UTILIZING PASSIVE ACOUSTIC MONITORING TO INVESTIGATE OCCUPANCY PATTERNS OF BABBLERS IN NATIVE AND PLANTED FOREST IN SARAWAK, MALAYSIA

by
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ABSTRACT

UTILIZING PASSIVE ACOUSTIC MONITORING TO INVESTIGATE OCCUPANCY PATTERNS OF BABBLERS IN NATIVE AND PLANTED FOREST IN SARAWAK, MALAYSIA

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The biodiversity-rich island of Borneo, situated within the Sundaland hotspot, faces escalating threats due to deforestation and habitat fragmentation, largely driven by global demands for natural resources. Focused on the Malaysian state of Sarawak's Planted Forest Zone (PFZ), where sustainable forest management practices are implemented, this thesis explores the impacts of habitat conversion on avian species, specifically babblers. With the aid of autonomous recording units and a bioacoustics analysis, the study investigates the environmental factors influencing the occurrence of these birds in both native and planted forest. Results indicate that complex forest structures significantly influence babbler occurrence, emphasizing the importance of biodiversity conservation within managed forest landscapes. The study underscores the potential of regenerated forest fragments in plantations to support biodiversity and highlights the importance of maintaining complex native forest structures. Despite limitations in sample size, the research contributes valuable insights to avian ecology in transformed habitats, utilizing advanced monitoring techniques for informed conservation strategies in regions facing socio-economic and ecological complexities.

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INTRODUCTION

Situated within the Sundaland biodiversity hotspot, the island of Borneo holds some of the most diverse ecosystems on the planet (Sodhi et al., 2004; Laurance, 2007; Struebig et al., 2022; Reid, 1998). Its lush rainforests, mangroves, peat swamps, and a vast network of mountain streams provide rich habitat for over 670 species of birds, of which 50 are found nowhere else on Earth (Myers, 2016; Phillipps, 2011). With nearly 30% of the 430 resident bird species classified as Near Threatened, Vulnerable, Endangered, or Critically Endangered by the IUCN (Birds of the World, 2022; IUCN, 2023), the urgency for avian conservation efforts in the region becomes increasingly evident. Further emphasizing the significance of these efforts, our understanding of these birds is still evolving, largely due to the limited number of comprehensive studies on the fundamental behaviors, diets, life histories, or ecologies of avian species in Borneo.

Coincidentally, this region is under immense human pressures that often result in deforestation and habitat fragmentation (Kummer & Turner, 1994; Miettinen et al., 2011; Verma et al., 2020). Largely driven by the global demand for natural resources such as timber, rubber, and palm oil, the conversion of complex natural secondary forest to simplified monoculture habitats has had detrimental effects on biodiversity and is a leading contributor to the global extinction crisis (Laurance, 2007; Sodhi et al., 2004, 2008, 2010). Recent studies reveal a significant loss of more than 18 Mha of old-growth forests in Borneo from 1973 to 2015, over 34% (Gaveau et al., 2016, 2019).

On the northwestern part of the island sits the Malaysian state of Sarawak, where the local government and forestry department are actively planning projects to conserve wildlife (ITTO, 2018; Forest Department Sarawak, 2021a, 2021b). In an effort to alleviate the burden on threatened natural forest while still providing opportunities for economic wealth and biodiversity conservation, systems for sustainable management of forest resources have been adopted (Forest Department Sarawak, 2021; MNREM, 2016; Stuebing, 2007).

Aiming to strike a balance between timber production and protected conservation areas, industrial tree plantations of fast-growing timber species have been encouraged by the government, with a target to have 1.0 Mha planted by 2025 (Chan, 2002; Forest Department Sarawak, 2021). In early 2003, the Sarawak Forest Department began to develop a plantation project known as the Sarawak Planted Forest Zone (hereafter PFZ, Figure 1). The PFZ is completely government owned, with Grand Perfect Sdn. Bhd (GP) serving as the implementing contractor (Stuebing, 2005, 2007). It covers approximately 500,000 ha in the Bintulu Division, with over 230,000 ha of forest designated for commercial forestry use, 150,000 ha dedicated to conservation areas, and 110,000 ha classified as Native Customary Rights land (Stuebing, 2007).

Commercial forest groves throughout the PFZ consist mainly of fast-growing exotic species like acacia (*Acacia mangium),* eucalyptus *(Eucalyptus pellita),* and albizia *(Paraserianthes falcataria)*, while allowing designated areas of natural forest to regenerate (Stuebing, 2007). The repercussions of forest conversion on biodiversity conservation have ranged from moderate to severe (Carnus et al., 2003). Biodiversity surveys have indicated that a reasonable number of vertebrate species could endure within these man-made habitats, although they do not encompass a comprehensive reflection of the entire forest ecosystem (Duff et al., 1984; Stuebing & Gasis, 1989, Mitra and Sheldon, 1993; Shadbolt & Ragai, 2010; Sheldon et al. 2010; Sheldon & Styring 2011; Styring et al., 2018).

