group, and functional traits. Both communities and ecosystems in ecology have grouped species into bigger classifications such as guild or functional groups. Animal ecology mostly uses guilds that are based on the usage of food resources (resource-centred guild approaches) as groupings rather than functional groups that focus on similarities in resource usage and ecosystem function or service (Blondel, 2003; Blaum et al., 2011). However, a classification system that goes beyond resource-centred guild approaches is needed to assess how communities respond to environmental changes. Species can be classified into functional groups based on their ecological similarities, such as functional traits (Bello et al., 2010). These traits strongly influence organismal performance and indirectly impact fitness through growth, reproduction, and survival.

Over the past two decades, trait-based studies have rapidly expanded (Mammola et al., 2021), particularly in functional ecology, though animal functional ecology is still a developing field compared to plant studies (Blaum et al., 2011; Luza et al., 2023). Research on animal traits, especially birds has been more common (Mayani-Parás et al., 2023), with tropical birds being extensively studied (Tscharntke et al., 2008; Sekercioglu, 2012; Newbold et al., 2014; Sayer et al., 2017). However, there has been relatively little research, particularly in paddy fields, a habitat that has been underexplored in functional ecology compared to other

agroecosystems like cacao and oil palm plantations (Clough et al., 2009; Edwards et al., 2013; Hua et al., 2016). Existing studies on bird traits have focused on factors like space, time, weather, and habitat features (de Arruda Almeida et al., 2019; He et al., 2021; Jarzyna and Stagge, 2023; Li et al., 2022; Mayani-Parás et al., 2023), but there's still limited consensus on how changes in paddy fields due to farming practices impact bird functional traits. Therefore, the objective of this study is to classify and compare bird functional groups in paddy fields during different paddy stages.

4.2 Methodology

4.2.1 Study Site

The study site is as described in Section 3.2.1.

4.2.2 Data Collection

The cycle of paddy farming is as outlined in Section 3.2.2. Data collection was carried out as described in Section 3.2.3, with additional steps taken to obtain functional trait information (feeding guild, locomotion, and feeding substrate + technique). Behavioural observations and tertiary references were used to classify species identified during line transects into the classification scheme.

For mist netting, stomach flushing was incorporated to identify the ingested food items of captured birds. This method followed Sing-Tyan et al. (2017) where 1% tartar emetic solution was dosed orally facilitated by a syringe fitted with a short catheter at the tip to the retained bird. The 1% tartar emetic solution was prepared by diluting 5 g antimony potassium tartrate (APT) in 500 ml of distilled water. The dosage was 1 ml of 1% tartar emetic per 100 g of bird body weight. Each bird was then put into a cylindrical collection chamber with holes for ventilation and placed in a dark area to allow it to calm down. After 10 minutes the birds were released, irrespective of whether they had regurgitated or not. After regurgitation, some

of the birds that experienced fatigue before release were given some commercial glucose solution to help with recovery. Ethical considerations are: no emetic was given to individuals captured twice or more often on the same day and stomach flushing was avoided later in the day to allow birds adequate time to recover (by regaining energy, rehydrating, and potentially re-foraging) before nightfall.

The regurgitated prey items were preserved in 70% ethanol, for later inspection under a stereo microscope (AmScope SW-2B24-V331). Broken specimens were still taken into consideration if the body part could be recognised and removed if it could not be distinguished and was entirely devoid of the associated compound. Most solid foods of vegetable and animal matter can be identified, but it is more difficult to discern between liquid foods like nectar and nearly digested food. Non-food materials ingested for purposes other than nutrition were not considered, such as grit, gravel and soil. Tertiary references on functional traits (feeding guild, locomotion, and feeding substrate + technique) were used to assist the assignment of mist netted bird species into the classification scheme.

4.2.3 Classification Scheme for Functional Group (FG) of Birds

Feeding guild, locomotion, and feeding substrate + technique information were obtained from stomach flushing content, behavioural notes made during the visual survey, and tertiary sources including field guides (Smythies, 1999; Amar-Singh, 2009; Davison and Chew, 2011; Elphick, 2014; Phillipps and Phillipps, 2014; Lim et al., 2020; Strange, 2002). Following Mayani-Parás et al. (2023), this information was compiled to assign bird species into a functional group (FG) classification scheme adopting functional traits (Table 4.1). Detail descriptions of the feeding guild categorisation were based on the avian diet classification types by Lopes et al. (2016). If a species consumed a variety of food and possessed locomotion and technique variations, the category with the largest percentage was selected.

Table 4.1: The classification scheme for bird functional groups in paddy fields. Functional groups consist of functional traits (i) feeding guild, (ii) locomotion, and (ii) feeding substrate + technique, with descriptions of the categorisation.

Functional trait	Category and description
(i) Feeding guild: This trait covers every aspect of species feeding behaviour as well as the movement of matter and energy within ecosystems.	Carnivore: Main food item is vertebrates such tetrapoda (e.g., amphibians, reptiles, birds, and mammals) and their eggs. Prey must be obtained alive to be considered a carnivore.
	Invertivore: Main food item is invertebrates: Hexapoda (insects and their kin) including the benthic aquatic forms (e.g., dragonflies, stoneflies, and mayflies), Chelicerata (e.g., ticks, spiders, and scorpions) and Myriapoda (e.g., centipedes and millipedes), Mollusks (e.g., snails, clams, cockles, oysters, mussels, squid, cuttlefish, and octopuses), all kinds of worm-like including Platyhelminthes (flatworms), Nemertea (ribbon worms), Annelida (segmented worms, such as sandworms, earthworms, and leeches), Nematoda (nematodes and roundworms), and Priapulida (priapulid worms).
	Aquatic vertivore/invertivore: Main food item is aquatic invertebrates and vertebrates.
	Granivore: Main food item is seeds, grains nuts, dry fruits, pines, grasses, sedges, composites, oaks and palms. Seeds are eaten and crushed, either during mandibulation or during gut passage.
	Herbivore: Main food item is vegetation (stems, shoots, leaves, buds, flowers, whole aquatic plants, ferns, clubmosses, and mosses).
	Nectarivore: Main food item is nectar of flowers.
	Frugivore: Main food item is fruits. Seeds when ingested are usually regurgitated or defecated whole.
	Omnivore: Main food item is plants and animals.

Table 4.1 continued

(ii) Locomotion: This functional trait corresponds to species morphology, how it uses resources spatially, and how it adapts its habitat.	Terrestrial: Species live and carry out their activities predominantly or entirely on the ground surface.
	Arboreal: Species carry out their activities on trees and live in them most or all of their lives.
	Semi-arboreal: Species with adaptations for climbing, that carry out their activities on trees, but spend a similar time on the surface of the earth.
	Semi-aquatic: Species with an affinity for the aquatic environment but must spend part of the day out of the water.
	Volant: Species move and carry out their activities mostly in the air and rarely perch.
(iii) Feeding substrate + technique: This functional trait associated with the method a species acquires food and where feeding behaviours are carried out. This functional characteristic shows the distribution of a species in microhabitats, its effects on resource usage, and the movement of matter and energy across ecosystems.	Ground gleaner/ browser/grazer: Species get their food on the ground.
	Ground hunter: Species hunt their prey on the ground.
	Arboreal gleaner/ browser: Species get their food from trees.
	Arboreal hunter: Species hunt their prey on trees.
	Aquatic surface gleaner/ browser: Species capture their food on the surface of water bodies.
	Aquatic surface hunter: Species hunt their prey on the surface of freshwater bodies.
	Wader: Species capture their food (aquatic invertebrates) in the mud or sand.
	Air hunter above canopy: Species hunt their prey in the air above the tree canopy.
	Air hunter under canopy: Species hunt their prey in the air under the tree canopy.

4.2.4 Statistical Analysis

Stacked bar plots with relative read abundance (%) were plotted to visualise the composition of three functional traits in birds (feeding guild, locomotion and feeding substrate + technique) during different paddy stages (planting, harvest and land preparation) in southwestern Sarawak.

An alluvial plot was produced to illustrate associations and data flows between three functional traits (feeding guild, locomotion, and feeding substrate + technique) in constructing functional groups in birds during different paddy stages (planting, harvest and land preparation). It is comprised of a few basic components: axes, strata, alluvium and flow (Saxena, 2021). Axes are the X-axis of the different states of being (functional traits: Feeding guild, Locomotion, Feeding substrate + technique; and Paddy stages). Strata are the various categories within axes. For example, the stratum within the Locomotion axis is Terrestrial, Arboreal, Semi arboreal, Semi aquatic and Volant. Alluvium shows movement across all the variables that span the entire graph. In this study, the movements were used to construct a classification of functional groups of birds in paddy fields. Flows are the segments of the alluvia between pairs of adjacent axes that also show the individual frequencies of each stratum of axes. Thin flows indicated a frequency under five individuals and were excluded as a significant functional group (FG) classification. A figure was drawn to visualise functional groups of birds in different paddy stage settings.

The Multi-Response Permutation Procedure (MRPP) was used to test for statistical differences between bird functional groups during three different paddy stages (planting, harvest, and land preparation). MRPP measures delta (δ), which is the mean distance (default: Euclidean distance) among sample units within each group. The T value calculates the difference between observed and expected delta (δ), indicating dissimilarity between groups. The greater the T value, the greater the differences. A value signifies the size of the effect defined as the chance-corrected within-group agreement, while P is the significance of delta, where $P \leq 0.05$ is statistically significant. The MRPP results were hypothesised as follows:

H_0 - There is no significant difference in the bird functional groups during different paddy stages;

H_A - There is a significant difference in the bird functional groups during different paddy stages.

All visualisations and analyses were performed using “ggplot2” (Wickham, 2016), “ggalluvial” (Brunson and Quentin, 2023), “stats” (R Core Team, 2024), and “vegan” (Oksanen et al., 2024) packages in R statistical software Version 2023.03.0+386 ((R Core Team, 2024).

4.3 Results

A total of 2552 birds were recorded, including 94 species from 43 families. 8.62% of birds from 14 species were successfully stomach flushed from 406 (51 species) mist netted birds. Invertivores were the most represented feeding guild with 34.04% (32 species) followed by carnivores with 18.09% (17 species). 53.19% of the bird community was arboreal species (50 species) followed by 19.15% of semi aquatic species (18 species). Arboreal hunter and arboreal gleaner/browser have the highest associated species, 26.60% (25 species) and 24.47% (23 species), respectively.

4.3.1 Functional Traits and Bird Assemblages

Figure 4.1, Figure 4.2 and Figure 4.3 illustrate the composition of birds with three functional traits ((i) feeding guild, (ii) locomotion and (iii) feeding substrate + technique) during three paddy stages. Generally, feeding guild: invertivores, locomotion: arboreal and feeding substrate + technique: arboreal browser/hunter are the most prominent functional traits. The planting stage harbours the most species with 12.99% frugivores (10 species), 31.17% invertivores (24 species) and 14.29% omnivores (11 species). Additionally, the number of arboreal species during planting is twice (54.55%, 42 species) of that during harvest (50.0%, 27 species) and land preparation (42.59%, 23 species). The number of semi aquatic species was also 19.48% higher (15 species) during planting. Arboreal browser/gleaner (27.27%, 21

species), arboreal hunter (24.68%, 19 species) and ground hunter (6.49%, 5 species) were higher in number during planting. During land preparation, the number of volant species was observed to increase (12.96%, 7 species) while the number of land birds decreased markedly (14.82%, 8 species). Waders were observed the least (11.11%, 6 species) during harvest and aquatic surface hunters were missing during land preparation.

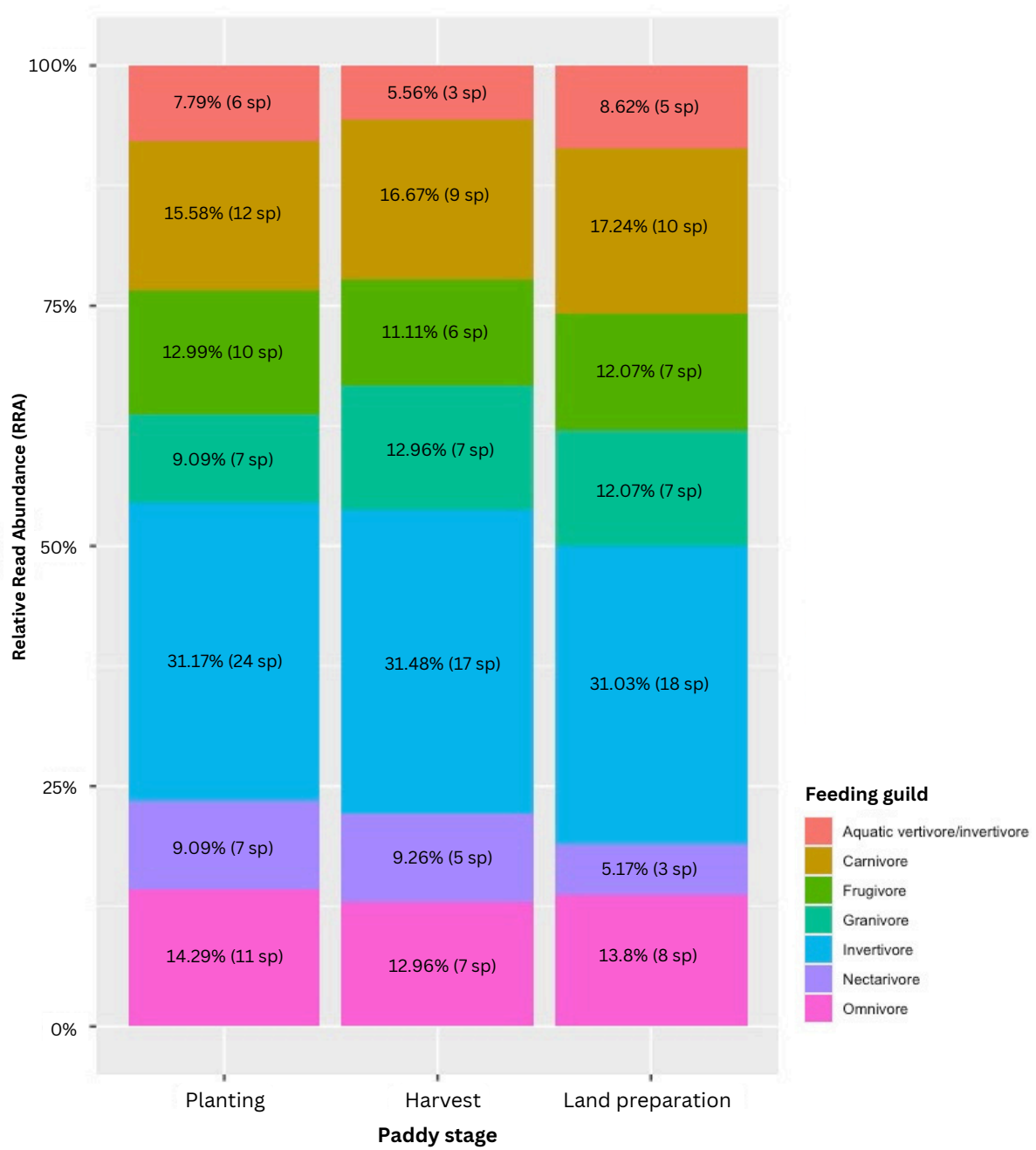


Figure 4.1: The abundance and percentage of bird species of functional traits: (i) feeding guild during planting, harvest and land preparation in paddy fields.

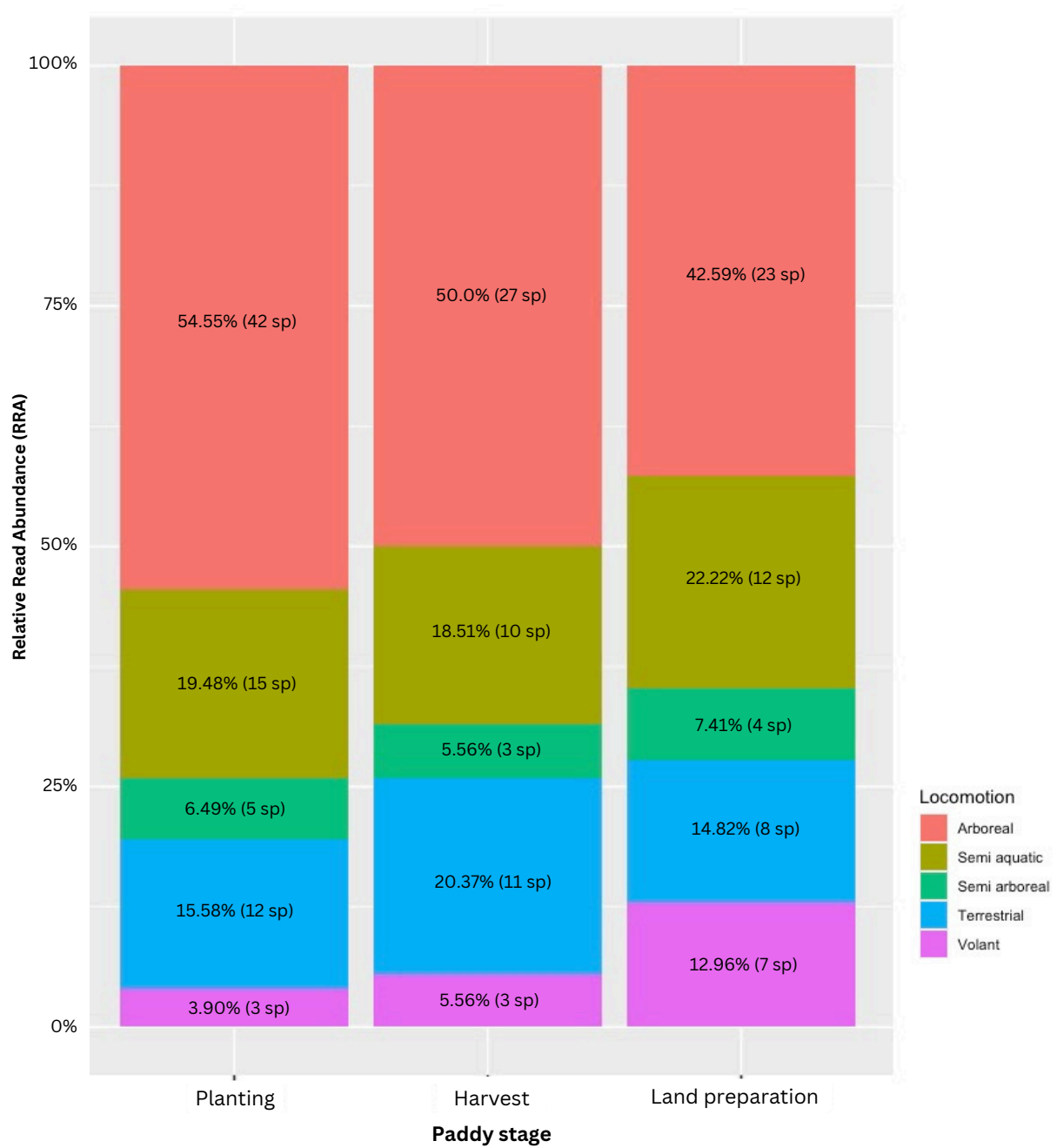


Figure 4.2: The abundance and percentage of bird species of functional traits: (ii) locomotion during planting, harvest and land preparation in paddy fields.