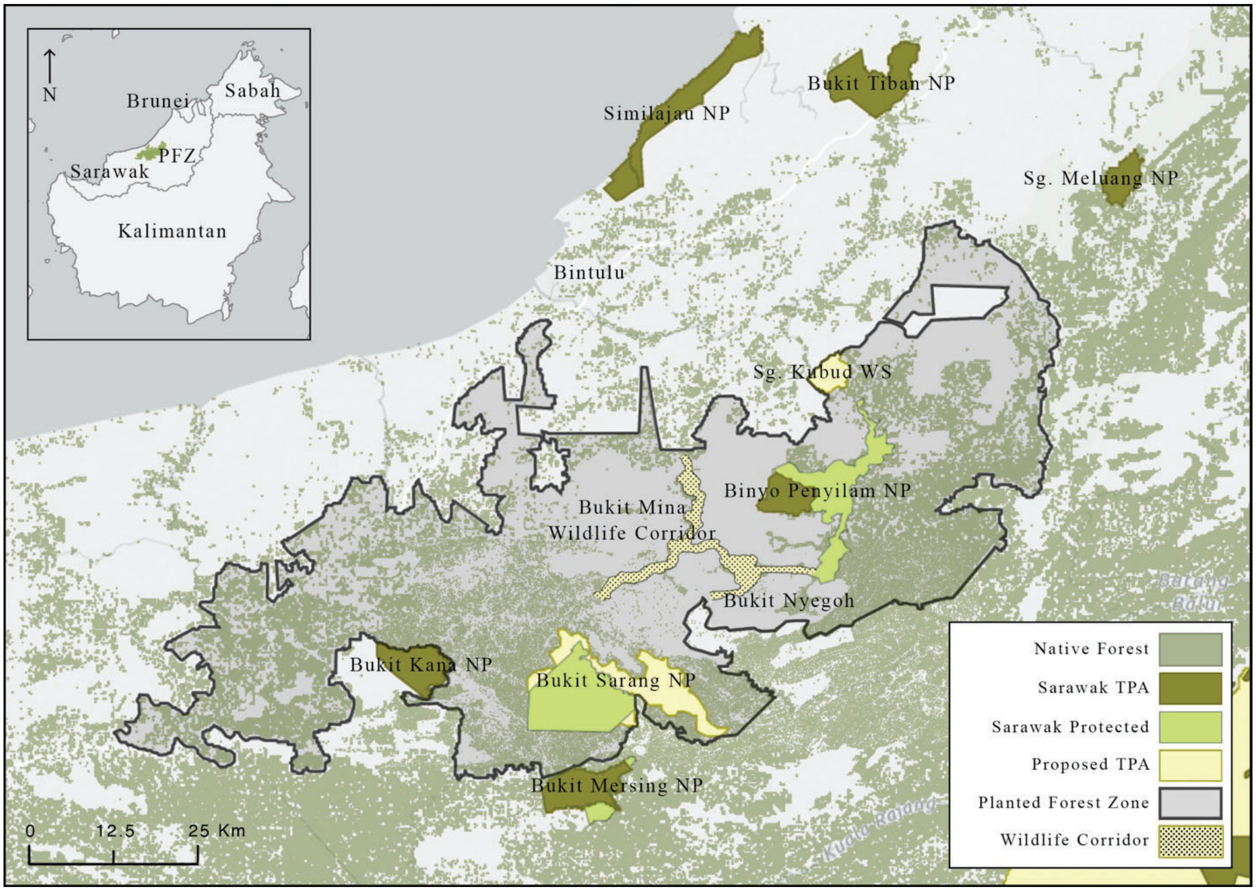

Figure 1. Map of Sarawak Planted Forest Zone and adjacent area. The region identified as native forest underwent logging over 30 years ago. TPA refers to Totally Protected Area; SPF refers to Sarawak Planted Forests. Proposed TPA is designated as Conservation Area but lack any formal protection. (Adapted from Styring et al., 2022).

While the planted forest landscape offers unique conservation benefits for wildlife, habitat fragmentation is inevitable, and little is known about how this impacts local wildlife. Forest fragmentation and its associated edge effects emerge as critical conservation concerns, wielding significant influence over habitat availability and holding the potential to profoundly shape biotic interactions (Broadbent et al., 2008; Malcom, 1994; Murcia, 1995; Robinson et al., 1995; Şekercioğlu et al., 2002; Sodhi et al., 2008).

For some, planted forests present a chance to alleviate pressure on natural forests in light of escalating demand and diminishing resource. Conversely, for others, they signify an extended exercise of corporate influence on both land and natural assets to the disadvantage of local communities—a demonstration of immediate financial greed above long-term sustainable efforts. Although the ongoing dispute about the societal worth of industrial plantations is unlikely to be settled in the immediate future, it is undeniable that plantations as a landscape element will persist. Nevertheless, plantations have the capacity to implement management plans that support biodiversity conservation (Brown et al., 2013; Fimbel et al., 2013; Hon & Shibata, 2013; Jennings et al., 2003; Stuebing, 2007). Regenerated forest fragments have the potential to harbor considerable amounts of biodiversity and can serve as connectivity between larger areas of native forest in a monoculture setting (Ancrenaz et al., 2021; Freemark & Merriam, 1986; Lambert et al., 2002; Martensen et al., 2012; Matos et al., 2020; Meijaard et al., 2005).

A fundamental step in conserving biodiversity in this landscape is identification of existing habitat areas that could potentially sustain populations of sensitive and threatened species. To understand conversion effects and effectively manage biodiversity, it is essential to identify species inhabiting plantations, identify which plantation species harbor more forest dependent organisms, and understand the environmental variables that influence spatial or temporal variation in species abundance or occurrence (Chazdon et al., 2009; Estrada et al., 1997; Waltert et al., 2004).

Birds often serve as indicator species because their populations reflect the health of ecosystems, and they respond rapidly to environmental changes (Fleishman et al., 2005; Gregory et al., 2003). Many species of birds produce a variety of songs and calls to communicate breeding, feeding and territorial demands. These species-specific acoustic signals can serve as a reliable indicator for species occurrence, abundance, and species richness (Aide et al., 2017), providing researchers with opportunities to study an environment through bioacoustics monitoring. However, many acoustic monitoring techniques often require multiple surveyors and labor-intensive field work to cover an ecosystem efficiently. Autonomous recording units (ARUs) offer an alternative and versatile method of sampling. Weatherproof devices can be programmed and deployed in an environment for an extended amount of time, providing opportunity to capture cryptic species that can easily go undetected during traditional surveys (Heinicke et al., 2015; Hill et al., 2018; Rosenthal & Ryan, 2000; Shonfield & Bayne, 2017). Moreover, they allow researchers to monitor at large spatial and temporal scales, contributing to analyses of long-term population trends needed to inform future conservation efforts and plantation management plans (Browning et al., 2017; Riede, 1998; Sugai et al., 2019; Wrege et al., 2017).

This thesis aims to provide a better understanding of the intricate relationship between babblers and their habitat preferences within both native and planted forest fragments in the Sarawak Planted Forest Zone. Through a bioacoustics analysis, this research aims to identify and understand the ecological factors influencing the occupancy patterns of these bird species, shedding light on the dynamics of their habitat preferences across different forest types. I hypothesize that bird and plant community complexity are correlated and connect the occupancy of each grove to the physical structure of the respective sites (MacArthur & MacArthur 1961; Hanowski et al., 1997). This exploration not only contributes to our understanding of the ecological interplay within these forested landscapes but also holds the potential to inform targeted conservation strategies and sustainable land-use practices for the benefit of both avian biodiversity and ecosystem health.

LITERATURE REVIEW

SUNDALAND

The Sunda Continental Shelf, hereafter referred to as Sundaland, is an extension of South-east Asia's mainland (Figure 2). It is comprised of the Thai-Malay Peninsula, Sumatra, Borneo, Java, Palawan, and thousands of smaller islands (Molengraaff, 1921). To the northeast, Sundaland is distinguished from the Philippine islands by Huxley's Line (Esselstyn et al., 2010). To the east, it is separated from Wallacea and the Sahul Shelf (Australia and New Guinea) by the deep oceanic trench of the Makassar Strait, delineating Wallace's Line (Lohman et al., 2011; Whitmore, 1981; Wallace, 1860). To the west, it is defined by the Java Trench, a deep and seismically active subduction zone. Much of the region is covered by the South China Sea, the Gulf of Thailand, and the Java Sea. Sitting between the Eurasian, Australian, Philippine, and Pacific plates, is one of the most tectonically dynamic and volcanic regions of the world. (Bellwood 2007; Hall & Morley, 2004; Metcalfe, 2017; Eaton et al., 2017).

Sundaland has a complex geologic history and sea level change has played an important role in altering the area and configuration of land (Hanebuth et al., 2000, 2009; Moore, 1982). The depth of the landmass varies, but it is generally a shallow region with depth ranging from a few meters to around 50 meters in some areas. At times during the Pleistocene epoch, which ended some 10,000 years ago, the polar ice caps underwent recurrent cycles of melting and freezing (Hopkins, 1982; Yang & Xie, 1984). During instances when sea levels decreased by over 100 meters, most of the shelf was exposed as dry land, forming its own 'Sundiac subcontinent' (Heaney, 1991; Morley, 2000, Hanebuth et al., 2000; Voris, 2000). This exposed area effectively created land bridges, connecting islands to one another and to the mainland (Bird et al., 2005; Heaney, 1991). This connection allowed biological communities to colonize new land and has profoundly influenced the fauna and flora of the region (Bellwood, 2007; Heaney, 1984; Meijaard, 2003; Morley, 2000; Sheldon et al., 2015). One notable phenomenon of the region is the Riau Pocket, an area along present-day Borneo's northwestern coast extending to the southern tip of the Malay peninsula, which remained a rainforest refuge during the coldest glacial periods with lowest sea level (MacKinnon et al., 1996; Phillipps, 2011; Sheldon et al., 2015; Wong, 1998). This has been reflected in distinct vegetation patterns across Borneo during this period, with savanna dominating the southwestern part and rainforests covering the northern and eastern regions (Bird et al., 2005; Heaney, 1991; Morley, 2000; Wurster et al., 2019).

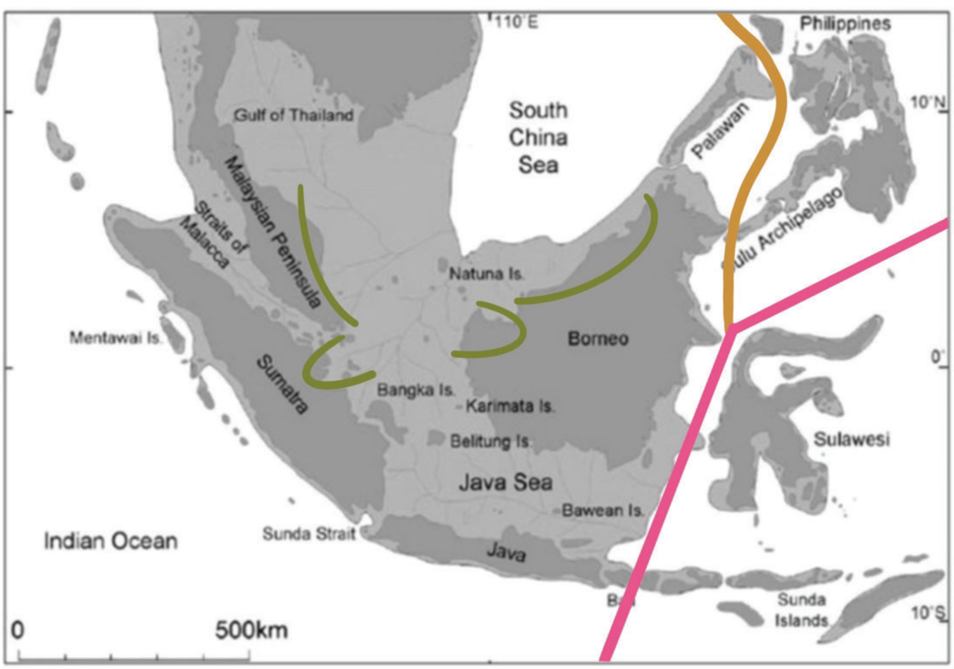

Figure 2. Map of Sundaland. Modern day landmasses shown in dark grey. Land exposed during Last Glacial Maximum in light grey. Wallace's Line in pink. Huxley's Line in orange. Riau Pocket in green (adapted from Bird et al., 2005; Gruweir et al., 2015).

When ice sheets retreated and sea levels stabilized during the Holocene epoch, the giant landmass became many smaller islands and Sundaland developed into a diverse and ecologically rich region (Anderson & Muller, 1975; Hunt & Premathilake, 2012). Tropical rainforests, mangroves, peat swamps, and extensive coral reefs flourished during this time, supporting a vast array of plant and animal life. Human populations also began to establish settled communities, engaging in agriculture and shaping the landscapes through various practices (Maloney et al., 2022).

The rich biodiversity of the region has attracted naturalist explorers like Alfred Russel Wallace, Thomas Huxley, Odoardo Beccari, and Robert Shelford (Beccari, 1904; Harrison, 1970; Mayr, 1944; Shelford, 1917). In the mid 1800's, Wallace noted that numerous avian species in the Sunda region, like hornbills and barbets, are absent in Sulawesi, and that several Sulawesi and Australian species, such as lorikeets and honeyeaters, are not found in Borneo. This observation led him to propose a biogeographical boundary influenced by geological and environmental factors, known as Wallace's Line (Mayr, 1944; Wallace, 1860; Whitmore, 1981). This boundary demarcates distinct zoogeographical regions based on differences in flora and fauna of the Asian biogeographic realm to the west of the marine Makassar trench, and the mixed fauna of the Wallacea region to the east (Ali & Heaney, 2021; Harrison, 1970; Wallace, 1860). Huxley's later extension of the Wallace line includes the Philippines (Esselstyn et al., 2010). Both lines underscore the profound impact that geographical history and isolation have had on the evolution and distribution of species in the region.