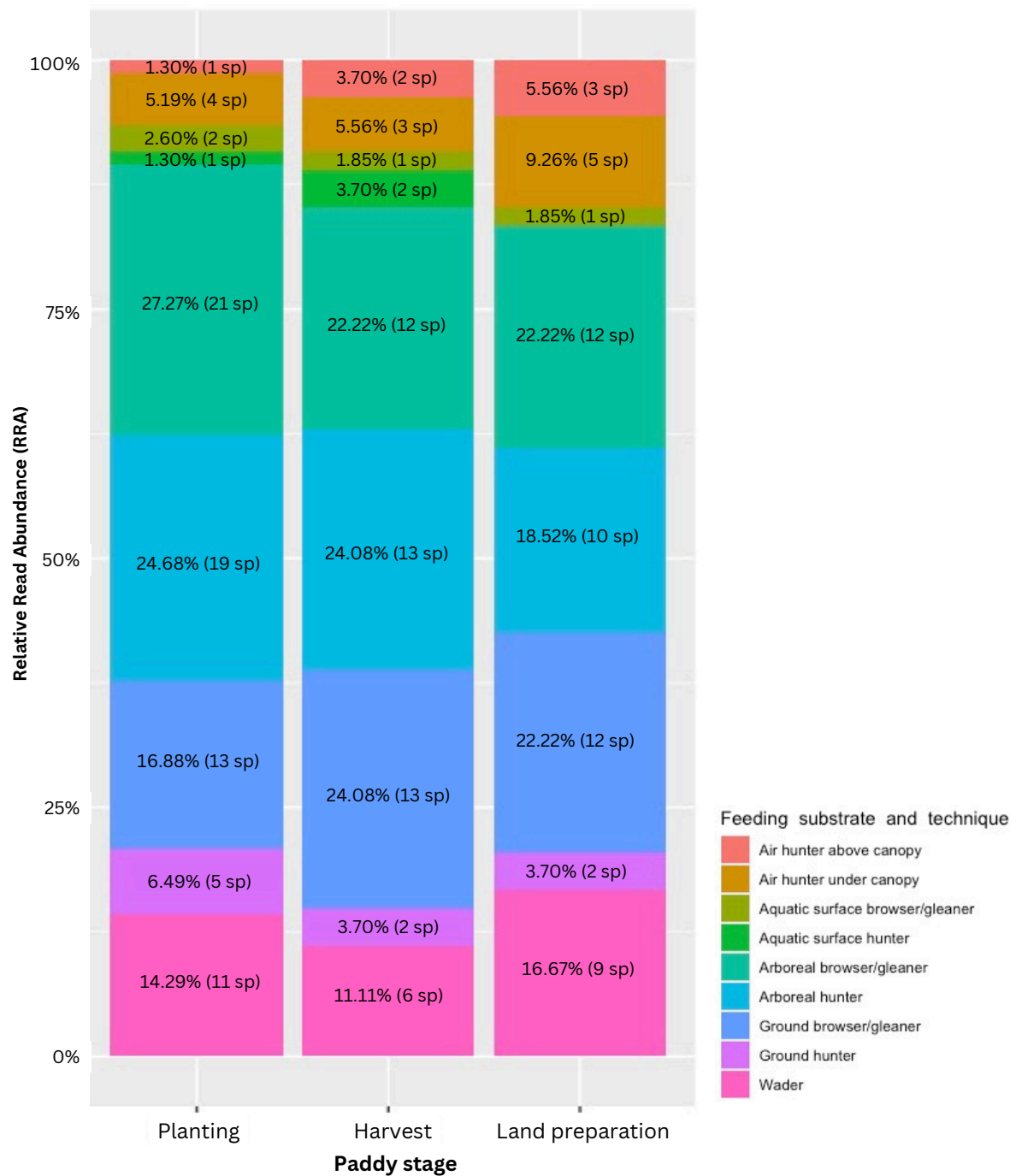


Figure 4.3: The abundance and percentage of bird species of functional traits: (iii) feeding substrate + technique during planting, harvest and land preparation in paddy fields.

4.3.2 Relationship of Functional Group (FG) of Birds with Paddy Stages

A total of 14 functional groups were identified from the alluvial plot in Figure 4.4 which visualises the network of functional traits into classifying significant functional groups in different paddy stages. Figure 4.5 illustrates the 14 functional groups and their respective approaches in different paddy stage settings.

Overall, FG 11: Terrestrial omnivores - ground browser/gleaner occupied all stages. During planting, FG 2: Semi aquatic carnivore wader, FG 5: Arboreal frugivore browser/gleaner, and FG 10: Arboreal nectarivore browser/gleaner were abundant. During harvest, the dominant functional group was FG 7: Terrestrial granivore - ground browser/gleaner. Planting and harvest both shared FG 4: Semi arboreal carnivore - ground hunter and FG 8: Arboreal invertivore hunter. Land preparation has the highest number of dominant functional guilds: FG 9: Volant invertivore - air hunter above canopy, FG 14: Volant carnivore - air hunter under canopy, FG 1: Semi aquatic vertivore/invertivore wader. Some functional groups were not dominant in any stages, such as FG 3: Arboreal carnivore hunter, FG 12: Semi aquatic omnivore - aquatic surface browser/gleaner, and FG 13: Semi aquatic carnivore - aquatic surface hunter.

The Multi-Response Permutation Procedure (MRPP) revealed a significant difference in bird functional groups with different paddy stages ($T = -4.592$, $A = 0.6087$, $P = 0.0008$), indicating strong dissimilarity between groups and strong similarity within the groups. Functional traits that cause significant effects are: Feeding guild - Invertivore = 4.667; Locomotion - Arboreal = 12.67; and Feeding substrate and technique - Wader = 3.333.

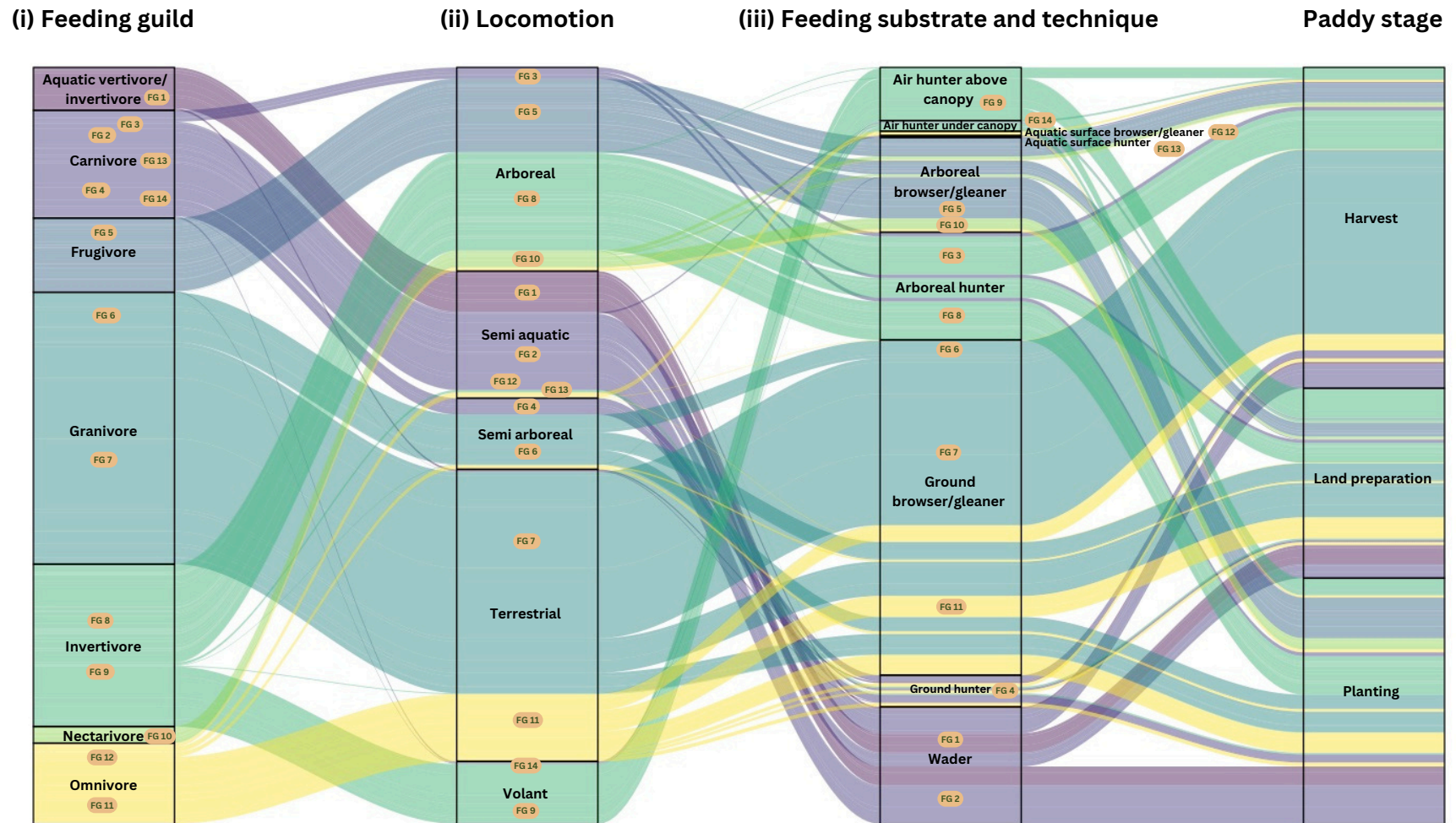


Figure 4.4: The alluvial plot shows the network of functional traits ((i) feeding guild, (ii) locomotion, and (iii) feeding substrate + technique) for classifying 14 significant functional groups in different paddy stages (planting, harvest and land preparation).

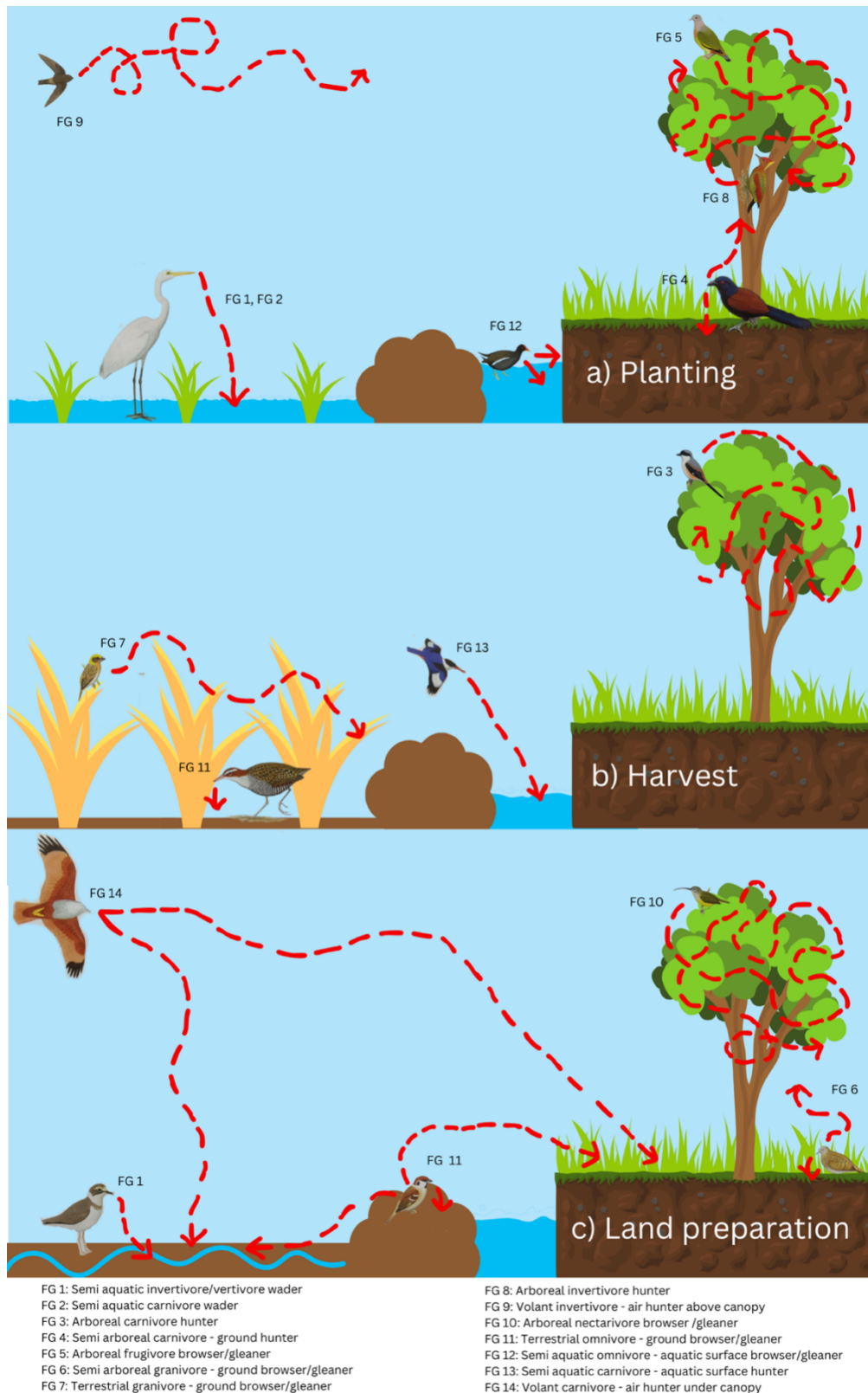


Figure 4.5: A visualisation of fourteen functional groups of birds and their approaches in paddy fields during a) planting, b) harvest and c) land preparation. Red dash arrows indicate the approach of each functional group related to their functional traits (feeding guild, locomotion, functional substrate + technique).

4.4 Discussion

While traditional approaches have often focused on the taxonomic diversity of birds, there is an increasing recognition that functional studies can provide important insights into what influences the response of biodiversity to the environment (Hastings et al., 2020) as well as the ecological processes and ecosystem functioning (Escalas et al., 2019). Paddy farming practices, through their impact on the landscape, can indirectly influence the composition of paddy field birds and their associated functional groups. Thus, the significant differences can also reflect the adaptation of birds through their feeding and foraging strategies in paddy fields. By considering the functional traits and groups of birds via their feeding and foraging strategies (feeding guild, locomotion, feeding substrate + technique), researchers can better understand the responses of birds in a particular ecosystem as well as how bird communities contribute to the overall functioning of the ecosystems they inhabit.

Functional groups that consistently thrive in the agroecosystem of paddy fields are invertivore and carnivore birds. Invertivore birds as such species like cisticolas, swallows, swiftlets, babblers, including migratory waders play a crucial role in the balance of paddy field ecosystems by maintaining populations of invertebrates, which can otherwise become dominant and disrupt the overall ecological equilibrium. They feed on pests such as grasshoppers, locusts, and other harmful insects that can damage paddy crops. Notably, volant invertivore - air hunter above canopy such as swiftlets were observed higher in number during the wet season caused by the Northeast monsoon (November to March) with substantial rainfall to the west of Sarawak (Malaysian Meteorology Department, 2025; Minggu, 2024) during planting and land preparation. This observation on swiftlets corresponds with Petkliang et al. (2017) where foraging over paddy intensifies during the wet season associated with increased insect availability, a period where pesticides were less effective to be used since the heavy rain would wash away the treatment. The washaways can cause a significantly high content of

pesticide residue in water during the wet season (Nyantakyi et al., 2022), hence, reducing the numbers of these insects by using birds to help minimise the need for chemical pesticides, which can have adverse environmental effects. A study in Sri Lanka on invertivore birds also mentioned the role of these birds to biomonitor toxic trace elements in an ecosystem (Samaraweera et al., 2022). Conventional paddy fields heavily utilise chemical pesticides, which have been reported to either directly kill birds or indirectly decrease the amount of food sources when applied in excess (Choi et al., 2021). Hence, monitoring birds potentially exposed to pollutants can assist in measuring the viability of an environment within the appropriate framework for conservation.

Nonseasonal fruits and flowers from surrounding forest edges benefitted birds, especially arboreal frugivores and nectarivores (Fleming and John Kress, 2011; Tsi et al., 2005) year-round. The paddy fields are often associated with waterbirds, whilst land birds such as those arboreal foragers are often neglected while there is an intricate relationship between arboreal birds and the monoculture ecosystem of paddy fields to be understood. Understanding the nuances of this association is crucial, not only for preserving the balance of these unique habitats but also for gaining deeper insights into bird composition and their responses to environmental changes (Martins et al., 2021). In this study, arboreal birds were recorded persistently high throughout paddy stages. Existing literature suggests that the diversity and distribution of arboreal birds in paddy fields are influenced by a complex interplay of factors, including habitat heterogeneity and resource availability (Johnson et al., 2011; Quazi and Ticktin, 2016). A diverse and abundant bird population generally signals a well-balanced ecosystem, while a decline in bird numbers may indicate problems such as pollution, pesticide overuse, or habitat degradation. These birds too, have the same ability to aid pollination as pollinating bees do and seed dispersal in and around paddy fields (Hass et al., 2018; Sebastián-González et al., 2020). While paddy itself is generally wind-pollinated (Matsui et al., 2020),

surrounding plants and other flora may benefit from the ecological services provided by these birds. In some cases, even waterbirds, such as certain species of waterfowl, feed on paddy seeds or grains that have fallen to the ground. While they may eat some seeds, they also scatter seeds from various plants across the paddy field, facilitating natural seed dispersal (Sebastián-González et al., 2020). This can encourage biodiversity and the growth of different plant species that contribute to the overall ecological balance of the area. Invertebrates and vertebrates such as insects and small mammals were abundant near these fruiting and flowering plants too, which provide food for arboreal invertivores and carnivores (Fleming and John Kress, 2011).