In present times, this hotspot is one of the biologically richest regions on Earth (Mittermeier, 1999; Myers et al., 2000; Raes et al., 2009; Reid, 1998; Struebig et al., 2022; Whitten et al., 2004) and the biodiversity and distribution of plant and animal life continues to captivate and inspire naturalists and researchers alike (Heaney 1984, 1986; Lim et al. 2011; Lim & Sheldon, 2011). With unparalleled levels of species endemism and ecological complexity, it is home to over 25,000 species of vascular plants, 770 bird species, over 380 mammal species, more than 450 species of reptiles, 240 species of amphibians, and over 1,000 species of freshwater fish (de Bruyn et al., 2014; Meijaard & Nijman, 2003; Raes et al., 2009; Whitten et al., 2004). Iconic species such as orangutans, rhinoceroses, and pygmy elephants inhabit the region. The area's ecosystems provide critical services such as water regulation, climate control, and food resources for millions of people.

Recently, challenging forest conditions have become prevalent across much of Southeast Asia (Kummer & Turner, 1994; Miettinen et al., 2011). Rapid habitat loss, agriculture expansion, illegal wildlife trade, and climate change pose severe threats to biodiversity, making conservation efforts crucial to preserving the unique and invaluable ecosystems of Southeast Asia (de Bruyn et al., 2014; Koh & Wilcove, 2008; Mittermeier, 1999; Sodhi et al., 2004; Wilcove et al., 2013).

BORNEO

The island of Borneo is politically partitioned into three nations— The northern part includes two Malaysian states, Sabah to the northeast and Sarawak to the northwest (the other 11 states are situated in Peninsular Malaysia, 650 km west across the South China Sea). Brunei occupies a small area along the northwest coast, surrounded by Sarawak. And the Indonesian provinces of Kalimantan Tengah (Central Kalimantan), Kalimantan Utara (North Kalimantan), Kalimantan Timur (East Kalimantan), Kalimantan Selatan (South Kalimantan), and Kalimantan

Barat (West Kalimantan) occupy nearly three-quarters of Borneo to the south (Figure 3). There are also thousands of smaller offshore islands.

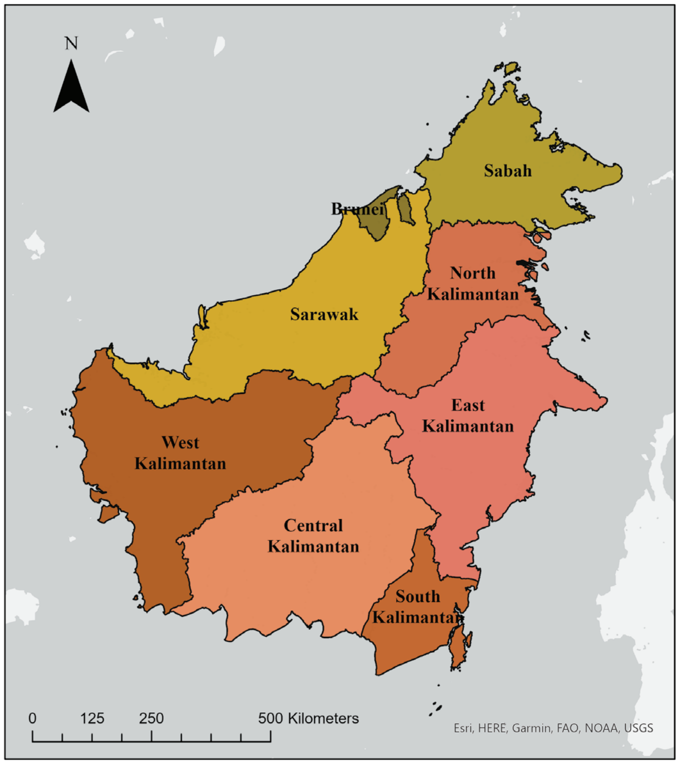

Figure 3. Map of Borneo country boundaries.

The Indigenous peoples of Borneo are ethnically and culturally diverse, maintaining distinct languages, traditions, and belief systems. Shared social elements include traditional dances, music, and festivals that celebrate the rich heritage of the Bornean people (Hose, 1984; Sada et al., 2019). Many of the Indigenous communities engage in activities aligned with the diverse landscapes of Borneo, such as local farming, gardening, fishing, and hunting (Brosius, 1991; Mulyoutami et al., 2009; Sutlive, 2001). Economic activities now extend beyond traditional practices, with industries such as palm oil, logging, and tourism playing significant roles in shaping the livelihoods of the people.

CLIMATE

Lying between 7°N and 4°S, the island straddles the Equator and has a predominately tropical climate with uniform temperature, high humidity, and copious rainfall throughout most of the year. Temperatures are generally stable, with daytime temperatures in the lowlands sitting around 28°C – 32°C, although there is a steady decrease as elevation rises toward the mountainous inland region. There is little seasonal variation, with longest and shortest daylight hours differencing only 45 minutes (Eaton et al., 2017). The "wet" monsoon season (November – April) brings the heaviest rainfall, averaging 15 inches a month, while the "dry" monsoon season (May – October) still sees an average of 8 inches a month (Sodhi et al. 2017). Higher totals are found over the interior mountains and outer slopes. Storms commonly move in from the sea and the coastal regions have their own unique patterns. The southeastern coast of the island has the driest climate, while the northwest is considered a high rainfall zone.

El Niño and La Niña are opposite phases of the El Niño-Southern Oscillation cycle (ENSO), which is a climate phenomenon in the tropical Pacific Ocean, occurring typically every two to seven years (McPhaden et al., 2006; Sarachik & Cane, 2010; Timmermann et al., 2018). The event is caused by variations in sea surface temperatures and atmospheric pressure. Under normal conditions, the trade winds blow from east to west across the equatorial Pacific, causing warm surface waters to pile up in the western Pacific near Indonesia. This warm water leads to lower sea level atmospheric pressure. During El Niño events, there is a reversal of the typical easterly trade winds, allowing the warm surface waters in the western Pacific to spread eastward along the equator toward the central and eastern Pacific. As the warm water moves eastward, it changes atmospheric circulation patterns, leading to rising air and changes in rainfall and weather patterns. La Niña is characterized by stronger-than-average easterly trade winds These stronger winds enhance the normal conditions, causing an upwelling of colder oceanic waters in the central and eastern Pacific. The increased upwelling brings cooler-than-average sea surface temperatures to the central and eastern equatorial Pacific.