The composition of birds via their functional groups can be directly influenced by the changing landscape of paddy fields due to paddy farming practices. The changing landscape can affect certain food availability in paddy fields, such as aquatic organisms due to inundation during planting and land preparation, and ripened paddy grains during harvest. However, birds were somehow observed to adapt through their feeding and foraging strategies in paddy fields. Temporal water fluctuations in the irrigation of paddy fields create microhabitats (Stafford et al., 2010) with various water levels that provide different foraging opportunities for waders of different sizes. Smaller waders with relatively short legs foraged efficiently in lower water levels whilst bigger waders preferred higher water levels (Tojo, 1996; Nam et al., 2015). Waders were the least during harvest because the inundation was drained and the dense paddy vegetation was perceived as not suitable for them to forage (King et al., 2010). Particularly larger waterbirds found it difficult to sight prey in densely vegetated paddy fields and therefore shifted their foraging strategies (Wales et al., 2001) and microhabitat use (Nam et al., 2015). Ditches and ponds can concentrate aquatic organisms that may be available for foraging (Hill et al., 2016), although they may not be sufficient to attract a higher number of waders during harvest compared to the extensive aquatic environment available during planting and land

preparation. Additionally, during harvest terrestrial granivores – ground browser/gleaner such as munias were higher in number than during other paddy stages that did not have as many grains. Munias were highly attracted to exploit ripened paddy that is available during harvest (Htay et al., 2024). Otherwise in other paddy stages, munias were observed opportunistically consuming seeds of various kinds of grass, most notably the leftover paddy that was not harvested, and the nutrient-rich filamentous alga *Spirogyra*, which supplies adequate protein to prepare for breeding (Amar-Singh, 2009; Avery, 1980).

Opportunists such as omnivores present in all stages feeding on food from surrounding habitats paddy fields have to offer (Bambaradeniya et al., 2004). The dynamic feeding habits of omnivores in paddy fields provide a level of flexibility in pest control (Gillespie, 2017; Kratina et al., 2012). Whilst herbivores or carnivores might specialise in particular plant or animal species, omnivores can shift their diet based on seasonal availability and pest outbreaks. This dietary adaptability ensures that omnivores can respond dynamically to fluctuations in pest populations, thereby enhancing their role in biological pest management (Gillespie, 2017). Additionally, omnivores also influence the interactions between other species within the ecosystem. By functioning as both predators and prey, omnivores contribute to the balance of the food web. This dual role supports greater species diversity and interactions, which in turn strengthens ecosystem resilience against disturbances (Ågren et al., 2012; Gillespie, 2017; Kratina et al., 2012). The presence of omnivores in paddy fields fosters an environment where a variety of species can coexist and perform their ecological functions. This diversity contributes to greater stability and adaptability in the face of environmental stresses. Moreover, their feeding and excretion processes also aid in the stabilisation of soil structure by enhancing the microbial activity within the soil, promoting the processes of mineralisation and nutrient cycling which are vital for plant growth and overall ecosystem productivity (Abraham et al., 2024; Wang et al., 2020; Wei et al., 2024).

Lastly, the limitation of this study is that stomach flushing yielded especially low except for invertivores, carnivores, herbivores and granivores. Most solid foods of vegetable and animal matter can be identified, but it is more difficult to discern between liquid foods like nectar and nearly digested food. Stomach flushing is used especially for insectivorous birds to identify their diet and feeding habits, as it allows researchers to examine the contents of the stomach (Poulin et al., 1994; Sing-Tyan et al., 2017; Mansor et al., 2018). However, it may not be as suitable for birds in other feeding guilds, like frugivores, granivores, or nectarivores because they may have more complex digestive processes, making it difficult to get accurate results from stomach flushing. The technique might not capture the full range of dietary items they consume. Other methods such as direct observation of feeding behaviour, faecal analysis, or molecular techniques might be more suitable for studying diet and feeding ecology, particularly when species-level identification is required (Jordan, 2005; Oehm et al., 2017). Additionally, although this study provides a broad-scale analysis across multiple bird taxa, it represents an initial classification and does not allow for finer functional resolution. However, a key recommendation is to refine the invertivore category by separating insectivores from other invertivores. Grouping all invertivores together can obscure important differences in resource partitioning among species, though this may be less of a concern when insects are the dominant or sole invertebrate prey. This distinction is important because foraging strategies used to capture insects (e.g., aerial hawking for flies, leaf gleaning for caterpillars, or bark probing for beetles) differ significantly from those used to capture other invertebrates (e.g., flipping rocks for worms or digging for snails). It is also recommended to conduct insect sampling to better understand the relationship between insect availability and bird functional groups across different paddy stages.

4.5 Conclusion

This study classified and compared functional groups of birds during different paddy stages in paddy fields of southwestern Sarawak. A total of fourteen functional groups were identified based on three functional traits (feeding guild, locomotion, feeding substrate + technique). This study revealed a significant difference in bird functional groups in different paddy stages, suggesting the influence of the changing landscape of paddy fields due to paddy farming on birds caused evolving feeding and foraging strategies. The changing landscape, including the inundation and growing paddy, ought to affect certain food availability in paddy fields for species that are dependent on aquatic organisms during planting and land preparation and ripened paddy grains during harvest. Meanwhile, a range of ecological services provided by birds that benefit the agroecosystem were further identified. The findings from these studies underscore the need for a comprehensive understanding of the factors that shape the bird composition in paddy fields, as this knowledge can inform effective conservation strategies and guide sustainable land-use practices. Future research should explore alternative methods like behavioural observation, faecal analysis, or molecular techniques for more accurate dietary assessment. Refining the broad “invertivore” category by separating insectivores and conducting insect sampling is also recommended to better understand bird-foraging strategies across paddy stages.

CHAPTER 5

THE EFFECTS OF LANDSCAPE-SCALE HABITAT MODIFICATION ON BIRD TAXONOMIC GROUPS IN PADDY FIELDS OF SOUTHWESTERN SARAWAK

5.1 Introduction

Paddy fields exhibit uniform spatial patterns and yet they potentially provide essential alternative habitats for a wide range of species, including plants, invertebrates, and vertebrates including those in need of conservation, particularly due to the loss of natural habitats though they were incomparable to natural wetlands (Yoon, 2009; King et al., 2010). Such agroecosystems are often perceived as degraded environments where the impact of habitat modification for paddy farming practices leads to different landscapes during different stages of paddy fields. The changing landscapes may also cause changing microhabitat, a small, specific, and often unique environmental area within a larger habitat that supports a particular group of organisms or species (Biology Online Dictionary, 2020). Unlike larger habitats that encompass broad ecosystems (e.g. paddy fields, forests, grasslands, or oceans), microhabitats are localised, offering distinct conditions for particular life forms (Shi et al., 2016). These conditions could be based on factors like temperature, humidity, moisture, light exposure, or the presence of specific food sources (Denney et al., 2020; de Frenne et al., 2021; Kørkjås et al., 2021; Bodineau et al., 2024). Microhabitats play a critical role in biodiversity (Moreno et al., 2016; Martin et al., 2022), as they provide specialised environments for species to thrive and often fulfil important ecological functions. For instance, the birds in forest microhabitats are responsible for seed dispersal, pest control, pollination, habitat structure and bioindicator, which ultimately supports plant life and the broader ecosystem (Whelan et al., 2015).

Little is known about how birds were affected by changing microhabitats at different paddy stages. Although several studies have examined the effects of habitat heterogeneity on

birds in paddy fields at the landscape scale (Maeda, 2001; Amano et al., 2008; Nam et al., 2012, 2015; Choi et al., 2021; Song & Kuo, 2022), research in tropical regions remains comparatively limited and has primarily focused on frogs and insects (Souza, 2014; Dominik et al., 2017, 2022; Matsushima et al., 2022). Additionally, environmental and seasonal effects (such as breeding, wintering, and rainy and dry seasons) have been shown to influence on microhabitat selection of birds (Maeda, 2001; Amano et al., 2008). The structure of microhabitats within paddy fields is largely shaped by human agricultural practices, including the timing and extent of flooding, application of fertilisers and pesticides, and methods of planting and harvesting. However, intensive agricultural practices can negatively impact the quality of these microhabitats and this remains a topic of active research with several studies calling for more sustainable management practices that protect the integrity of these microhabitats while maintaining agricultural productivity (Abudulai et al., 2022; Schmid and Schöb, 2023). Hence, the objective of this study is to identify the patterns of microhabitat selection and assess the effects of landscape-scale habitat modifications on bird taxonomic groups during three different paddy stages in paddy fields of southwestern Sarawak.

5.2 Methodology

5.2.1 Study Site and Data Collection

The study sites are as described in Chapter 3.2.1. The cycle of paddy farming involves various stages such as planting, harvesting, and land preparation, as outlined in Chapter 3.2.2. A detailed description of data collection utilising active and passive surveys is described in Chapter 3.2.3. However, in this chapter, aural data from active surveys were excluded due to the difficulty of accurately identifying the microhabitat utilised by birds solely through their vocalisation. Individuals that were observed either stationary, roosting or foraging within the microhabitats during the line transects were recorded. Comparatively, birds caught in the mist

nets were considered to be using the paddy plots as their active microhabitat, as the nets were positioned within and around the paddy fields.

5.2.2 Description of Bird Taxonomic Group and Microhabitats

Birds were identified at the species level (Chapter 3.3) and categorised into waterbirds and land birds. Following (Choi et al., 2021) the waterbirds and land birds were classified by Orders into the following groups (i) urban-garden birds (Passeriformes, Columbiformes, Caprimulgiformes), (ii) grassland birds (Passeriformes), (iii) birds of prey (Accipitriformes, Strigiformes), (iv) shorebirds (Charadriiformes), (v) stork-like birds (Pelecaniformes), and (vi) waterfowl (Gruiformes) based on tertiary references (Smythies, 1999; Strange, 2002; Amar-Singh, 2009; Davison and Chew, 2011; Elphick, 2014; Phillipps and Phillipps, 2014; Lim et al., 2020; Lepage, 2023).

Six microhabitat types where birds were recorded include (a) paddy plot, (b) levee, (c) ditch and pond, (d) grass and scrubs, (e) tree and (f) artificial substrate (Figure 5.1, Table 5.1). These microhabitats were classified according to water level, soil condition, and vegetation structure (Table 5.1).

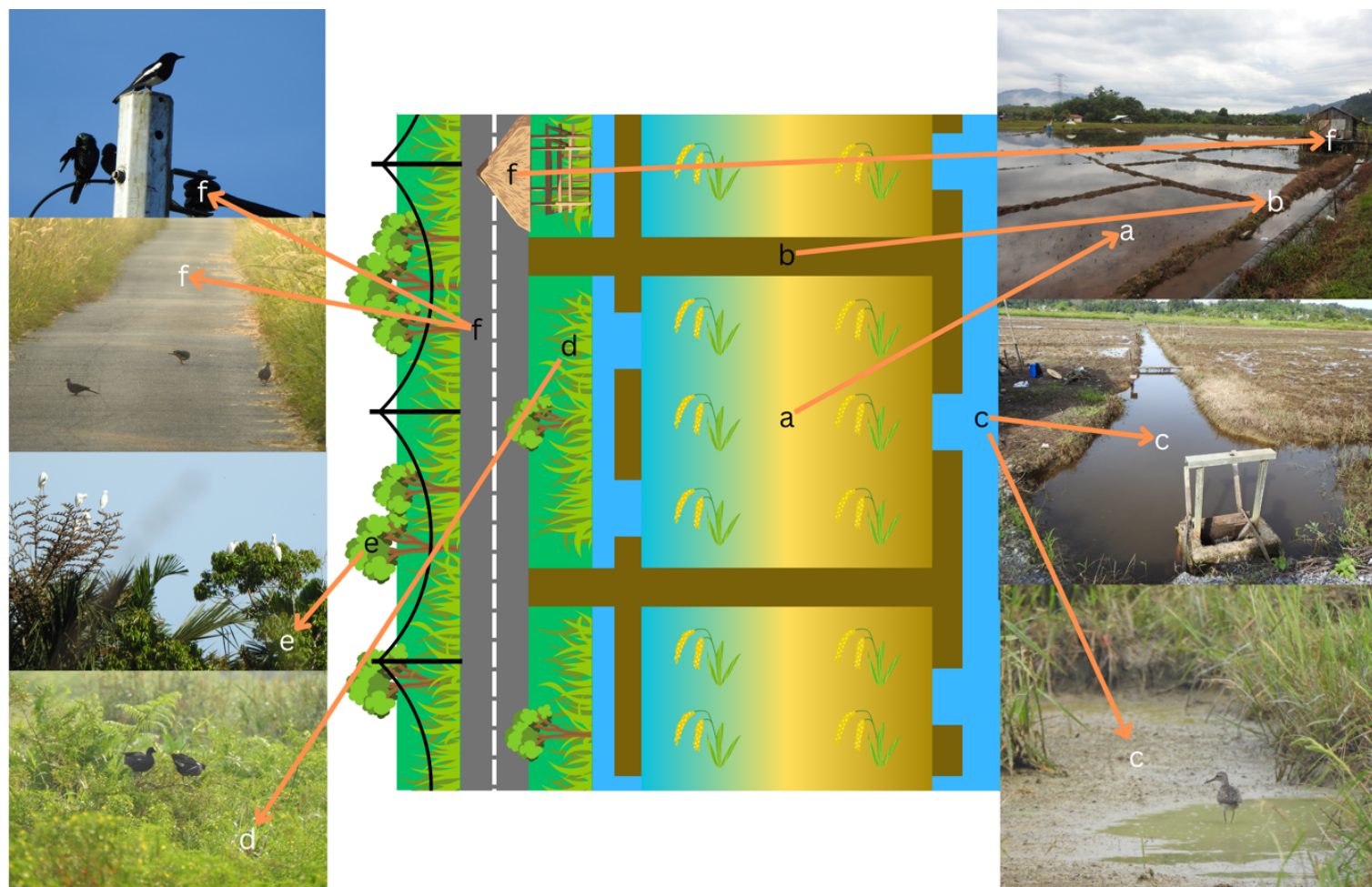


Figure 5.1: A composite diagram showing six corresponding microhabitat types in the paddy fields: a) paddy plot, b) levee, c) ditch and pond, d) grass and scrubs, e) tree and f) artificial substrate. Photographs are taken from selected sampling sites (Kampung Skuduk, Kampung Baru and Kampung Pueh-Siru Dayak).

Table 5.1: The description of six microhabitat types. The alphabetic numerals correspond to the letters (a, b, c, d, e, f) in Figure 5.1.

Microhabitat type	Description
a) Paddy plot	The space where paddy is planted and grown, regardless of shape and size. This microhabitat is highly affected by monsoon season and anthropogenic activities. Paddy may or may not occupy the plots during a particular stage such as land preparation when the soil is being ploughed and prepared for an upcoming planting stage. The weather and level of irrigation caused daily variations in the level of inundation. The paddy height (average height: planting = ± 32.46 cm, harvest = ± 106.97 cm) and inundation level (average depth: planting = ± 11.30 cm, land preparation = ± 5.38 cm) vary across stages. A more detailed description on paddy stages and farming scheme are in Chapter 2.3 This microhabitat also includes the aerial space above the paddy plots which considered birds such as swiftlets that forage over the paddy field and never perch.
b) Levee	The embankment of soil bordering the paddy plot and does not experience much seasonal physical changes as paddy plot. This microhabitat may provide a vital substitute that compensates for the paddy's reduced microhabitat function when paddy density is high preventing the access of some bird species.

Table 5.1 continued

c) Ditch and pond	This microhabitat includes water bodies with significant accumulation of water throughout the paddy stages in the paddy fields. Ditches are channels that may be narrow or wide, with shallow or deep indentation for irrigation and drainage. Ponds are small and still body of water that could be occurring either naturally or man-made in or nearby the paddy fields. This microhabitat may form aquatic ecosystems that shape the structure of the bird-aquatic community.
d) Grass and scrubs	It is comprised of any species of short plants not taller than trees surrounding and in the paddy fields.
e) Tree	Any plant with an elongated stem or trunk with supporting branches and leaves, regardless of being fruit-bearing or not. This includes any trees planted in and surrounding the paddy plots such as banana tree, palm tree, jackfruit tree, etc.
f) Artificial substrate	Any man-made material or substance including the concrete structures, birdhouses, nest boxes, road, huts, houses, pillars, utility poles, wires, discarded farm equipment, scarecrows, any bird-scaring erections in the paddy plots, etc.

5.2.3 Statistical Analysis

The Self Organising Map (SOM) visualises similarity relations in data items that produce low-dimensional projection images (a two-dimensional hexagonal grid) of high-dimensional data distributions (Kohonen, 2001). The SOM can be trained to recognise patterns embedded in the input data space effectively (Olawoyin et al., 2013). In the unsupervised artificial neural network consisting of linked input and output layers, the distribution and structure of bird assemblages in the paddy fields were patterned to understand their

microhabitat selection. The input data (number of individuals: 59 species $\times$ 3 paddy stages $\times$ 3 surveys) underwent data normalisation to balance the impact of all variables on the distance calculation and improve the performance of the neural networks algorithm (Wei, 2023). The number of output layer neurons was determined by the heuristic rule of $5\sqrt{n}$ by Vesanto et al., 2000, where n is the number of data points in the input layer (9 surveys) which finally generated 15 output neurons (five horizontal and three vertical). After the self-learning of SOM, individual hexagon-shaped neurons (V_n) were classified into clusters comprising single or multiple neurons. The Euclidean distance measured the distance between neurons and clusters were classified using the Ward linkage method which automatically grouped data points into clusters based on similarities (Bodjam, 2024). The SOM produced a heat map, unified distance matrix (U-matrix) map and dendrogram to visualise the pattern of microhabitat use by birds in paddy fields. The relative abundance bar plots were constructed to illustrate the composition of clustering by SOM according to paddy stages, species proportions and microhabitat selection.

The Multi-Response Permutation Procedure (MRPP) was used for testing significant differences between clusters, subsequently to evaluate the pattern of microhabitat usage by birds in paddy fields during three different paddy stages (planting, harvest, and land preparation). MRPP measures delta (δ), which is the mean distance (default: Euclidean distance) among sample units within each group. The T value, which calculates the difference between the observed and expected delta, indicates dissimilarity between groups. A larger negative T value indicates greater dissimilarity between groups (Rogers and Šebesta, 2019; Mallik, 2022). A value signifies the size of effect defined as the chance-corrected within-group agreement (1.0 = perfect agreement, 0 = no better than expected by chance, and an A value of > 0.3 is considered a strong indicator of within-group species homogeneity) (Rogers and

Šebesta, 2019; Mallik, 2022), while P value is the significance of delta, where $P \leq 0.05$ is statistically significant. The MRPP results were hypothesised as follows:

H_0 - There is no significant differences between the pattern of microhabitat usage by birds in paddy fields at three different paddy stages (planting, harvest, and land preparation);

H_A - There is significant differences between the pattern of microhabitat usage by birds in paddy fields at three different paddy stages (planting, harvest, and land preparation).