Borneo tends to experience drier-than-average conditions during El Niño events and wetter-than-average conditions during La Niña events (Gomyo & Kuraji, 2009). The El Niño season is associated with a warming of sea surface temperatures, leading to decreased rainfall in some areas. This reduced rainfall can elevate the risk of wildfires, particularly in areas with dry vegetation. Borneo has witnessed increased incidences of forest fires during El Niño, contributing to air pollution and habitat destruction (Chapman et al., 2020; Chen et al., 2016; Sloan et al., 2017; Wooster et al., 2012). La Niña is characterized by cooler-than-average sea surface temperatures, often leading to increased rainfall in certain regions. The surplus rainfall can result in flooding and landslides, impacting communities and ecosystems (Hidayat et al., 2018; Tangang et al., 2017). The increased runoff can also affect river systems and water quality. It's important to note that while these are general trends associated with El Niño and La Niña events, the specific impacts can vary depending on the strength and duration of the events, as well as other regional climate influences (Capotondi & Sardeshmukh, 2015). Additionally, climate change can modify the patterns and intensities of these events, potentially influencing their impacts on Borneo and other regions. (Curran et al., 1999; Harrison, 2001; Wooster et al., 2012).

HABITATS

A prominent characteristic of Borneo is the central mountain range that divides the island into a northern and southern part, contributing to the geographical diversity and influencing the climate patterns and ecosystems on either side (de Bruyn et al., 2014; Sheldon et al., 2015). Another major feature of the island is its extensive and intricate river system, originating in the central highlands and cascading down towards the coasts in all directions (Phillipps 2011; Smythies, 1999). These once clear mountain streams become turbid and acquire a brownish hue from silt and peat stains as they approach the lowlands, where the shallow bar at the mouth extends towards the sea. This river system is of significant importance for the island's ecology and human communities. They sustain diverse ecosystems, provide habitats for numerous species, and serve as crucial water sources for local populations, supporting agriculture, transportation, and various aspects of daily life (Langub, 2020; Langub & Ishikawa, 2017; Ritzema & Wösten, 2002).

Some of Borneo’s native habitat types include primary and secondary lowland rainforests, sub-montane and montane forests, mangrove forests, peat swamp forest, heath forest (kerangas), freshwater swamps, rivers, and lakes (Myers, 2016; Phillipps, 2011; Smythies, 1999). Primary forest is considered to have had little or no human disturbance. Secondary forest is forest in which large trees have been removed but there has been some regeneration (Chokkalingam & De Jong, 2001). Lowland rainforest is the most extensive and supports the greatest biological diversity on the island. With over 15,000 species of flowering plants, the exceptionally high floral diversity is comparable to that of New Guinea or the Amazon. Throughout all of Borneo, soil characteristics are important factors in influencing floristic richness and forest composition (Ashton & Hall, 1992; Palmiotto et al,. 2004, Paoli 2008). Heath forests, peat swamp forests, and forests growing on limestone and ultrabasic soils share a common trait of nutrient deficiency and limitations in drainage. These environments typically support a reduced diversity of species compared to the more varied mixed dipterocarp forests. (Holmes & Wall 1989, Myers 2016, Eaton et al., 2017, Smythies 1999).

The presence of modern humans in the area spans over approximately 50,000 years, and agricultural practices involving forest alterations likely have roots dating back at least half of that period (Barker & Badang, 2013; Kusmartono et al. 2017, Stuebing, 2005). Relatively recently, large-scale alterations to terrestrial habitat distributions have occurred, with Borneo's forests undergoing significant modifications from their "pristine" condition, leaving ancient forest only in small remote patches (Primack and Hall, 1992; Johns, 1992; Stuebing, 2005). The last four decades in particular have witnessed intensified agricultural practices and spreading urbanization, resulting in the establishment of novel man-made habitats that frequently lack distinct or specialized fauna and flora communities (Drummond & Taylor 1997; Gaveau et al., 2014; Gaveau et al., 2016; Ichikawa, 2007; Kaur, 1998; Reynolds et al 2011; Smythies, 1963; Wicke et al., 2011).

LOWLAND AND SUBMONTANE MIXED DIPTEROCARP FOREST (sea-level to 1,000m)

The lowland dipterocarp rainforests of Borneo support the greatest biological diversity, often containing upward of twelve hundred tree species dominated by the Dipterocarpaceae family (Slik et al., 2003). In addition to a lush plant community, they support the greatest diversity of birds, mammals, and insects, many of which are completely confined to or dependent to some degree on this forest type (Burner et al., 2019; Lambert et al., 2002; Phillipps, 2011; Mitra & Sheldon 1993; Smythies, 1999; Wells et al., 1979).

Reaching up to 60 m when mature, dipterocarp trees thrive on well-drained soil and can usually be found up to an altitude of around 1,000 m (Ashton & Hall, 1992; Smythies, 1999; Wells, 2007). They are named for their two-winged fruits (In Greek di = two; ptero = wing; carpos = seed). Many species of dipterocarp flower and fruit synchronously at intervals of several years, a phenomenon called mast fruiting (Ashton et al., 1988; Janzen, 1974; Visser et al., 2011). During mast fruiting occasions, communities of dipterocarps will all begin to flower and spend a few weeks to further mature their fruits together. Within a few weeks, the fruits drop to the forest floor and immediately begin germination. It is hypothesized that irregular fruiting may increase seed survival and pollination efficiency (Kelly, 1994; Kelly & Stork, 2002). Some animals will migrate in pursuit of mast fruiting events and some species, like hornbills, rarely breed during non-masting years (Curran & Leighton, 2000; Myers, 2016; Phillipps, 2011; Smythies, 1999).