The birds of prey were excluded in the subsequent analysis due to the low number of individuals to fit the model (Akbari-Lakeh et al., 2017). Bar plots were constructed to visualise the microhabitat selection of each bird taxonomic group in three paddy stages in the paddy fields. Moran's I test is used to examine the spatial autocorrelation (the relationship between spatial units (Getis, 2010)) in the data set. This analysis was applied to assess the distribution patterns of bird taxonomic groups within the paddy fields of southwestern Sarawak. However, it may provide an inaccurate estimation of spatial dependence when used for small areas (Aswi et al., 2021), and hence the alternative Modified Moran's I was considered. Modified Moran's I is designed to work more accurately when there are few areas. This study followed Modified Moran's I calculations by Aswi et al., (2021). The values of Moran's I and Modified Moran's I are ranged from positive spatial autocorrelation to negative spatial autocorrelation, where +1 indicates perfect spatial clustering, 0 indicates no autocorrelation (perfect randomness), and -1 indicates perfect spatial dispersion. Spatial clustering means geographically nearby values of a variable tend to be similar on a map and vice versa for spatial dispersion (Griffith, 2009).

GLMM can be used to address the considerable positive autocorrelation (clustering) in a data set (McCulloch and Searle, 2000) tested by Modified Moran's I. A generalised linear mixed model (GLMM, Poisson distribution and log link) was used to evaluate the effects of microhabitat type (paddy plots, levee, ditch and pond, grass and scrubs, tree, and artificial

substrate) and paddy stages (planting, harvest and land preparation) on the bird taxonomic groups. In the GLMM, the number of birds per taxonomic group was designated as a response variable, and the microhabitat type and paddy stage were considered as fixed effects. Fixed effects are typically considered as factors where all possible values of interest are represented in the dataset and can be utilised for scoring (IBM Documentation, 2025). The area of paddy fields (hectares) and monsoon seasons during the surveys were treated as random effects, whose random values from the population may contribute extra variability in the scoring (IBM Documentation, 2024).

All analyses and visualisations were performed using “kohonen” (Wehren and Buydens, 2007), “aweSOM” (Boelaert et al., 2022), “vegan” (Oksanen et al., 2024), “ape” (Paradis and Schliep, 2019), “lme4” (Bates et al., 2015), and “ggplot2” (Wickham, 2016) packages in R statistical software Version 2023.03.0+386 (R Core Team, 2024).

5.3 Results

Using the Self Organising Map (SOM), the bird composition found in various microhabitats in paddy fields was split into five clusters. The largest cluster in the heat map is Cluster 2 which consists of nine neurons V3, V4, V7, V8, V9, V10, V11, V12, and V13 (Figure 5.2). The unified distance matrix (U-matrix) (Figure 5.3) and dendrogram (Figure 5.4) show the Euclidean distance matrix of the neurons in the map. Cluster 2 has the highest similarities with U-matrix values ranging from 1.39, 2.00 to 2.61, 3.22 and the dendrogram of height ranges from 0.5083174 to 5.8451666. The following neuron clusters that have high similarities are Cluster 1 (V1, V2 and V6; U-matrix = 2.00, 2.61 - 3.22, 3.83; dendrogram height = 2.255413 - 3.2029784) and Cluster 4 (V14; U-matrix = 5.05, 5.66; dendrogram height = 6.0820233). Contrastingly, neuron V5 in Cluster 3 is the neural cluster that is located farthest in the mapping (U-matrix = 5.66, 6.28; dendrogram height = 9.7779472). V5 is entirely isolated from the other neurones in the dendrogram, therefore its simplicifolius pattern suggests that the species

distribution in V5 differs significantly from that of the other neurones. The dissimilarity distance is followed by Cluster 5 (V15; U-matrix = 5.66, 6.28; dendrogram height = 7.31).

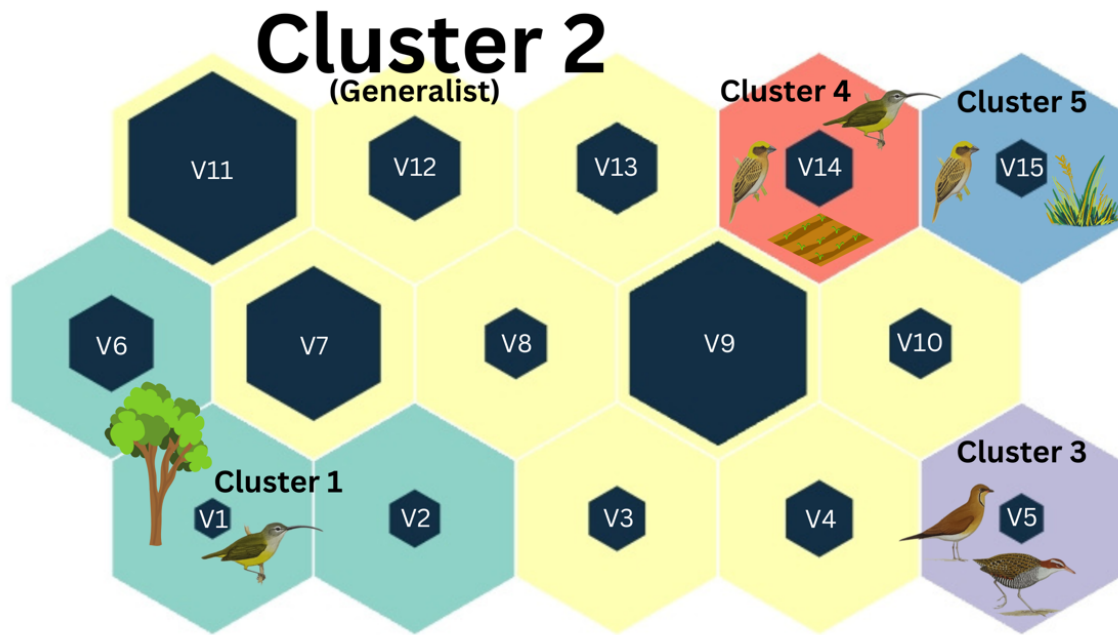


Figure 5.2: The heat map generated by a self organising mapping shows five clusters of single and multiple neurones (coloured hexagons) showing bird distribution in different microhabitats in paddy fields. Cluster 2 (the generalist, in yellow hexagons) is the largest cluster while other clusters are specialists of specific bird taxonomic groups and microhabitats as indicated by the icons. The size of the inner hexagon (black-coloured hexagon) of each neuron indicates a high or low abundance of birds.



Figure 5.3: Mirroring the neurons in the heat map, the U-matrix map visualises the distance matrix of the neurons in the map. The distances indicate the similarities of the neurons: a smaller distance indicates more similarities or a greater distance indicates fewer similarities. Cluster 2 (labelled as number 2) followed by Cluster 1 (labelled as number 1) and Cluster 4 (labelled as number 4) have higher similarities among the neurons. Cluster 3 (labelled as number 3) and Cluster 5 (labelled as number 5) appear to be the furthest (yellow-coloured hexagon with Euclidean distances of 5.66, 6.28).

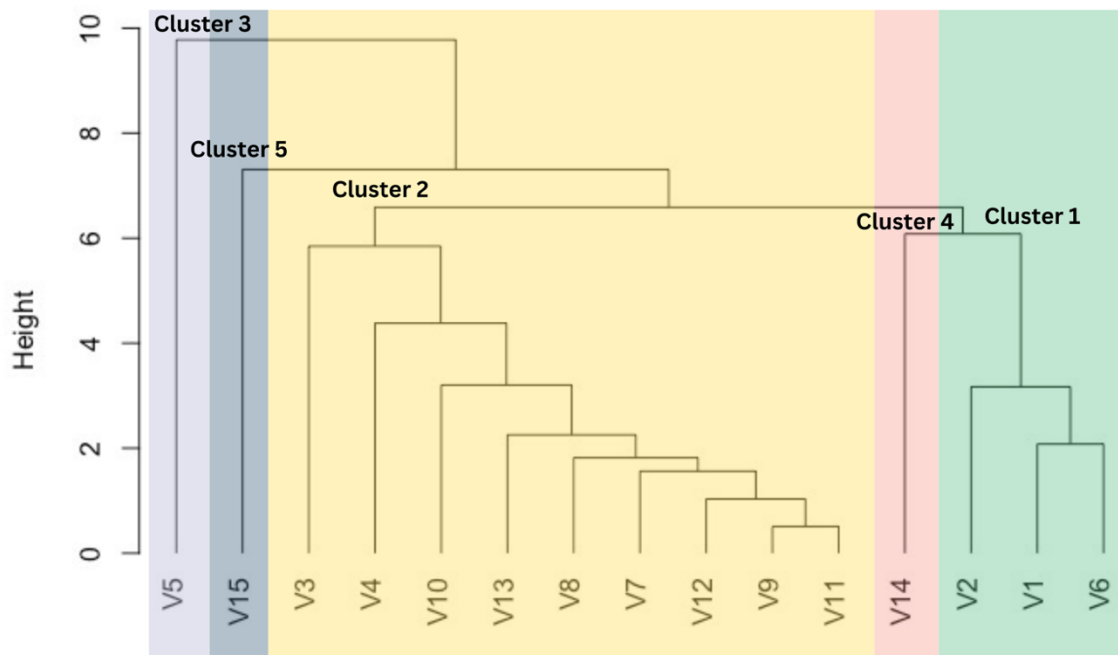


Figure 5.4: The dendrogram generated the Euclidean distance matrix of the neurons in the mapping. The arrangement of the clades depicts neurons most similar to each other. The height of the vertical lines indicates the degree of difference between branches: the longer the line, the greater the difference. Neuron V5 of Cluster 3 (in a purple-coloured box) is the furthest from other neurons, having the least similarities among the neurons.

Figure 5.5 illustrates the composition (Relative Read Abundance, RRA, %) according to paddy stages, species proportions and microhabitat selection. All clusters consisted of every paddy stage, although Cluster 4 appears to have the highest percentage of harvest stage (71.43%) and the lowest percentage (14.29%) of planting and land preparation. Cluster 2 has the most diverse species proportion, consisting of all bird taxonomic groups. The paddy plot was included in all clusters, followed by grass and scrubs. Clusters 2 and 3 have the most diverse patterns of microhabitat use. Contrarily, Cluster 1 preferred tree, Cluster 4 preferred paddy plot, and Cluster 5 preferred grass and scrubs. Grassland birds were found in nearly every cluster except Cluster 3, which may be responsible for the highest dissimilarity of Cluster 3. Additionally, Cluster 3 specifically had the highest percentage of using ditch and pond (28.57%).

The Multi-Response Permutation Procedure (MRPP) revealed a significant difference in the five clusters produced by SOM in terms of the number of individuals and species ($T = -4.212$, $A = 0.3663$, $P = 0.001$), concluding different bird taxonomic groups significantly employ different microhabitats at different stages of the paddy. There is a high dissimilarity between clusters and a strong homogeneity within the clusters as indicated by large negative T and by $A > 0.3$.

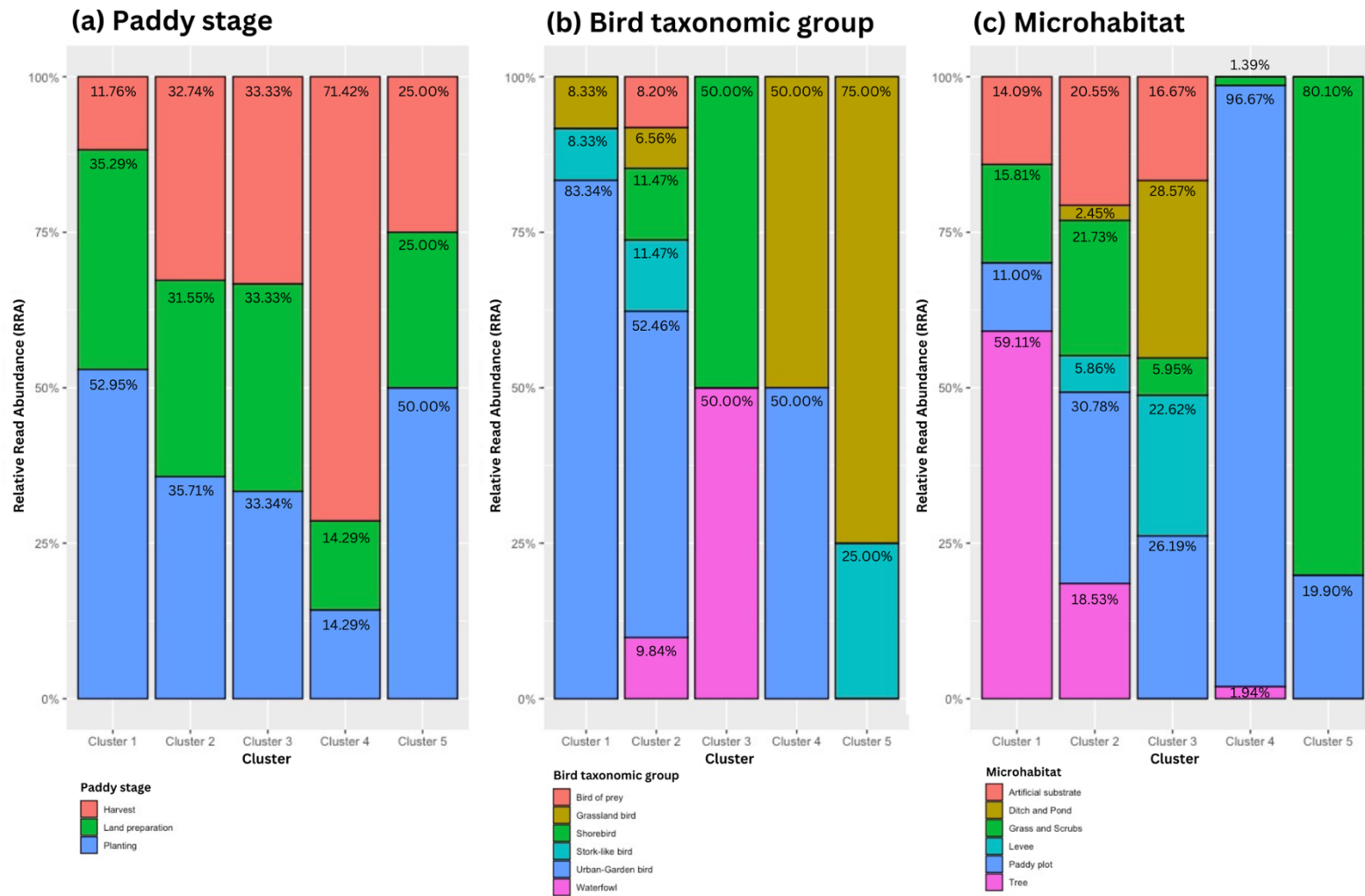


Figure 5.5: The stacked bar plots visualise the composition (Relative Read Abundance, RRA, %) of clusters by SOM according to a) paddy stage, b) species proportion by bird taxonomic groups, and c) microhabitat.

Paddy plots were used by all bird taxonomic groups more frequently than other microhabitats, with grassland and shorebird birds especially using them. Additionally, grass and shrubs are often used by stork-like and grassland birds. Trees are primarily utilised by urban-garden birds. Urban-garden birds and waterfowl frequently use artificial substrate. Waterfowls occasionally used levees, ditches, and ponds although the microhabitats were not utilised frequently by the majority of the groups. Figure 5.6 shows the microhabitat selection of five bird taxonomic groups in three paddy stages in the paddy fields of southwestern Sarawak. Birds of prey were excluded due to low sightings, hence negligible to be included in the analysis.

Moran's I test in Table 5.2 showed negative spatial autocorrelation, indicating dispersion in the distribution of bird taxonomic groups in the paddy field. However, these values are statistically not significant (Table 5.2). Hence, Modified Moran's I was used as an alternative to Moran's I test, which proved positive spatial autocorrelation (Table 5.2) indicating clustering was observed among the distribution of bird taxonomic groups in paddy fields of southwestern Sarawak.

The result of the Generalised Linear Mixed Model (GLMM) revealed that different bird taxonomic groups had varying levels of associations with microhabitat type and paddy stage (Table 5.2). Generally, the effects are low levels with only urban-garden and stork-like birds being highly significant. Random effects appear to cause low variability in the distribution of the groups, except for grassland birds exhibit moderate variability (monsoon: SD = 0.4791).

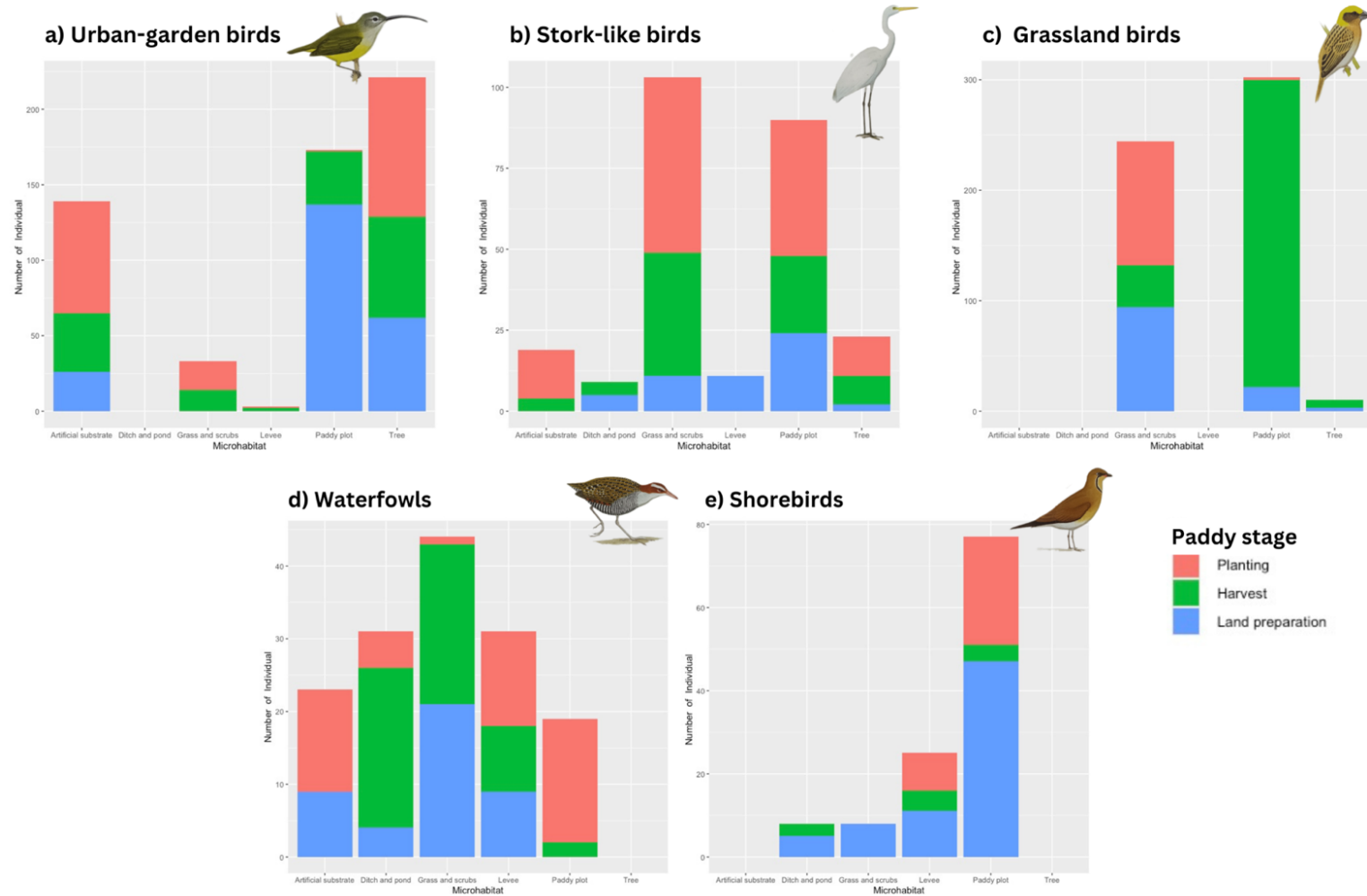


Figure 5.6: The bar plots show the microhabitat selection of five bird taxonomic groups a) urban-garden birds, b) stork-like birds, c) grassland birds, d) waterfowls, and e) shorebirds) in three paddy stages (planting, harvest and land preparation) in the paddy fields.

Table 5.2: The result of Moran's I and Modified Moran's I for spatial autocorrelation at which the bold fonts represent positive autocorrelation in the bird taxonomic group. The Generalised Linear Mixed Models (GLMM) for examining the impacts of microhabitat type and paddy stages on the distribution of bird taxonomic groups in paddy fields show only urban-garden birds and stork-like birds have statistical significance (in bold). *Non-significant P-values of Moran's I is a prerequisite for Modified Moran's I. **P-values of GLMM indicate significant associations of distribution of bird taxonomic groups and variables.

Bird Taxonomic Group (Order)	Moran's I (I)				Modified Moran's I (MMI)	Generalised Linear Mixed Models (GLMM)						
	Observed	Expected	SD	*P-value		Variable	Estimate	SE	Z-value	**P-value	Variance	SD
Urban-garden birds (Passeriformes, Columbiformes, Caprimulgiformes)	-0.0205325	-0.0117647	0.01161688	0.4504037	0.8659577	Microhabitat	0.10540	0.04020	2.622	0.00874		
						Paddy stage	0.54551	0.07444	7.328	2.34e-13		
						Microhabitat × Paddy stage	-0.13596	0.01806	-7.527	5.17e-14		
						Monsoon					0.01858	0.1363
						Paddy field area size					0.04174	0.2043
Grassland birds (Passeriformes)	-0.0038389	-0.0416667	0.05565253	0.4966855	1.0000000	Microhabitat	-0.05504	0.10831	-0.508	0.611		
						Paddy stage	0.23666	0.18945	1.249	0.212		
						Microhabitat × Paddy stage	0.02825	0.04932	0.573	0.567		
						Monsoon					0.22953	0.4791
						Paddy field area size					0.05201	0.2281

Table 5.2 continued

Stork-like birds (Pelecaniformes)	-0.0483235	-0.0217391	0.02489509	0.2855848	0.9516453	Microhabitat	-0.55461	0.11527	-4.811	1.50e-06		
						Paddy stage	-1.58803	0.28810	-5.512	3.55e-08		
						Microhabitat × Paddy stage	0.27958	0.06572	4.254	2.10e-05		
						Monsoon					0.02400	0.1549
						Paddy field area size					0.14310	0.3782
Waterfowls (Gruiformes)	-0.0750198	-0.0263158	0.03142138	0.1211346	0.9236496	Microhabitat	0.15587	0.12327	1.264	0.2061		
						Paddy stage	0.13540	0.20675	0.655	0.5125		
						Microhabitat × Paddy stage	-0.09369	0.06283	-1.491	0.1359		
						Monsoon					0.00000	0.0000
						Paddy field area size					0.14610	0.3822
Shorebirds (Charadriiformes)	-0.0352084	-0.0454546	0.09383802	0.9130517	1.0000000	Microhabitat	-0.13080	0.49570	-0.264	0.79183		
						Paddy stage	-0.24390	0.26320	-0.927	0.35409		
						Microhabitat × Paddy stage	0.14040	0.16290	0.862	0.38879		
						Monsoon					0.06588	0.2567
						Paddy field area size					0.10560	0.3250

5.4 Discussion

The distribution of paddy birds in southwestern Sarawak was spatially clustered, which reflects the coexisting patterns (Velázquez et al., 2014; Wiegand et al., 2021) and direct interactions between species of various bird taxonomic groups in the paddy fields (e.g., mutualism or predation) (Peterson et al., 2011). No significant differences were observed in the diversity of birds between all the paddy stages and across all sites because most bird species can coexist geographically, biologically and ecologically over spatial factors (Getis, 2001; Pang et al., 2023). This spatial clustering may be due to the paddy fields being in the same geographical radius (Knox, 1989) of southwestern Sarawak with an area of 2,084.8 km² (Figure 3.1). Furthermore, paddy fields proved to be viable landscapes where species may cluster for the fertile land with access to water and availability of food resources in a favourable climate (Gomez-Aparicio et al., 2005; Koh and Wilcove, 2008; Sahrawat, 2012; Dunna and Roy, 2013). Birds may also cluster due to species interactions such as competition for resources or symbiotic relationships (Peterson et al., 2011), such as those exerted by bird functional groups (Chapter 4). Subsequently, these create a more favourable microhabitat that provides the conditions necessary for their survival (Klecka and Boukal, 2014; Beermann et al., 2018; Vilenica et al., 2018). Choi et al. (2021) reported similarly clustered patterns, particularly in the distribution of land birds, in response to paddy farming practices. Given the limited number of studies available in paddy fields for direct comparison, other research has nonetheless identified positive spatial autocorrelation in bird distribution patterns within other wetland landscapes (Li et al., 2011; Ysebaert et al., 2000).

5.4.1 Patterns of Microhabitat Use by Birds in Paddy Fields

Bird distribution within paddy fields exhibits spatial segregation at finer landscape scales, consistent with the findings of Li et al. 2011. In this study, bird taxonomic groups ranged from microhabitat generalists, which occupied nearly all microhabitats across the various paddy stages, to specialists that demonstrated preferences for specific microhabitats.

The paddy plot emerged as a key microhabitat, extensively utilised by all bird taxonomic groups throughout the paddy stages. This is likely due to its considerable size and the pronounced seasonal variations it undergoes, resulting in alternating aquatic and terrestrial conditions (Caguiat & Samoy-Pascual, 2023). Such environmental dynamics create a highly valuable and heterogeneous habitat that supports diverse bird species by providing essential resources for feeding, foraging and nesting. Waterbirds (stork-like birds, waterfowl and shorebirds) occupy inundated paddy plots during planting and land preparation where prey such as aquatic organisms are more accessible (Stafford et al., 2010). Smaller species, such as shorebirds and waterfowl with shorter legs, are better adapted to foraging in shallow water, whereas larger species, including stork-like birds, tend to utilise areas with deeper water levels (Tojo, 1996; Nam et al., 2015). Additionally, migrating waterbirds specifically utilised the paddy plot as a staging habitat prior to continuing their migratory journey, consistent with the findings of Choi et al. (2022). In the present study, the wintering Oriental Pratincole *Glareola maldivarum* which migrates through Borneo en route to Australia (Phillipps and Phillipps, 2014), was observed foraging within the paddy plot during the land preparation. Land birds like grassland and urban-garden birds also depend on the paddy plots. During land preparation, birds were attracted to exploit the exposed soil of paddy plots, which provides abundant resources

such as invertebrates, insects, seeds, and waste rice (Fujioka et al., 2010a; Stafford et al., 2010). Urban-garden bird species, particularly those from the families Passeridae and Columbidae, were observed in notably higher numbers taking advantage of these food resources. Munias, typically observed exploiting ripened paddy during harvest, can also be seen feeding on waste rice during land preparation (Stafford et al., 2006; Htay et al., 2024). Furthermore, they are present during the planting stage, likely due to overlapping paddy stages where some plots already contain mature grains. Meanwhile, the abundance of swiftlets foraging for aerial insects over the paddy plots increased markedly during land preparation and planting. These two stages coincide with the wet season, brought on by the Northeast monsoon (November to March), which delivers substantial rainfall to western Sarawak (Malaysian Meteorological Department, 2024). This pattern of swiftlet foraging aligns with findings by Petklian et al. (2017), reporting increased aerial insectivory over paddy fields during the wet season, attributed to higher insect abundance. Beyond their function as feeding habitats, paddy plots are also critical for nesting for birds. Stork-like birds, such as Cinnamon Bittern *Ixobrychus cinnamomeus* were observed nesting within the paddy plots, particularly in areas with higher water levels. Waterfowl such as rails also utilised the paddy plots intensively for nesting, likely due to the similarity to their preferred cryptic nesting in marshes (Pierluissi, 2010). Farmers have reported finding nests within the paddy plots during harvest and waterfowl are significantly impacted during the paddy clearance, as agricultural modernisation (such as using harvester trucks) often results in nest destruction. Similar observations were reported by Pierluissi (2010) and Herring et al. (2021), who documented nest destruction in paddy fields hydrological changes caused by intensified farming practices. In contrast,

traditional harvesting methods such as employing hand tools appear to be less disruptive, allowing greater survival of waterfowl nests during the clearance.

Nonetheless, some bird taxonomic groups exhibited preferences for specific microhabitats over others. Grass and scrubs were frequently utilised by grassland birds, stork-like birds, and waterfowl for perching, nest-building materials and food sources. Smaller birds like munias and cisticolas can perch on grass while bigger birds like stork-like birds and waterfowls use scrubs. A pair of Eurasian Moorhen *Gallinula chloropus* was often seen perching on scrubs while sunbathing and preening feathers in the morning in Kampung Skuduk. Additionally, birds variously use grass in their nesting structure. Grassland birds use grass as material for building their nests (Conn et al., 2017) while waterfowl use thicker grass as their nesting cover to ensure survivability against predators (Pasitschniak-Arts et al., 1995). Diverse grass seeds and scrub including other farm crops such as chilli plants provide food for birds (Stafford et al., 2010; Hulick, 2016). Additionally, trees also serve as important microhabitats that helps to regulate the foraging and nesting activities of some bird taxonomic groups (especially urban-garden birds) by providing food resources either within the paddy field matrix or in adjacent habitats such as secondary or agricultural forests. For example, sunbirds can be seen consuming flower nectar from banana and coconut trees. Whilst, grassland and stork-like birds were also seen to use trees as their perching and nesting. Species like munias favour perching and nesting on the palm trees whilst egrets that reside in the paddy field all year round use trees to sleep at night (Conn et al., 2017). Bitterns were also reportedly breeding on trees surrounding the paddy fields (Pierluissi, 2010). In addition, the combination of ditches, ponds, paddy plots, and levees was specifically utilised by shorebirds and waterfowl. These microhabitats collectively create a solid aquatic ecosystem in the paddy

field which draws a variety of smaller waterbird species (H.-K. Nam et al., 2015a). Water bodies are valuable habitats for aquatic and terrestrial animals by supplying food resources and performing connectivity functions within an ecosystem (Herzon and Helenius, 2008). Levee, on the other hand, was used as an open environment where birds tend to forage, sunbathe, or rest, consistent with observation by Choi et al. (2021). Their use became especially prominent during the harvest stage, when larger waterbirds such as stork-like species preferred foraging along levees. This preference likely arose as the increasing density of the paddy made the fields less accessible to these larger birds, as similarly noted by Nam et al. (2015).

Various birds exist in paddy fields due to landscape heterogeneity that provides structural complexity and food resources, which also include artificial substrate interspersed in the paddy fields (Amira et al., 2018; Mallet et al., 2022; Paulino et al., 2024). These substrates were primarily used for nesting, perching and feeding, particularly by urban-garden birds, stork-like species and waterfowl. Huts and houses in and around paddy fields were observed being used as nesting sites by the Eurasian Tree Sparrow *Passer montanus*, a cavity-nesting species that synanthropically occupies structural cavities or holes in buildings (Cho et al., 2025). Pillars, utility poles, wires, scarecrows and any erections in the paddy plots were used mostly for perching. Pacific Swallow *Hirundo tahitica* and Barn Swallow *Hirundo rustica* often perch on these substrates while hawking for insects. Long-tailed Shrike *Lanius schach* was also seen impaling insects found on artificial substrates such as pillars, poles, and wires, particularly those entangled with creeper plants. Additionally, artificial substrates like roads act as links to various microhabitats that constitute terrestrial ecosystems. Waterfowl species, including the White-breasted Waterhen *Amaurornis phoenicurus*,

were often observed crossing roadways to access these interconnected microhabitats (Austin et al., 2000). Although artificial substrates are often overlooked as viable microhabitats, especially in ecological studies, they can serve important functions in man-made landscapes when natural features are scarce. This aligns with studies showing that certain adaptable bird species frequently exploit artificial substrates when natural features are limited (Afrifa et al., 2023; McCloy et al., 2024). In intensively managed environments such as paddy fields, natural perches and cover might be scarce, and birds may use artificial substrates out of necessity rather than preference. Moreover, birds might learn that artificial substrates provide specific benefits (e.g., wires offer good perching for aerial hawking, pillars hold lights that attract insects at night) (D'Amico et al., 2018; Lammers & Collopy, 2007) and thus disproportionately select them and may introduce bias. However, in this study, artificial substrates did not appear to significantly affect microhabitat selection more than the paddy plots, suggesting that their presence complemented rather than distorted the broader microhabitat distribution and usage by birds. These findings are consistent with those of Afrifa et al. (2023), whose study conducted in an urban context demonstrated that while artificial substrates cannot fully replace natural resources, their integration with natural features can significantly enhance avian survival.

5.4.2 Bird-Microhabitat Association

This study evaluates the effects of paddy farming practices across different paddy stages on microhabitat dynamics, and how these changes may influence the distribution of bird species from a landscape-scale perspective. All bird taxonomic groups have shown low association levels with their microhabitats and paddy stages, which suggests these birds are less dependent on the varying microhabitats and changing paddy stages. This

was evident in stork-like birds and urban-garden birds, where these birds were especially less affected by the habitat modification causing landscape change due to paddy farming. These bird taxonomic groups were present in all stages and were seen distributed in all microhabitats provided by the paddy fields. These birds demonstrated their ability to adapt by shifting how they used their microhabitats. Stork-like birds use inundated paddy plots during planting and land preparation where prey such as aquatic organisms are more accessible (Stafford et al., 2010). They shifted to ditches and ponds which concentrate aquatic organisms during harvest (S. Townsend et al., 2006). Food availability was continuous throughout the paddy stages too where insects, nonseasonal fruits and flowers continued to provide for birds, similarly observed by Supahan (2022). Furthermore, these bird taxonomic bird groups were adapted to the proximity of humans, especially urban-garden birds such as swiftlets, mynas, starlings, pigeons and doves. Their frequent occurrence near human settlements suggests behavioural and ecological flexibility, enabling them to exploit anthropogenic resources such as buildings for nesting, artificial substrates for perching, and human-altered landscapes for foraging. This pattern is consistent with findings by (Møller, 2009), who reported that certain bird species demonstrate greater tolerance to human presence and urban disturbances, facilitating their persistence in intensively managed or developed habitats like paddy fields.

Although the direct effect of paddy farming practices across different paddy stages on microhabitat dynamics and bird distribution appears to be of relatively low magnitude, the main threats in paddy fields for birds are pesticide contamination, nest destruction due to agricultural modernisation (as discussed in Chapter 5.4.1), and ongoing human–wildlife conflict. Among the three study sites, Kampung Skuduk was notably more modernised and appeared to be particularly affected by pesticide use. During land

preparation, a large number of dead fish were observed in irrigation ditches, indicating contamination. While no birds were directly observed feeding on these fish, this does not preclude the possibility of sublethal or indirect effects on bird populations through contaminated food sources or trophic pathways (Kumar et al., 2021). Furthermore, mechanised harvesting using truck-mounted harvesters and the cyclical draining and flooding of paddy plots were reported to destroy bird nests, particularly those of waterbirds. Human–wildlife conflict, particularly in the form of crop raiding, remains a significant source of tension between farmers and wildlife. Crop damage caused by birds is perceived as a major contributor to yield losses (Honda, 2015; Maurice et al., 2019). Farmers identified grassland bird species, such as munias and weavers, as the most problematic taxonomic groups, citing substantial crop damage especially during the grain-ripening stage (Honda, 2015; Wiafe, 2023). In response, farmers often resort to aggressive deterrent methods that are both ineffective and detrimental. These include arbitrary shooting or trapping of suspected crop-raiding species, practices that provide only temporary relief and may exacerbate long-term conservation issues (Horgan & Kudavidanage, 2020; Maurice et al., 2019; Sillero-Zubiri & Switzer, 2001). For example, while stork-like birds such as egrets are generally beneficial to paddy agriculture by consuming pests (e.g., insects, frogs, and rodents), some farmers mistakenly perceive them as threats and reportedly shoot them. Munias are frequently trapped in efforts to reduce their numbers and mitigate crop damage. Such retaliatory actions may reduce immediate agricultural losses but risk long-term ecological consequences. These include the local decline or extirpation of bird populations and the disruption of ecosystem services (Mumby & Plotnik, 2018). Ultimately, these conflicts underscore the need for

integrative, sustainable strategies that address both agricultural productivity and biodiversity conservation.

5.4.3 Study Limitations

One of the main limitations of this study is its broad taxonomic scope at the Order level, which poses challenges for detailed identification and analysis. Although identification at the family level would provide more specific ecological insights, achieving this resolution is challenging due to the scale and complexity of the dataset (encompassing 43 bird families). Another challenge is, although this study looks at a finer spatial scale (microhabitat) in the landscape scale of paddy fields, the spatial resolution was not sufficient to assess individual microhabitat features in detail (other than inundation level and paddy height of paddy plots). Future research could benefit from focusing on a specific microhabitat to investigate how its structural changes across paddy stages influence selection patterns and distributions of birds. Methodologically, although the mist netting data were integrated with visual survey during line transects, birds caught in the mist nets were considered to be using the paddy plots as their active microhabitat as the nets were positioned within and around the paddy fields. However, some bird species may have been passing through rather than actively occupying the area. Mist netting was biased toward flying birds, particularly when nets were positioned along the edges of paddy plots that serve as flight corridors and buffer zones connecting to other habitats (Sánchez-Guzmán et al., 2007). To enhance the precision of future analyses, it is recommended to document the exact location of each mist net with specific microhabitat features within the paddy fields (e.g., levees, ditches, ponds, trees, grasses or artificial substrates). This would enable finer-scale interpretation of microhabitat use.