Many other types of trees occur throughout the lowlands and forests are far from uniform across the island. The forest layers display a marked stratification, distinguishable as forest floor, lower, middle, upper and emergent stories (Smythies, 1999; Wells, 2007). Woody climbing plants, small flowering plants and ferns commonly grow as epiphytes on larger trees. Massive strangler figs (*Ficus spp*.) can reach over 10 meters in circumference as they wind themselves around their host tree. The fruit from these fig trees is a major food source for many animals (Kinnaird et al., 1996; Lambert, 1989; Naniwadekar et al., 2015).

The lowland dipterocarp forests are very important commercially (Cropper & Putz, 2017; Sist et al., 2013; Widiyono, 2021) In the last few decades they have been exploited for timber and are rapidly being replaced by plantations, in particular oil palm (Gaveau et al., 2016). They are one of the most threatened habitats in the region and few large intact areas remain. A coveted species within the timber industry is the Borneo ironwood (Eusyderoxylon zwageri), commonly referred to as Belian wood (Peluso, 1992). Renowned for its exceptional durability, density, and resistance to decay, Belian wood is highly sought after for various construction and woodworking applications (Kurokawa et al., 2003; Wong et al., 2005).

Species dependent upon lowland dipterocarp forests include orangutans (*Pongo pygmaeus*), Sumatran rhinoceros (*Dicerorhinus sumatrensis*), the Borneo pygmy elephant (*Elephas maximus borneensis*), leopard cat (*Cynocephalus variegatus*), proboscis monkey (Nasalis larvatus) and the Bornean tarsier (Tarsius bancamus), among many others (Corlett, 2007; Das et al., 2018; Hanya et al., 2020; McConkey et al., 2022). Bird groups commonly found in lowland dipterocarp forests include hornbills, barbets, babblers, kingfishers, woodpeckers, sunbirds, and flycatchers (Myers, 2016; Phillipps, 2011; Smythies, 1999; Wells, 2007).

MONTANE FORESTS (>1000m)

The altitudinal gradient in Borneo's montane forests fosters a broad spectrum of microenvironments and ecological niches (Grytnes et al., 2006). The seclusion of numerous peaks mirrors islands within a vast expanse of lowland forest, contributing to the evolution of many distinct species (Gawin et al., 2014; Heaney, 1991; Sheldon et al., 2015). There is a discernible shift in the biodiversity composition from hill and submontane forest around 900 m (Aiba et al., 2004; Burner et al., 2019; Sheldon et al., 2015; Slik et al., 2009). At this elevation, mossy cloud forest, also known as montane forest, emerges along ridge tops. Another distinctive transformation occurs at >1,800 m (upper montane forest), characterized by stunted trees dripping with moss and epiphytes, and the proliferation of berry-bearing bushes (Phillipps, 2011; Smythies, 1999). Montane forests feature a diverse array of vegetation, encompassing broadleaf evergreen trees, mosses, ferns, and various plant species well-suited to cooler climatic conditions (Aiba et al., 2004; Ohsawa, 1991; 1995). More than 60% of the endemic bird species on the islands are inhabitants of montane regions (Myers, 2016; Phillipps, 2011; Smythies, 1999). As altitude increases, tree height and wildlife diversity decreases. Consequently, numerous lowland bird species extend into hilly terrain but become less prevalent as elevation increases into the highlands (Sheldon et al., 2015). Characteristic species include Bulwer's Pheasant, Orange-breasted Trogon, Hose's Broadbill, and Blue-banded Pittas (Smythies, 1999).

Montane forests play a crucial role in watershed protection. They regulate water flow, reduce soil erosion, and contribute to the overall hydrological balance of the region (Carlson et al., 2014; Salinas et al., 2021). The health of montane ecosystems is directly linked to the availability of freshwater resources downstream, making their conservation vital for both ecological integrity and human well-being. Montane forests, like many other habitats in Borneo, face threats from human activities such as logging, agriculture expansion, and infrastructure development (Brooks et al., 1997; Miettinen et al. 2011; Sodhi et al., 2004; Wilcove et al., 2013; Wong, 1998). Climate change also poses challenges, as shifts in temperature and precipitation patterns can impact the composition and structure of these ecosystems (Seidl et al., 2017).

MANGROVES

Most of the region's shallow brackish water and muddy estuaries support mangrove forests, dominated by five or six tree species with roots submerged in water (Giri et al., 2011, 2015; Smythies, 1999). The vegetation created by clusters of Nipah palm (*Nypa fruticans*) is also recognized as mangrove, despite its distinctive structural characteristics (Tsuji et al., 2011). Mangrove tree species exhibit impressive adaptations that enable their survival in otherwise inhospitable conditions (Kathiresan & Bingham, 2001). These adaptations include a sophisticated system that effectively filters much of the salt and a complex root system that anchors the tree securely in the shifting sediments at the water-land interface (Srikanth et al., 2016).

Mangroves not only manage to survive in challenging conditions, but this ecosystem also supports an incredible diversity of creatures. About 21 bird species are largely or exclusively dependent on this habitat (Wells, 1985; Smythies, 1999) and upward of 135 bird species have been recorded in mangroves, including the Oriental White-eye, Great Tit, Abbott's Babbler, Ruddy Kingfisher, Mangrove Blue Flycatcher, Lesser Adjutant, and nesting herons and egrets (Edwards & Parish, 1988; Eve & Guigue, 1989; Phillipps, 2011; Smythies, 1999). Charismatic mammals found in mangroves includes the proboscis monkey (*Nasalis larvatus*), a Bornean endemic (Kawabe & Mano, 1972). Mangroves play a pivotal role as an essential habitat for both terrestrial and marine fauna and simultaneously contribute significantly to the preservation of the coastline's structure. Additionally, they store disproportionately high densities of carbon compared with other ecosystems (Donato et al., 2011; Siikamäki et al., 2012). Currently, mangrove habitat faces escalating challenges, with mounting pressures stemming from timber extraction and the conversion of mangrove areas into prawn ponds (Giri et al., 2011; Richards & Friess, 2016; Sukardjo et al., 2013; Valiela et al., 2001; Wong et al., 2020).

HEATH / KERANGAS

In substantial sections of Sarawak and Brunei, the soil is poor in nutrients and consists mainly of coarse silica (Katagiri et al., 1991, Newbery et al., 1986) These soils support a forest that is more open and uniform in structure, with trees being generally thin and stunted. In Sarawak, heath forests are dominated by *Cratoxylon, Calophyllum, and Rhodamnia* trees, and many of the plants have toxic leaves (Newbery, 1991; Miyamoto et al., 2016). Often birdlife in heath forests is a subset of that of nearby lowland dipterocarp or peat-swamp forests and includes species such as Dark-necked Tailorbird, Cream-vented Bulbul, Hook-billed Bulbul, Grey-chested Jungle Flycatcher, and Scarlet -breasted Flowerpecker (Myers 2009; Phillipps, 2011; Smythies, 1999).

LIMESTONE FORESTS

Limestone (or karst) forest is characterized by the presence of limestone formations, which consist of sedimentary rocks primarily composed of calcium carbonate (Clements et al., 2006; Tolentino et al., 2020). These formations can take various forms, such as hills, cliffs, caves, and sinkholes. Frequently, these terrains feature an intricate underground drainage network, where rivers literally disappear into the rock and re-emerge, sometimes at considerable distances. Plants in limestone forests often exhibit adaptations to the harsh conditions, including limited soil and water availability (Chin, 1977; Yong, 2004). Some species may have specialized mechanisms for nutrient uptake.

Some limestone caves in Borneo are home to large bat colonies, playing a crucial role in the ecosystem through pollination and seed dispersal (Abdullah et al., 2007). Additionally, swiftlets (genus *Aerodramus*) often roost and nest in areas characterized by limestone formations

(Mansor et al., 2011; Mukhlisi et al., 2021; Tolentino et al., 2020). Their edible saliva nests are considered a delicacy and are one of the most expensive animal resources that humans consume (Thorburn, 2015). These limestone outcrops are under immense pressure from mining interests, local harvest of animal resources, land conversion, and over-extraction of timber products (Clements et al. 2006; Struebig et al. 2009).

PEAT SWAMP FOREST

Peat swamp is the dipterocarp forest found along the coastal lowlands, thriving atop a substantial layer of poorly drained marshy peat (Anderson, 1961; Andriesse, 1988; Bruenigh & Droste, 1995; Phillips, 1998). They originate from the buildup of decomposed plants, sometimes reaching depths of up to 20 meters, in naturally low-oxygen conditions, resulting in high acidity (Cranbrook & Edwards, 1994). These trees often boast stilt and air-breathing roots or pneumatophores, and the forest itself is drained by rivers carrying acidic black water. The ground is typically marshy underfoot and may experience seasonal flooding. This forest type exhibits a somewhat simpler structure compared to nearby mixed dipterocarp forests, showcasing significantly reduced plant diversity (Anderson, 1961; Bruenigh & Droste, 1995; Cranbrook & Edwards, 1994). The interior of peat swamp forest is characterized by a uniform canopy, the absence of a middle story, and a depauperate and thorny lower story.

Although peat swamps lack any endemic bird species (Sheldon et al., 2014) some species are frequently found in this environment compared to nearby dipterocarp forests located in drier areas. It is conceivable that the abundance of these species in peat swamp forests may be because they face less competition from other organisms that avoid or are less adapted to that specific habitat (Sheldon et al., 2014). Notable examples include the Hook-billed Bulbul, Grey-breasted

Babbler, and Scarlet-breasted Flowerpecker (Gaither, 1994; Sheldon et al., 2014; Smythies, 1999). Other numerous lowland avian species are present, albeit in low densities, including the Wrinkled Hornbill, Fiery Minivet, Crestless Fireback, and Abbott's Babbler (Gaither, 1994; Posa, 2011; Posa & Marques, 2012). The Bornean Bristlehead was once primarily associated with peat swamp forests but is now recognized to inhabit a broader range of forest types (Smythies, 1999).

During periods of drought or after logging, dried soil is extremely susceptible to fires and peat swamp communities can easily be destroyed (Siegert et al., 2001; Page et al., 2009). In addition to fire, peat swamp faces threats from deforestation and logging, drainage for agriculture, changes in climate patterns, introduction of invasive species, and pollution (Dommain et al., 2016; Mishra et al., 2021).

GRASSLANDS

The most extensive grasslands are found mainly in Sabah, West, and Central Kalimantan. There are no large areas of grasslands in Sarawak (Shim, 1993; Smythies, 1999). Grasslands in Borneo occur both naturally and anthropogenically, resulting from various factors such as fire, seasonal flooding, or specific soil conditions (Brookfield et al., 1995; Garrity et al., 1996; Turvey, 1994). Fires, in particular, play a crucial role in shaping and maintaining grassland habitats in the region. Grasslands dominated by *Imperata cylindrica*, also known as alang-alang, are well-adapted to fire-prone environments and serve as an indication of the challenges prompting shifts in land use in Borneo (Dove 1981). Other plants, including scattered trees and shrubs, may also be present.

The recent chronicle of fires in Borneo has left a significant imprint on vegetation, impacting various lowland forest categories, with a pronounced influence on peat swamp and freshwater swamp forests (Chen et al., 2016; Sloan et al. 2017; Wooster et al., 2012). Large-scale agricultural activities, particularly in regions like West and Central Kalimantan, may contribute to the creation of extensive grasslands. Additionally, oil palm plantations and other monoculture crops can replace natural habitats with grassy landscapes, illustrating the pressures for change in Bornean land use (Brookfield et al., 1995; Dove 1981).

PADDY FIELDS

Paddy fields, also known as rice fields, are cultivated areas where rice is grown. In Borneo, the cultivation of paddy fields has been an integral part of the agricultural landscape for centuries and is deeply woven into the cultural fabric of the region (Freeman, 1955; Padoch, 1988; Kendawang et al., 2005). Paddy fields are dispersed across various regions of Borneo, with varying landscapes, including lowlands, hill, and uplands. In certain hilly or mountainous regions, the cultivation of rice follows a traditional practice known as shifting cultivation (Barker et al., 2018; Freeman, 1955). This method involves periodically burning forested hillsides, typically at intervals exceeding 10 years, followed by planting with local varieties. These hillside terracing techniques create flat surfaces and helps manage water flow and prevent soil erosion on sloped terrain.

The scarcity of freshwater habitats has constrained the proliferation of waterbird communities in Borneo. However, the recent augmentation of irrigated rice cultivation has precipitated a surge in the population of migratory waterbirds, including species like Common

Moorhen, Purple Swamphen, Yellow Bittern, and various Egrets (Phillipps, 2011; Smythies, 1999).