Additionally, filtering the species list to include only those expected to primarily use paddy fields as habitat would further improve ecological relevance in paddy fields.

5.5 Conclusion

This study studied the microhabitat selection of birds in different paddy stages and evaluated the effect of landscape-scale habitat modifications (microhabitat and paddy stages) on birds of paddy fields community in southwestern Sarawak. The spatially clustered distribution of paddy field birds in southwestern Sarawak reflects the coexistence of diverse taxonomic groups and highlights the viability of paddy fields as habitats, supported by fertile soil, water availability, food abundance, and favourable climate. Additionally, this study identified distinct microhabitat selection patterns among bird taxonomic groups, with the paddy plot as the most widely used microhabitat across all stages due to its size and seasonal variation, while other groups showed preferences for specific features: stork-like and grassland birds for grasses and shrubs, urban-garden birds and waterfowl for trees and artificial substrates, and shorebirds and waterfowl occasionally for levees, ditches, and ponds. All bird taxonomic groups showed low associations with specific microhabitats and paddy stages, indicating limited dependence on these variations, particularly among stork-like and urban-garden birds, which are highly adaptable and capable of shifting microhabitat use in paddy fields. While paddy farming practices exerted relatively low direct influence on bird distribution and microhabitat dynamics, several key threats persist including pesticide contamination, nest destruction from modernised agriculture, and human–wildlife conflict. In response, farmers often employ harmful deterrent methods such as indiscriminate shooting and trapping, which may provide short-term relief but carry long-term ecological consequences. These findings underscore the need for sustainable, integrative strategies

that reconcile agricultural productivity with bird conservation objectives. Future research should focus on specific microhabitats to better understand how structural changes across paddy stages influence bird selection and distribution. Recording the exact placement of mist nets with reference to microhabitat features would improve analytical precision. Moreover, narrowing the species list to those primarily associated with paddy fields would enhance ecological relevance.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

This study has successfully demonstrated how birds respond to ongoing habitat changes in paddy field ecosystems by examining taxonomic diversity, functional groups, distribution patterns, and microhabitat preferences. Seasonal variations from paddy farming did not appear to significantly affect bird populations; however, it may be important to consider potential influences from metapopulation or metacommunity dynamics across the larger landscape. The taxonomic diversity did not differ significantly, as there was a high shared species between the paddy stages. This also correlated with the spatially clustered distribution of birds in southwestern Sarawak, which reflects the coexisting patterns of various bird taxonomic groups for their biotic requirements in the paddy fields. Furthermore, all bird taxonomic groups exhibited weak associations with specific microhabitats and paddy stages, suggesting that these birds are relatively resilient to the changing landscape of paddy fields. The considerable variation observed in their functional groups indicates that their feeding and foraging strategies are adapting in response to the dynamic use of microhabitats across different paddy stages.

Birds in different paddy stages provide information about the relationship between community structure and ecosystem functioning in response to environmental changes brought about by paddy farming. The findings could help with the formulation of habitat or agroecosystem management plans for the taxonomic groups of birds that live in the paddy fields. This would be crucial to gauge ecological redundancy and ecosystem resilience because changing habitats could have a detrimental effect on ecosystem

function and the availability of environmental services in the future. Such scenario includes if paddy farming further exacerbates its methods through overused of hazardous pesticides or advanced technology being used, causing significant habitat degradation. This is consistent with the United Nation's Sustainable Development Goals (UN-SDGs 12 and 15) of the United Nations, which emphasise the significance of responsible production and consumption, the attainment of environmentally sound management of chemicals and all wastes throughout their life cycle, and the incorporation of ecosystem and biodiversity values into planning and development processes at the national and local levels. These findings can also help local communities by increasing their understanding of how different bird species interact with paddy field environments and the importance of diverse microhabitat dynamics. By recognising the adaptive behaviours and ecological roles of birds, such as pest control and seed dispersal, farmers can gain a better appreciation of the benefits that come from conserving bird populations. This knowledge can encourage more sustainable farming practices that protect both crop yields and biodiversity, ultimately supporting healthier ecosystems and improved livelihoods.

6.2 Recommendations

Nevertheless, since classification may vary depending on methods of paddy farming and overlapping paddy stages, future research should extend the study period and sampling visits for each paddy stage while using distinct partitioning of paddy stages with at least four stages (i.e., planting, growing, harvest, and land preparation). Further research should also extend the assessment to upland paddy fields in Sarawak because its dry and upland ecosystems may yield interesting bird diversity and complex functional ecology in response to habitat modifications caused by paddy farming.

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APPENDICES

Appendix A: Journal Publication

1. **Bilang, I. B.**, Ramji, M.F.S., Sazali, S.N., Tuen, A.A., & Wan Ismail, W.N. (2024). Diversity and evenness of birds during seasonal paddy farming practice in southwestern Sarawak. *Turkish Journal of Zoology*, 48(7), 675-684.

Appendix B: The numerical values of estimated sample completeness profiles, size-based rarefaction and extrapolation curves, asymptotic and empirical diversity profiles, coverage-based rarefaction and extrapolation curves and the evenness profiles.

Step 1. Sample completeness profiles			
Completeness	q = 0	q = 1	q = 2
Planting	74.0%	97.0%	100.0%
Harvest	75.0%	99.0%	100.0%
Land preparation	87.0%	98.0%	100.0%
Overall	75.0%	99.0%	100.0%
Step 2. Asymptotic analysis			
Diversity	q = 0	q = 1	q = 2
Planting			
Asymptotic	103.86	42.75	30.25
Empirical	77.00	39.98	29.22
Undetected	26.86	2.77	1.03
Harvest			
Asymptotic	71.98	18.40	9.55
Empirical	54.00	17.78	9.48
Undetected	17.98	0.62	0.07
Land preparation			
Asymptotic	62.32	30.00	20.16
Empirical	54.00	28.49	19.58
Undetected	8.32	1.51	0.58
Overall			
Asymptotic	125.99	35.25	21.59
Empirical	94.00	34.34	21.41
Undetected	31.99	0.91	0.18
Step 3. Non-asymptotic coverage-based rarefaction and extrapolation			
Maximum standardised coverage $C_{max} = 98.8\%$			
Diversity	q = 0	q = 1	q = 2
Planting	92.01	41.61	29.73
Harvest	53.11	17.74	9.47
Land preparation	56.07	28.80	19.69
Overall	87.46	34.08	21.36
Step 4. Evenness among species abundances			
Evenness	Pielou index, J'	q = 1	q = 2
Planting	0.82	0.45	0.32
Harvest	0.72	0.32	0.16
Land preparation	0.83	0.50	0.34
Overall	0.79	0.38	0.24

Appendix C: Stomach content (insect, grass, nymph, grain, fish) of 35 stomach-flushed individuals from fourteen bird species in paddy fields of southwestern Sarawak.

Species	Stomach content					Total individuals (N)
	Insect	Nymph	Grass	Grain	Fish	
Wood Sandpiper	2	6	3	0	0	11
White-breasted Waterhen	0	1	0	0	0	1
Common Moorhen	0	1	0	0	0	1
White-bellied Erpornis	1	0	0	0	0	1
Lesser Coucal	1	0	0	0	0	1
Rufous-tailed Tailorbird	2	0	0	0	0	2
Ashy Tailorbird	1	0	0	0	0	1
Yellow-bellied Prinia	1	0	0	0	0	1
Baya Weaver	0	0	5	6	0	11
Long-tailed Shrike	1	0	0	0	0	1
Swinhoe's Snipe	1	0	0	0	0	1
Plaintive Cuckoo	1	0	0	0	0	1
Pin-tailed Snipe	1	0	0	0	0	1
Cinnamon Bittern	0	0	0	0	1	1
						35

Appendix D: Functional traits for 94 bird species in paddy fields of southwestern Sarawak and the Functional Groups (FG) assigned to them. Some were not classified into FG due to insignificant frequency under five individuals.

Functional group	Family	Common Name	Feeding Guild	Locomotion	Feeding substrate and technique
FG 1	Scolopacidae	Common Sandpiper	Aquatic vertivore/invertivore	Semi aquatic	Wader
FG 1	Scolopacidae	Little-ringed Plover	Aquatic vertivore/invertivore	Semi aquatic	Wader
FG 1	Glareolidae	Oriental Pratincole	Aquatic vertivore/invertivore	Semi aquatic	Wader
FG 1	Scolopacidae	Pacific Golden Plover	Aquatic vertivore/invertivore	Semi aquatic	Wader
FG 1	Scolopacidae	Wood Sandpiper	Aquatic vertivore/invertivore	Semi aquatic	Wader
FG 1	Ardeidae	Yellow Bittern	Aquatic vertivore/invertivore	Semi aquatic	Wader
FG 2	Ardeidae	Chinese Pond Heron	Carnivore	Semi aquatic	Wader
FG 2	Ardeidae	Cinnamon Bittern	Carnivore	Semi aquatic	Wader
FG 2	Ardeidae	Great Egret	Carnivore	Semi aquatic	Wader
FG 2	Ardeidae	Intermediate Egret	Carnivore	Semi aquatic	Wader
FG 2	Ardeidae	Little Egret	Carnivore	Semi aquatic	Wader
FG 2	Ardeidae	Striated Heron	Carnivore	Semi aquatic	Wader
FG 3	Cuculidae	Chestnut-breasted Malkoha	Carnivore	Arboreal	Arboreal hunter
FG 3	Lanidae	Long-tailed Shrike	Carnivore	Arboreal	Arboreal hunter
FG 3	Strigidae	Sunda Scops Owl	Carnivore	Arboreal	Arboreal hunter
FG 4	Cuculidae	Lesser Coucal	Carnivore	Semi arboreal	Ground hunter
FG 5	Sturnidae	Asian Glossy Starling	Frugivore	Arboreal	Arboreal browser/gleaner
FG 5	Sturnidae	Common Hill Myna	Frugivore	Arboreal	Arboreal browser/gleaner
FG 5	Eurylamidae	Green Broadbill	Frugivore	Arboreal	Arboreal browser/gleaner
FG 5	Columbidae	Little Green Pigeon	Frugivore	Arboreal	Arboreal browser/gleaner

FG 5	Pycnonotidae	Olive-winged Bulbul	Frugivore	Arboreal	Arboreal browser/gleaner
FG 5	Columbidae	Pink-necked Green Pigeon	Frugivore	Arboreal	Arboreal browser/gleaner
FG 5	Megalaimidae	Red-throated Barbet	Frugivore	Arboreal	Arboreal browser/gleaner
FG 5	Dicaeidae	Scarlet-backed Flowerpecker	Frugivore	Arboreal	Arboreal browser/gleaner
FG 5	Dicaeidae	Yellow-breasted Flowerpecker	Frugivore	Arboreal	Arboreal browser/gleaner
FG 5	Pycnonotidae	Yellow-vented Bulbul	Frugivore	Arboreal	Arboreal browser/gleaner
FG 6	Columbidae	Spotted Dove	Granivore	Semi arboreal	Ground browser/gleaner
FG 6	Columbidae	Zebra Dove	Granivore	Semi arboreal	Ground browser/gleaner
FG 7	Ploceidae	Baya Weaver	Granivore	Terrestrial	Ground browser/gleaner
FG 7	Estrildidae	Chestnut Munia	Granivore	Terrestrial	Ground browser/gleaner
FG 7	Estrildidae	Dusky Munia	Granivore	Terrestrial	Ground browser/gleaner
FG 7	Estrildidae	Scaly-breasted Munia	Granivore	Terrestrial	Ground browser/gleaner
FG 8	Cisticolidae	Ashy Tailorbird	Invertivore	Arboreal	Arboreal hunter
FG 8	Picidae	Banded Woodpecker	Invertivore	Arboreal	Arboreal hunter
FG 8	Timaliidae	Chestnut-winged Babbler	Invertivore	Arboreal	Arboreal hunter
FG 8	Timaliidae	Fluffy-backed Tit-babbler	Invertivore	Arboreal	Arboreal hunter
FG 8	Rhipiduridae	Malaysian Pied Fantail	Invertivore	Arboreal	Arboreal hunter
FG 8	Pachycephalidae	Mangrove Whistler	Invertivore	Arboreal	Arboreal hunter
FG 8	Picidae	Maroon Woodpecker	Invertivore	Arboreal	Arboreal hunter
FG 8	Cuculidae	Moustache Hawk-cuckoo	Invertivore	Arboreal	Arboreal hunter
FG 8	Coraciidae	Oriental Dollarbird	Invertivore	Arboreal	Arboreal hunter
FG 8	Muscicapidae	Oriental Magpie Robin	Invertivore	Arboreal	Arboreal hunter
FG 8	Acrocephalidae	Oriental Reed Warbler	Invertivore	Arboreal	Arboreal hunter
FG 8	Campephagidae	Pied Triller	Invertivore	Arboreal	Arboreal hunter
FG 8	Cuculidae	Plaintive Cuckoo	Invertivore	Arboreal	Arboreal hunter

FG 8	Picidae	Rufous Piculet	Invertivore	Arboreal	Arboreal hunter
FG 8	Cisticolidae	Rufous-tailed Tailorbird	Invertivore	Arboreal	Arboreal hunter
FG 8	Tephrodornithidae	Rufous-winged Philentoma	Invertivore	Arboreal	Arboreal hunter
FG 8	Timaliidae	Scaly-crowned Babbler	Invertivore	Arboreal	Arboreal hunter
FG 8	Timaliidae	Short-tailed Babbler	Invertivore	Arboreal	Arboreal hunter
FG 8	Sittidae	Velvet-fronted Nuthatch	Invertivore	Arboreal	Arboreal hunter
FG 8	Vireonidae	White-bellied Erpornis	Invertivore	Arboreal	Arboreal hunter
FG 8	Artamidae	White-breasted Wood Swallow	Invertivore	Arboreal	Arboreal hunter
FG 8	Muscicapidae	White-rumped Shama	Invertivore	Arboreal	Arboreal hunter
FG 8	Cisticolidae	Yellow-bellied Prinia	Invertivore	Arboreal	Arboreal hunter
FG 9	Apodidae	Glossy Swiftlet	Invertivore	Volant	Air hunter above canopy
FG 9	Apodidae	White-nest Swiftlet	Invertivore	Volant	Air hunter above canopy
FG 10	Nectariniidae	Brown-throated Sunbird	Nectarivore	Arboreal	Arboreal browser/gleaner
FG 10	Nectariniidae	Crimson Sunbird	Nectarivore	Arboreal	Arboreal browser/gleaner
FG 10	Nectariniidae	Little Spiderhunter	Nectarivore	Arboreal	Arboreal browser/gleaner
FG 10	Nectariniidae	Olive-backed Sunbird	Nectarivore	Arboreal	Arboreal browser/gleaner
FG 10	Dicaeidae	Orange-bellied Flowerpecker	Nectarivore	Arboreal	Arboreal browser/gleaner
FG 10	Nectariniidae	Plain Sunbird	Nectarivore	Arboreal	Arboreal browser/gleaner
FG 10	Nectariniidae	Purple-naped Spiderhunter	Nectarivore	Arboreal	Arboreal browser/gleaner
FG 11	Rallidae	Buff-banded Rail	Omnivore	Terrestrial	Ground browser/gleaner
FG 11	Passeridae	Eurasian Tree Sparrow	Omnivore	Terrestrial	Ground browser/gleaner
FG 11	Rallidae	Slaty-breasted Rail	Omnivore	Terrestrial	Ground browser/gleaner
FG 11	Rallidae	White-breasted Waterhen	Omnivore	Terrestrial	Ground browser/gleaner
FG 12	Rallidae	Eurasian Moorhen	Omnivore	Semi aquatic	Aquatic surface browser/gleaner
FG 12	Rostratulidae	Greater Painted Snipe	Omnivore	Semi aquatic	Aquatic surface browser/gleaner

FG 13	Alcedinidae	Blue-eared Kingfisher	Carnivore	Semi aquatic	Aquatic surface hunter
FG 13	Alcedinidae	Collared Kingfisher	Carnivore	Semi aquatic	Aquatic surface hunter
FG 14	Accipitridae	Brahminy Kite	Carnivore	Volant	Air hunter under canopy
FG 14	Accipitridae	Crested Serpent Eagle	Carnivore	Volant	Air hunter under canopy
FG 14	Accipitridae	Grey-headed Fish Eagle	Carnivore	Volant	Air hunter under canopy
FG 14	Accipitridae	White-bellied Sea Eagle	Carnivore	Volant	Air hunter under canopy
-	Hirundinidae	Barn Swallow	Invertivore	Volant	Air hunter under canopy
-	Cuculidae	Black Magpie	Omnivore	Arboreal	Arboreal browser/gleaner
-	Eurylamidae	Black-and-red Broadbill	Invertivore	Arboreal	Ground hunter
-	Meropidae	Blue-throated Bee-eater	Invertivore	Arboreal	Air hunter above canopy
-	Timaliidae	Bold-Striped Tit-babbler	Invertivore	Terrestrial	Ground browser/gleaner
-	Pycnonotidae	Buff-vented Bulbul	Omnivore	Arboreal	Arboreal browser/gleaner
-	Ardeidae	Cattle Egret	Carnivore	Terrestrial	Ground hunter
-	Sturnidae	Common Myna	Omnivore	Terrestrial	Ground hunter
-	Turdidae	Eye-browed Thrush	Omnivore	Arboreal	Arboreal browser/gleaner
-	Cuculidae	Greater Coucal	Omnivore	Semi arboreal	Ground browser/gleaner
-	Dicruridae	Greater Racket-tailed Drongo	Omnivore	Arboreal	Arboreal browser/gleaner
-	Caprimulgidae	Large-tailed Nightjar	Invertivore	Semi arboreal	Air hunter under canopy
-	Psittacidae	Long-tailed Parakeet	Frugivore	Volant	Arboreal browser/gleaner
-	Hirundinidae	Pacific Swallow	Invertivore	Volant	Air hunter under canopy
-	Estrildidae	Pin-tailed Parrotfinch	Granivore	Arboreal	Arboreal browser/gleaner
-	Scolopacidae	Pin-tailed Snipe	Omnivore	Semi aquatic	Ground browser/gleaner
-	Scolopacidae	Swinhoe's Snipe	Invertivore	Semi aquatic	Ground hunter
-	Rallidae	White-browed Crane	Aquatic vertivore/invertivore	Terrestrial	Ground hunter

Appendix E: Data of birds according to their cluster, cell, site, taxonomic groups (Order, Family, Species) and microhabitat use.

Cluster	Cell	Sampling number	Site	Paddy stage	Order	Family	Bird species	Microhabitat use
1	1	Sampling 1	Skuduk	Planting	Caprimulgiformes	Apodidae	Mossy-nest Swiftlet	Paddy plot
1	1	Sampling 2	Baru	Planting	Columbiformes	Columbidae	Pink-necked Green Pigeon	Paddy plot
1	2	Sampling 1	Skuduk	Planting	Charadriiformes	Charadriidae	Pacific Golden Plover	Paddy plot
1	2	Sampling 9	Pueh-Siru Dayak	Planting	Charadriiformes	Charadriidae	Pacific Golden Plover	Paddy plot
1	2	Sampling 8	Baru	Land preparation	Charadriiformes	Scolopacidae	Swinhoe's Snipe	Paddy plot
1	2	Sampling 8	Baru	Land preparation	Charadriiformes	Charadriidae	Pacific Golden Plover	Paddy plot
2	3	Sampling 8	Baru	Land preparation	Columbiformes	Columbidae	Pink-necked Green Pigeon	Paddy plot
2	3	Sampling 3	Pueh-Siru Dayak	Harvest	Charadriiformes	Scolopacidae	Pin-tailed Snipe	Paddy plot
2	3	Sampling 1	Skuduk	Planting	Columbiformes	Columbidae	Pink-necked Green Pigeon	Paddy plot, Levee
2	3	Sampling 3	Pueh-Siru Dayak	Harvest	Columbiformes	Columbidae	Pink-necked Green Pigeon	Paddy plot, Levee
2	3	Sampling 1	Skuduk	Planting	Charadriiformes	Scolopacidae	Wood Sandpiper	Paddy plot, Grass and scrubs
2	4	Sampling 3	Pueh-Siru Dayak	Harvest	Cuculiformes	Cuculidae	Lesser Coucal	Tree
2	4	Sampling 1	Skuduk	Planting	Cuculiformes	Cuculidae	Lesser Coucal	Tree
2	4	Sampling 2	Baru	Planting	Passeriformes	Sturnidae	Asian Glossy Starling	Tree, Artificial substrate
2	4	Sampling 1	Skuduk	Planting	Passeriformes	Estrildidae	Dusky Munia	Grass and scrubs, Tree

2	4	Sampling 8	Baru	Land preparation	Passeriformes	Sturnidae	Asian Glossy Starling	Grass and scrubs, Tree
2	4	Sampling 2	Baru	Planting	Gruiformes	Rallidae	White-breasted Waterhen	Tree, Artificial substrate
2	4	Sampling 8	Baru	Land preparation	Gruiformes	Rallidae	Buff-banded Rail	Artificial substrate
3	5	Sampling 1	Skuduk	Planting	Gruiformes	Rallidae	Eurasian Moorhen	Artificial substrate
3	5	Sampling 9	Pueh-Siru Dayak	Planting	Gruiformes	Rallidae	White-breasted Waterhen	Artificial substrate
3	5	Sampling 1	Skuduk	Planting	Gruiformes	Rallidae	White-breasted Waterhen	Artificial substrate
1	6	Sampling 1	Skuduk	Planting	Passeriformes	Artamidae	White-breasted Woodswallow	Artificial substrate
1	6	Sampling 3	Pueh-Siru Dayak	Harvest	Passeriformes	Hirundinidae	Pacific Swallow	Artificial substrate
1	6	Sampling 1	Skuduk	Planting	Passeriformes	Sturnidae	Asian Glossy Starling	Artificial substrate
1	6	Sampling 4	Baru	Harvest	Accipitriformes	Accipitridae	Crested Serpent Eagle	Artificial substrate
1	6	Sampling 5	Skuduk	Harvest	Caprimulgiformes	Apodidae	Glossy Swiftlet	Artificial substrate
1	6	Sampling 4	Baru	Harvest	Caprimulgiformes	Apodidae	Glossy Swiftlet	Artificial substrate
1	6	Sampling 7	Skuduk	Land preparation	Charadriiformes	Charadriidae	Pacific Golden Plover	Artificial substrate
1	6	Sampling 7	Skuduk	Land preparation	Charadriiformes	Glareolidae	Oriental Pratincole	Artificial substrate
1	6	Sampling 7	Skuduk	Land preparation	Passeriformes	Passeridae	Eurasian Tree Sparrow	Artificial substrate
1	6	Sampling 9	Pueh-Siru Dayak	Planting	Columbiformes	Columbidae	Pink-necked Green Pigeon	Paddy plot
1	6	Sampling 9	Pueh-Siru Dayak	Planting	Passeriformes	Nectariniidae	Orange-bellied Flowerpecker	Paddy plot

2	7	Sampling 7	Skuduk	Land preparation	Cuculiformes	Cuculidae	Greater Coucal	Paddy plot
2	7	Sampling 7	Skuduk	Land preparation	Passeriformes	Sturnidae	Asian Glossy Starling	Paddy plot
2	7	Sampling 6	Pueh-Siru Dayak	Land preparation	Strigiformes	Strigidae	Sunda Scops Owl	Paddy plot
2	7	Sampling 3	Pueh-Siru Dayak	Harvest	Columbiformes	Columbidae	Spotted Dove	Paddy plot
2	7	Sampling 8	Baru	Land preparation	Columbiformes	Columbidae	Zebra Dove	Paddy plot
2	7	Sampling 2	Baru	Planting	Passeriformes	Cisticolidae	Yellow-bellied Prinia	Paddy plot
2	7	Sampling 1	Skuduk	Planting	Pelecaniformes	Ardeidae	Great Egret	Paddy plot
2	7	Sampling 6	Pueh-Siru Dayak	Land preparation	Cuculiformes	Cuculidae	Lesser Coucal	Paddy plot
2	7	Sampling 6	Pueh-Siru Dayak	Land preparation	Passeriformes	Estrildidae	Scaly-breasted Munia	Paddy plot
2	7	Sampling 7	Skuduk	Land preparation	Passeriformes	Ploceidae	Baya Weaver	Paddy plot
2	7	Sampling 1	Skuduk	Planting	Columbiformes	Columbidae	Spotted Dove	Paddy plot
2	7	Sampling 1	Skuduk	Planting	Coraciiformes	Alcedinidae	Collared Kingfisher	Paddy plot
2	7	Sampling 2	Baru	Planting	Pelecaniformes	Ardeidae	Great Egret	Paddy plot
2	7	Sampling 6	Pueh-Siru Dayak	Land preparation	Passeriformes	Passeridae	Eurasian Tree Sparrow	Paddy plot
2	7	Sampling 5	Skuduk	Harvest	Passeriformes	Hirundinidae	Pacific Swallow	Paddy plot
2	7	Sampling 4	Baru	Harvest	Passeriformes	Estrildidae	Dusky Munia	Paddy plot, Artificial substrate
2	7	Sampling 7	Skuduk	Land preparation	Columbiformes	Columbidae	Pink-necked Green Pigeon	Levee

2	7	Sampling 7	Skuduk	Land preparation	Passeriformes	Pycnonotidae	Yellow-vented Bulbul	Paddy plot, Levee
2	7	Sampling 3	Pueh-Siru Dayak	Harvest	Passeriformes	Estrildidae	Dusky Munia	Levee
2	7	Sampling 8	Baru	Land preparation	Passeriformes	Pycnonotidae	Yellow-vented Bulbul	Levee
2	7	Sampling 3	Pueh-Siru Dayak	Harvest	Passeriformes	Passeridae	Eurasian Tree Sparrow	Levee, Artificial substrate
2	7	Sampling 1	Skuduk	Planting	Passeriformes	Pycnonotidae	Yellow-vented Bulbul	Paddy plot, Levee, Artificial substrate
2	7	Sampling 3	Pueh-Siru Dayak	Harvest	Coraciiformes	Meropidae	Blue-throated Bee-eater	Paddy plot, Levee
2	7	Sampling 1	Skuduk	Planting	Passeriformes	Ploceidae	Baya Weaver	Paddy plot, Levee, Ditch and pond
2	7	Sampling 9	Pueh-Siru Dayak	Planting	Accipitriformes	Accipitridae	Grey-headed Fish Eagle	Ditch and pond
2	7	Sampling 9	Pueh-Siru Dayak	Planting	Columbiformes	Columbidae	Spotted Dove	Paddy plot, Levee, Ditch and pond
2	7	Sampling 6	Pueh-Siru Dayak	Land preparation	Passeriformes	Sturnidae	Asian Glossy Starling	Ditch and pond
2	7	Sampling 2	Baru	Planting	Passeriformes	Pycnonotidae	Yellow-vented Bulbul	Paddy plot, Levee, Ditch and pond
2	8	Sampling 2	Baru	Planting	Passeriformes	Ploceidae	Black Magpie	Paddy plot, Levee, Ditch and pond, Artificial scrubs
2	8	Sampling 1	Skuduk	Planting	Passeriformes	Lanidae	Long-tailed Shrike	Grass and scrubs
2	8	Sampling 1	Skuduk	Planting	Passeriformes	Nectariniidae	Plain Sunbird	Grass and scrubs
2	8	Sampling 1	Skuduk	Planting	Passeriformes	Passeridae	Eurasian Tree Sparrow	Grass and scrubs
2	8	Sampling 3	Pueh-Siru Dayak	Harvest	Passeriformes	Pycnonotidae	Yellow-vented Bulbul	Grass and scrubs

2	8	Sampling 3	Pueh-Siru Dayak	Harvest	Pelecaniformes	Ardeidae	Cinnamon Bittern	Grass and scrubs
2	9	Sampling 4	Baru	Harvest	Columbiformes	Columbidae	Spotted Dove	Grass and scrubs
2	9	Sampling 5	Skuduk	Harvest	Gruiformes	Rallidae	White-breasted Waterhen	Grass and scrubs
2	9	Sampling 7	Skuduk	Land preparation	Pelecaniformes	Ardeidae	Great Egret	Grass and scrubs
2	9	Sampling 7	Skuduk	Land preparation	Passeriformes	Artamidae	White-breasted Woodswallow	Paddy plot, Grass and scrubs
2	9	Sampling 6	Pueh-Siru Dayak	Land preparation	Pelecaniformes	Ardeidae	Intermediate Egret	Paddy plot, Grass and scrubs
2	9	Sampling 8	Baru	Land preparation	Passeriformes	Cisticolidae	Yellow-bellied Prinia	Ditch and pond, Grass and scrubs
2	9	Sampling 9	Pueh-Siru Dayak	Planting	Passeriformes	Muscicapidae	Oriental Magpie Robin	Ditch and pond, Grass and scrubs
2	9	Sampling 3	Pueh-Siru Dayak	Harvest	Passeriformes	Nectariniidae	Olive-backed Sunbird	Ditch and pond, Grass and scrubs
2	9	Sampling 3	Pueh-Siru Dayak	Harvest	Passeriformes	Lanidae	Long-tailed Shrike	Grass and scrubs, Artificial substrate
2	9	Sampling 7	Skuduk	Land preparation	Gruiformes	Rallidae	White-breasted Waterhen	Grass and scrubs
2	9	Sampling 6	Pueh-Siru Dayak	Land preparation	Gruiformes	Rallidae	White-breasted Waterhen	Grass and scrubs
2	9	Sampling 7	Skuduk	Land preparation	Passeriformes	Estrildidae	Scaly-breasted Munia	Paddy plot, Grass and scrubs
2	9	Sampling 6	Pueh-Siru Dayak	Land preparation	Passeriformes	Pycnonotidae	Yellow-vented Bulbul	Paddy plot, Levee, Grass and scrubs
2	9	Sampling 2	Baru	Planting	Passeriformes	Lanidae	Long-tailed Shrike	Levee, Ditch and pond, Grass and scrubs

2	9	Sampling 2	Baru	Planting	Passeriformes	Muscicapidae	Oriental Magpie Robin	Paddy plot, Levee, Ditch and pond, Grass and scrubs
2	9	Sampling 6	Pueh-Siru Dayak	Land preparation	Passeriformes	Nectariniidae	Crimson Sunbird	Paddy plot, Levee, Ditch and pond, Grass and scrubs
2	9	Sampling 1	Skuduk	Planting	Passeriformes	Nectariniidae	Crimson Sunbird	Ditch and pond
2	9	Sampling 9	Pueh-Siru Dayak	Planting	Passeriformes	Timaliidae	Bold-striped Tit-babbler	Grass and scrubs
2	9	Sampling 6	Pueh-Siru Dayak	Land preparation	Gruiformes	Rallidae	Slaty-breasted Rail	Grass and scrubs
2	9	Sampling 9	Pueh-Siru Dayak	Planting	Pelecaniformes	Ardeidae	Little Egret	Paddy plot, Grass and scrubs
2	9	Sampling 9	Pueh-Siru Dayak	Planting	Passeriformes	Pycnonotidae	Olive-winged Bulbul	Paddy plot, Grass and scrubs
2	9	Sampling 9	Pueh-Siru Dayak	Planting	Pelecaniformes	Ardeidae	Great Egret	Grass and scrubs
2	9	Sampling 8	Baru	Land preparation	Columbiformes	Columbidae	Spotted Dove	Paddy plot, Grass and scrubs
2	9	Sampling 7	Skuduk	Land preparation	Passeriformes	Sturnidae	Common Myna	Paddy plot, Grass and scrubs
2	9	Sampling 7	Skuduk	Land preparation	Pelecaniformes	Ardeidae	Cinnamon Bittern	Paddy plot, Levee, Grass and scrubs
2	9	Sampling 9	Pueh-Siru Dayak	Planting	Cuculiformes	Cuculidae	Chestnut-breasted Malkoha	Paddy plot, Levee, Ditch and pond, Grass and scrubs
2	9	Sampling 4	Baru	Harvest	Passeriformes	Estrildidae	Scaly-breasted Munia	Grass and scrubs
2	9	Sampling 2	Baru	Planting	Pelecaniformes	Ardeidae	Intermediate Egret	Grass and scrubs
2	9	Sampling 4	Baru	Harvest	Passeriformes	Cisticolidae	Yellow-bellied Prinia	Grass and scrubs, Artificial substrate
2	9	Sampling 8	Baru	Land preparation	Pelecaniformes	Ardeidae	Intermediate Egret	Grass and scrubs

2	9	Sampling 3	Pueh-Siru Dayak	Harvest	Passeriformes	Sturnidae	Common Myna	Grass and scrubs
2	9	Sampling 7	Skuduk	Land preparation	Gruiformes	Rallidae	Eurasian Moorhen	Grass and scrubs
2	9	Sampling 2	Baru	Planting	Pelecaniformes	Ardeidae	Little Egret	Paddy plot, Grass and scrubs
2	9	Sampling 2	Baru	Planting	Passeriformes	Passeridae	Eurasian Tree Sparrow	Grass and scrubs
2	9	Sampling 5	Skuduk	Harvest	Passeriformes	Estrildidae	Scaly-breasted Munia	Grass and scrubs
2	9	Sampling 6	Pueh-Siru Dayak	Land preparation	Passeriformes	Lanidae	Long-tailed Shrike	Paddy plot, Grass and scrubs
2	9	Sampling 7	Skuduk	Land preparation	Passeriformes	Rhipiduridae	Pied Fantail	Paddy plot, Grass and scrubs
2	9	Sampling 9	Pueh-Siru Dayak	Planting	Cuculiformes	Cuculidae	Greater Coucal	Tree
2	9	Sampling 1	Skuduk	Planting	Passeriformes	Cisticolidae	Yellow-bellied Prinia	Tree
2	9	Sampling 9	Pueh-Siru Dayak	Planting	Passeriformes	Corvidae	Black Magpie	Tree
2	9	Sampling 9	Pueh-Siru Dayak	Planting	Pelecaniformes	Ardeidae	Cattle Egret	Tree
2	9	Sampling 5	Skuduk	Harvest	Columbiformes	Columbidae	Spotted Dove	Tree
2	9	Sampling 5	Skuduk	Harvest	Cuculiformes	Cuculidae	Lesser Coucal	Tree
2	9	Sampling 5	Skuduk	Harvest	Gruiformes	Rallidae	Buff-banded Rail	Tree
2	9	Sampling 5	Skuduk	Harvest	Gruiformes	Rallidae	White-browed Crake	Tree
2	9	Sampling 4	Baru	Harvest	Passeriformes	Artamidae	White-breasted Woodswallow	Tree
2	9	Sampling 5	Skuduk	Harvest	Passeriformes	Estrildidae	Chestnut Munia	Tree
2	9	Sampling 4	Baru	Harvest	Passeriformes	Lanidae	Long-tailed Shrike	Tree
2	9	Sampling 4	Baru	Harvest	Passeriformes	Pycnonotidae	Olive-winged Bulbul	Tree

2	10	Sampling 4	Baru	Harvest	Passeriformes	Sturnidae	Asian Glossy Starling	Tree
2	10	Sampling 5	Skuduk	Harvest	Pelecaniformes	Ardeidae	Cinnamon Bittern	Tree
2	10	Sampling 6	Pueh-Siru Dayak	Land preparation	Accipitriformes	Accipitridae	Brahminy Kite	Tree
2	10	Sampling 7	Skuduk	Land preparation	Caprimulgiformes	Apodidae	Mossy-nest Swiftlet	Tree
2	10	Sampling 7	Skuduk	Land preparation	Charadriiformes	Scolopacidae	Wood Sandpiper	Tree
2	10	Sampling 6	Pueh-Siru Dayak	Land preparation	Coraciiformes	Meropidae	Blue-throated Bee- eater	Tree
2	11	Sampling 7	Skuduk	Land preparation	Pelecaniformes	Ardeidae	Intermediate Egret	Tree
2	11	Sampling 7	Skuduk	Land preparation	Pelecaniformes	Ardeidae	Little Egret	Tree
2	11	Sampling 4	Baru	Harvest	Passeriformes	Estrildidae	Chestnut Munia	Paddy plot, Tree, Artificial substrate
2	11	Sampling 5	Skuduk	Harvest	Passeriformes	Cisticolidae	Yellow-bellied Prinia	Grass and scrubs, Tree, Artificial substrate
2	11	Sampling 9	Pueh-Siru Dayak	Planting	Cuculiformes	Cuculidae	Lesser Coucal	Tree
2	11	Sampling 9	Pueh-Siru Dayak	Planting	Cuculiformes	Cuculidae	Plaintive Cuckoo	Tree
2	11	Sampling 3	Pueh-Siru Dayak	Harvest	Passeriformes	Corvidae	Black Magpie	Tree, Artificial substrate
2	11	Sampling 9	Pueh-Siru Dayak	Planting	Passeriformes	Pycnonotidae	Yellow-vented Bulbul	Tree, Artificial substrate
2	11	Sampling 9	Pueh-Siru Dayak	Planting	Passeriformes	Turdidae	Eyebrowed Thrush	Tree

2	11	Sampling 4	Baru	Harvest	Columbiformes	Columbidae	Pink-necked Green Pigeon	Tree
2	11	Sampling 4	Baru	Harvest	Columbiformes	Columbidae	Zebra Dove	Tree
2	11	Sampling 4	Baru	Harvest	Cuculiformes	Cuculidae	Lesser Coucal	Tree
2	11	Sampling 5	Skuduk	Harvest	Passeriformes	Lanidae	Long-tailed Shrike	Tree
2	11	Sampling 5	Skuduk	Harvest	Passeriformes	Ploceidae	Baya Weaver	Tree
2	11	Sampling 5	Skuduk	Harvest	Pelecaniformes	Ardeidae	Great Egret	Tree
2	11	Sampling 4	Baru	Harvest	Piciformes	Picidae	Banded Woodpecker	Tree
2	11	Sampling 6	Pueh-Siru Dayak	Land preparation	Caprimulgiformes	Apodidae	White-nest Swiftlet	Tree
2	11	Sampling 6	Pueh-Siru Dayak	Land preparation	Columbiformes	Columbidae	Zebra Dove	Tree
2	11	Sampling 6	Pueh-Siru Dayak	Land preparation	Passeriformes	Estrildidae	Chestnut Munia	Tree
2	11	Sampling 6	Pueh-Siru Dayak	Land preparation	Passeriformes	Sturnidae	Common Myna	Paddy plot, Tree
2	11	Sampling 4	Baru	Harvest	Gruiformes	Rallidae	White-browed Crake	Grass and scrubs, Tree
2	11	Sampling 6	Pueh-Siru Dayak	Land preparation	Columbiformes	Columbidae	Spotted Dove	Paddy plot, Levee, Grass and scrubs, Tree
2	11	Sampling 9	Pueh-Siru Dayak	Planting	Passeriformes	Estrildidae	Scaly-breasted Munia	Grass and scrubs, Tree
2	11	Sampling 8	Baru	Land preparation	Passeriformes	Estrildidae	Scaly-breasted Munia	Grass and scrubs, Tree
2	11	Sampling 2	Baru	Planting	Cuculiformes	Cuculidae	Lesser Coucal	Tree
2	11	Sampling 2	Baru	Planting	Gruiformes	Rallidae	Buff-banded Rail	Tree
2	11	Sampling 8	Baru	Land preparation	Gruiformes	Rallidae	White-breasted Waterhen	Tree

2	11	Sampling 2	Baru	Planting	Passeriformes	Cisticolidae	Rufous-tailed Tailorbird	Tree
2	11	Sampling 9	Pueh-Siru Dayak	Planting	Passeriformes	Cisticolidae	Yellow-bellied Prinia	Tree
2	11	Sampling 2	Baru	Planting	Passeriformes	Estrildidae	Chestnut Munia	Grass and scrubs, Artificial substrate
2	11	Sampling 3	Pueh-Siru Dayak	Harvest	Passeriformes	Estrildidae	Scaly-breasted Munia	Tree
2	11	Sampling 9	Pueh-Siru Dayak	Planting	Pelecaniformes	Ardeidae	Chinese Pond Heron	Tree
2	11	Sampling 5	Skuduk	Harvest	Charadriiformes	Scolopacidae	Wood Sandpiper	Tree, Artificial substrate
2	11	Sampling 4	Baru	Harvest	Gruiformes	Rallidae	White-breasted Waterhen	Tree
2	11	Sampling 6	Pueh-Siru Dayak	Land preparation	Psittaciformes	Psittacidae	Long-tailed Parakeet	Tree
2	11	Sampling 9	Pueh-Siru Dayak	Planting	Passeriformes	Sturnidae	Asian Glossy Starling	Grass and scrubs, Tree
2	11	Sampling 2	Baru	Planting	Gruiformes	Rallidae	Eyebrowed Crake	Tree, Artificial substrate
2	11	Sampling 3	Pueh-Siru Dayak	Harvest	Passeriformes	Estrildidae	Chestnut Munia	Tree
2	11	Sampling 1	Skuduk	Planting	Passeriformes	Estrildidae	Scaly-breasted Munia	Tree
2	11	Sampling 9	Pueh-Siru Dayak	Planting	Passeriformes	Rhipiduridae	Pied Fantail	Tree
2	11	Sampling 3	Pueh-Siru Dayak	Harvest	Passeriformes	Sturnidae	Asian Glossy Starling	Tree
2	11	Sampling 5	Skuduk	Harvest	Columbiformes	Columbidae	Zebra Dove	Tree
2	11	Sampling 4	Baru	Harvest	Gruiformes	Rallidae	Buff-banded Rail	Tree, Artificial substrate
2	11	Sampling 5	Skuduk	Harvest	Passeriformes	Nectariniidae	Brown-throated Sunbird	Tree

2	12	Sampling 5	Skuduk	Harvest	Passeriformes	Sturnidae	Asian Glossy Starling	Tree
2	12	Sampling 5	Skuduk	Harvest	Pelecaniformes	Ardeidae	Little Egret	Tree
2	12	Sampling 4	Baru	Harvest	Pelecaniformes	Ardeidae	Yellow Bittern	Tree
2	12	Sampling 6	Pueh-Siru Dayak	Land preparation	Passeriformes	Corvidae	Black Magpie	Tree, Artificial substrate
2	12	Sampling 2	Baru	Planting	Passeriformes	Estrildidae	Scaly-breasted Munia	Tree, Artificial substrate
2	12	Sampling 1	Skuduk	Planting	Passeriformes	Hirundinidae	Pacific Swallow	Tree
2	12	Sampling 5	Skuduk	Harvest	Passeriformes	Sturnidae	Common Myna	Tree
2	12	Sampling 7	Skuduk	Land preparation	Gruiformes	Rallidae	Buff-banded Rail	Tree
2	12	Sampling 5	Skuduk	Harvest	Pelecaniformes	Ardeidae	Intermediate Egret	Tree
2	12	Sampling 4	Baru	Harvest	Passeriformes	Nectariniidae	Olive-backed Sunbird	Tree, Artificial substrate
2	12	Sampling 5	Skuduk	Harvest	Gruiformes	Rallidae	Eurasian Moorhen	Tree
2	12	Sampling 5	Skuduk	Harvest	Passeriformes	Artamidae	White-breasted Woodswallow	Tree
2	12	Sampling 7	Skuduk	Land preparation	Charadriiformes	Scolopacidae	Common Sandpiper	Tree
2	13	Sampling 2	Baru	Planting	Passeriformes	Sturnidae	Common Myna	Grass and scrubs, Tree
2	13	Sampling 9	Pueh-Siru Dayak	Planting	Passeriformes	Sturnidae	Common Myna	Tree
2	13	Sampling 7	Skuduk	Land preparation	Charadriiformes	Charadriidae	Little-ringed Plover	Tree, Artificial substrate
2	13	Sampling 6	Pueh-Siru Dayak	Land preparation	Passeriformes	Muscicapidae	Oriental Magpie Robin	Paddy plot, Tree
2	13	Sampling 5	Skuduk	Harvest	Passeriformes	Nectariniidae	Orange-bellied Flowerpecker	Tree
2	13	Sampling 7	Skuduk	Land preparation	Accipitriformes	Accipitridae	White-bellied Sea Eagle	Tree

2	13	Sampling 3	Pueh-Siru Dayak	Harvest	Pelecaniformes	Ardeidae	Little Egret	Paddy plot, Grass and scrubs, Tree
2	13	Sampling 3	Pueh-Siru Dayak	Harvest	Caprimulgiformes	Apodidae	Glossy Swiftlet	Paddy plot
2	13	Sampling 2	Baru	Planting	Caprimulgiformes	Apodidae	Glossy Swiftlet	Tree
2	13	Sampling 8	Baru	Land preparation	Caprimulgiformes	Apodidae	Glossy Swiftlet	Tree
4	14	Sampling 8	Baru	Land preparation	Charadriiformes	Scolopacidae	Wood Sandpiper	Paddy plot
4	14	Sampling 9	Pueh-Siru Dayak	Planting	Pelecaniformes	Ardeidae	Cinnamon Bittern	Paddy plot
4	14	Sampling 1	Skuduk	Planting	Pelecaniformes	Ardeidae	Yellow Bittern	Paddy plot
4	14	Sampling 3	Pueh-Siru Dayak	Harvest	Pelecaniformes	Ardeidae	Great Egret	Paddy plot
4	14	Sampling 2	Baru	Planting	Charadriiformes	Scolopacidae	Wood Sandpiper	Paddy plot
4	14	Sampling 2	Baru	Planting	Pelecaniformes	Ardeidae	Cinnamon Bittern	Paddy plot, Grass and scrubs
4	14	Sampling 9	Pueh-Siru Dayak	Planting	Piciformes	Picidae	Banded Woodpecker	Paddy plot, Tree
5	15	Sampling 6	Pueh-Siru Dayak	Land preparation	Pelecaniformes	Ardeidae	Great Egret	Paddy plot, Grass and scrubs
5	15	Sampling 8	Baru	Land preparation	Pelecaniformes	Ardeidae	Great Egret	Grass and scrubs
5	15	Sampling 1	Skuduk	Planting	Pelecaniformes	Ardeidae	Little Egret	Paddy plot, Grass and scrubs
5	15	Sampling 8	Baru	Land preparation	Pelecaniformes	Ardeidae	Cinnamon Bittern	Grass and scrubs

Abbreviations: Baru = Kampung Baru; Skuduk = Kampung Skuduk; Pueh-Siru Dayak = Kampung Pueh-Siru Dayak

Appendix F: Paddy height and inundation level measurements in three paddy fields during different paddy stages.

Stage	Site	Point	Paddy height (cm)	Inundation level (cm)
Planting	Kampung Skuduk	1	20.4	15.2
		2	25.4	20.5
		3	27.8	17.6
		4	30.6	15.3
		5	28.9	16.7
		6	27.5	11.9
		7	20.6	30.6
		8	19.4	24.5
		9	16.8	20.4
		10	24.2	13.3
	Kampung Baru	1	40.6	10.4
		2	37.0	11.3
		3	33.6	12.8
		4	36.0	5.4
		5	39.4	8.9
		6	40.2	9.6
		7	41.3	7.9
		8	34.8	6.5
		9	46.7	5.5
		10	45.9	7.3
	Kampung Pueh-Siru Dayak	1	36.5	5.2
		2	34.8	4.6
		3	30.6	4.2
		4	36.4	3.6
		5	39.7	7.9
		6	29.6	9.4
		7	31.3	10.7
		8	28.4	8.7
		9	33.7	5.6
		10	35.6	7.4
32.4566667			11.2966667	
Harvest	Kampung Skuduk	1	101.7	0.0
		2	117.9	0.0

		3	96.5	0.0
		4	81.8	0.0
		5	106.4	0.0
		6	157.2	0.0
		7	120.6	0.0
		8	129.8	0.0
		9	103.4	0.0
		10	106.5	0.0
	Kampung Baru	1	86.9	0.0
		2	103.4	0.0
		3	129.5	0.0
		4	113.4	0.0
		5	123.3	0.0
		6	120.7	0.0
		7	85.9	0.0
		8	112.4	0.0
		9	117.3	0.0
		10	104.6	0.0
	Kampung Pueh-Siru Dayak	1	108.4	0.0
		2	87.7	0.0
		3	72.6	0.0
		4	76.4	0.0
		5	90.5	0.0
		6	124.4	0.0
		7	108.0	0.0
		8	102.1	0.0
		9	96.5	0.0
		10	123.3	0.0
106.97			0.0	
Land preparation	Kampung Skuduk	1	0.0	16.5
		2	0.0	18.4
		3	0.0	17.1
		4	0.0	14.6
		5	0.0	15.8
		6	0.0	7.9
		7	0.0	5.3
		8	0.0	3.5
		9	0.0	3.8

	10	0.0	7.3
Kampung Baru	1	0.0	7.4
	2	0.0	4.8
	3	0.0	3.2
	4	0.0	8.2
	5	0.0	7.3
	6	0.0	5.8
	7	0.0	3.4
	8	0.0	4.2
	9	0.0	3.7
	10	0.0	3.1
Kampung Puch-Siru Dayak	1	0.0	0.0
	2	0.0	0.0
	3	0.0	0.0
	4	0.0	0.0
	5	0.0	0.0
	6	0.0	0.0
	7	0.0	0.0
	8	0.0	0.0
	9	0.0	0.0
	10	0.0	0.0
		0.0	5.37666667

Appendix G: Some of the codes used for statistical analysis in R statistical software (Version 2023.03.0+386). Their application may vary depending on the specific data and analytical requirements.

Friedman test: ‘friedman.test’ functions from R ‘stats’ package (R Core Team, 2024).

```
friedman.test(Richness ~ Stage | Site, data = Friedman Data)
```

Biodiversity assessments: ‘iNEXT.4steps’ (Four Steps of Interpolation and Extrapolation) package (Chao and Hu, 2023).

```
install_github('AnneChao/iNEXT.3D')
install.packages("iNEXT.4steps")
install.packages("ggplot2")
library(iNEXT.4steps)
library(ggplot2)
iNEXTT<-as.data.frame(iNEXTdata)
iNEXT4steps(iNEXTT)
```

Indicator values (IndVal): ‘indicspecies’ package (de Cáceres and Legendre, 2009).

```
install.packages("indicspecies")
library(indicspecies)
#upload excel(column=species, row=site)
#classification of data steps
sstry<-kmeans(SpeciesIndVal_for_Stages, centers = 2)
sstry
groupkmeans<-sstry$cluster
groupkmeans
#multipatt steps
indval2<-multipatt(SpeciesIndVal,GroupsIndVal$Sites,control=how(nperm = 999))
indval2
summary(indval2)
summary(indval2, alpha=1)
str(indval2)
coverage(SpeciesIndVal,indval2) #to check coverage
boxplot(indval2$str)
boxplot(indval2$A)
boxplot(indval2$B)
```

Stacked bar plots: “ggplot2” package (Wickham, 2016).

```
library(ggplot2)
data=Barplot Waterbirds
#x variable
Microhabitat=data$Microhabitat
#y variable
Abundance=data$Abundance
#set colour of legend
Stage=data$Season
#run
ruru=ggplot(data,aes(Microhabitat,Abundance,fill=Stage))+geom_bar(stat = "identity",
position=position_dodge(),alpha=.75)
ruru
```

An alluvial plot: “ggalluvial” (Brunson and Quentin, 2023).

```
install.packages("ggalluvial")
library(ggplot2)
library(ggalluvial)
axis1=Sankey_C4$`Feeding Guild`
axis2=Sankey_C4$Locomotion
axis3=Sankey_C4$`Feeding substrate and technique`
axis4=Sankey_C4$`Paddy stage`
fill=Sankey_C4$Occurrence
ggplot(Sankey_C4, aes(axis1=axis1, axis2=axis2, axis3=axis3, axis4=axis4,
y=fill))+geom_alluvium(aes(fill=axis1), curve_type="cubic")+geom_stratum(aes(fill=NA))+geom_text(stat
= "stratum", aes(label=after_stat(stratum)))+theme_void()+theme(legend.position =
"none")+scale_fill_viridis_d()+scale_color_viridis_d()
#to flip
+coord_flip()
```

Multi-Response Permutation Procedure (MRPP): “vegan” (Oksanen et al., 2024).

```
install.packages("vegan")
library(vegan)
abundance=MRPP_Chapter_5$Abundance
Cluster=MRPP_Chapter_5$Cluster
simple.results.mrpp <- mrpp(
  dat = abundance,
  grouping = Cluster,
  permutations = 1234)
simple.results.mrpp
```

Self-Organising Map (SOM): “kohonen” (Wehren and Buydens, 2007) and “aweSOM” (Boelaert et al., 2022).

```
install.packages("kohonen")
install.packages("aweSOM")
library(kohonen)
library(aweSOM)
full.data=aweSOM_data_by_species
#select column of variables
train.data=full.data[,c("Paddy plot","Levee","Ditch and Pond","Grass and Scrubs","Tree","Artificial
substrate")]
#scale training data
train.data=scale(train.data)
#random number generator for reproducibility
set.seed(31388)
# initialisation of PCA grid
init=somInit(train.data,58, 6)
#Train SOM
iris.som=kohonen::som(train.data,grid=kohonen::somgrid(10,3,"hexagonal"))
#quality check
somQuality(iris.som,train.data)
#SOM superclasses
superclust_pam=cluster::pam(iris.som$codes[[1]],5)
superclasses_pam=superclust_pam$clustering
superclust_hclust=hclust(dist(iris.som$codes[[1]]),"complete")
superclasses_hclust=cutree(superclust_hclust,5)
#plotting (hitmap/umatrix), hitmap for number of observations per cell, umatrix is for topography distance
neighbour
awesomm=aweSOMplot(som = iris.som,type = "Hitmap",superclass = superclasses_pam)
awesomm
aweSOMplot(som = iris.som,type = "UMatrix",superclass = superclasses_pam)
aweSOMsmoothdist(iris.som)#better map for umatrix to prevent bias
awesomm$x #to view more info
#dendroSOM
aweSOMdendrogram(clust = superclust_hclust,nclass=5)
aweSOMdendrogram(clust = superclust_hclust) #without bracket
```

Moran’s I test: “ape” (Paradis and Schliep, 2019).

```
grassland.by.site.dist=as.matrix(dist(cbind(Moran_I_Grassland_birds$Lon,Moran_I_Grassland_birds$Lat)))
#inverse of matrix values replace with diagonal entries of zero
```

```

grassland.dist.inv=1/grassland.by.site.dist
grassland.dist.inv[is.infinite(grassland.dist.inv)]=0
#calc moran i
morannngrassland=Moran.I(Moran_I_Grassland_birds$`Abundance`,grassland.dist.inv)
morannngrassland

```

Modified Moran's I: calculations by Aswi et al. (2021) using R 'stats' package.

```

y=Moran_I_Grassland_birds$Lat
x=Moran_I_Grassland_birds$Lon
W=as.matrix(dist(cbind(Moran_I_Grassland_birds$Lon,Moran_I_Grassland_birds$Lat)))
Wr=W/rowSums(W)
Z=(y-mean(y))
Zw=t(Wr)%*%y-mean(y)
a=t(Z)%*%Zw
b=sqrt(t(Z)%*%Z)
c=sqrt(t(Zw)%*%Zw)
I.mod=(a/(b*c))
I.mod

```

Generalised Linear Mixed Model (GLMM): "lme4" (Bates et al., 2015).

```

rungrasslandbirds=glmer(y~1+Microhabitat+Stage+MicrohabitatXStage+(1|Monsoon)+(1|Coastal),
family=poisson(), data = GLMM_Grassland_Birds)
rungrasslandbirds
summary(rungrasslandbirds)

```