TREE PLANTATIONS AND OIL PALM

Much of Southeast Asia is confronting a severe and escalating crisis of habitat loss, primarily driven by rapid urbanization, agricultural expansion, logging, and infrastructure development (Gibbs et al., 2010; Kummer & Turner, 1994; Miettinen et al. 2011; Sodhi et al. 2004; Wilcove et al., 2013). Vast tracts of tropical rainforests have been converted into agricultural lands, particularly for oil palm (*Elais guineenis*), rubber (*Hevea brasiliensis*), eucalyptus (*Eucalyptus sp*.), acacia (*Acacia mangium*.), and albizia (*Paraserianthes falcataria*) plantations.

Debates persist regarding the interplay between the expansion of plantations and the occurrence of deforestation (Meijaard et al., 2013, 2018). While some plantations supplant mature forests, a noteworthy proportion utilizes land that had been cleared of forests many years ago—highlighting the nuanced nature of plantation developments and their varying impacts on deforestation (Gaveau et al., 2019). The assessment of such consequences has proven to be intricate and subject to controversy.

The impact of the spread of these industrial forests on wildlife populations has been particularly detrimental (Fitzherbert et al., 2008; Sodhi et al., 2004; Sodhi et al., 2008). This extensive habitat modification not only directly displaces numerous species but also fragments ecosystems, isolating populations and disrupting vital ecological processes (Hanowski et al., 1997; Hill et al., 2011; Lambert et al., 2002; Malcom, 1994; Martensen et al., 2012; McShea et al., 2009). Moreover, the construction of roads and other infrastructure further exacerbates habitat fragmentation, making it increasingly challenging for wildlife to find suitable habitats. The consequences of habitat loss are profound, resulting in increased carbon emissions (Henders et al., 2015), the disruption of intricate ecological relationships (Drescher et al., 2016), and a heightened risk of biodiversity loss in one of the world's most biologically rich regions (Edwards et al., 2014; Meijaard et al., 2020).

Between 2000 and 2017, the primary forests in Borneo witnessed a decline of 14%, amounting to a loss over 6 million hectares. Simultaneously, Borneo saw an increase of 6.20 million hectares in industrial plantations, with 88% dedicated to oil palm cultivation and 12% to pulpwood (Gaveau et al., 2019). Currently, over 87% of global oil palm production takes place in Indonesia and Malaysia (FAO, 2023).

Acacia, albizia, and eucalyptus plantations in Borneo are often established for commercial purposes, particularly for the production of wood pulp and paper. These “renewable” species are commonly cultivated for their fast growth and suitability for pulp and paper production. Remarkably, these groves establish a relatively high canopy, exceeding 7 meters at three years and reaching over 20 meters when mature (Pedley, 1975), and provide enough space for a substantial understory, sometimes even midstory (Mitra & Sheldon, 1993; Sheldon et al., 2010; Styring et al., 2011). Albizia has exhibited a proclivity for hosting a more diverse array of bird species in comparison to acacia of similar age (Mitra & Sheldon, 1993; Sheldon & Styring, 2011). This phenomenon is possibly attributed to Albizia's elevated structural intricacy and presumably more affluent invertebrate community, thereby presenting an enticing food source for avian species with insectivorous and omnivorous dietary preferences (Mitra & Sheldon, 1993; Sheldon et al., 2010; Styring et al., 2011; Styring et al., 2018). In mature acacia groves, the presence of secondary flora serves as an attraction, resulting in a diversified community of nectarivores and frugivores (Styring et al., 2011).

Bird species of planted forests encompass a diverse mix of open-country and coastal forest avian species, such as the Magpie Robin, Spotted-necked Dove, Glossy Starling, Greater and Lesser Coucals, and certain insectivorous birds managing to persist in proximity to native forests (Phillipps, 2016; Smythies, 1999). Within oil palm environments, approximately 30 species can be identified, with 14 resident birds capable of breeding and thriving in this habitat, including the Scaly-Breasted, Dusky, and Chestnut Munias, Yellow-bellied Prinia, Magpie Robin, as well as Grass and Barn Owls (Edwards et al., 2010; Mitra & Sheldon, 1993; Sheldon et al., 2010; Smythies, 1999; Phillipps, 2011).

Both tree and oil palm plantations in Borneo are part of the larger context of industrial forestry, contributing to economic development but also raising environmental and social challenges. Industrial plantations create employment opportunities in forestry-related activities, including planting, harvesting, and processing. Sustainable practices, certification programs, and responsible land use planning are essential to balance the economic benefits of these plantations with the need to preserve biodiversity and ecosystem health (Carnus et al., 2003; Chan, 2002; Drummond & Taylor, 1997; Takeuchi et al., 2017; Stuebing, 2007; Styring et al. 2022; Verma et al., 2020).

HISTORY OF FORESTRY IN SARAWAK

The Malaysian state of Sarawak is a global hotspot of tropical deforestation and there is a long history of forest products from this area (Ichikawa, 2007; Kaur, 1998; Sellato, 2001). This region has experienced extensive land-use changes and deforestation primarily driven by activities such as logging, agricultural expansion, and infrastructure development. The long history of forest exploitation in this area dates back to the colonial era when timber extraction and logging activities began on a significant scale (Bevis, 1995, Jomo et al., 2004; Kaur, 1998; Porter, 1967; Smythies, 1963).

Before James Brooke assumed the role of the Rajah of Sarawak in 1841, the virgin forests of Borneo remained largely untouched. Over centuries, a modest exchange of Bornean Forest goods with China transpired, involving commodities such as bird feathers, bezoar stones, beeswax, and the sought-after hornbill ivory, known as Ho-ting (Bevis, 1995, Jomo et al., 2004; Kaur, 1998; Sellato, 2001). From the cultivation of sago from swampy areas to the art of cultivating wet and hill paddy, the inhabitants of Borneo cultivated an agrarian lifestyle, complemented by hunting and gathering that was sustainable at low population densities (Jomo et al., 2004; Kaur, 1998; Mead, 1925; Porter, 1967).

The end of the nineteenth century saw a remarkable increase in the demand for rubber and *Gutta percha* and *Jelutang* trees held high value in the market (Kaur, 1998; Mead, 1925; Smythies, 1963). Consequently, the management of land became a paramount concern driven by purely commercial motives. As law and order gradually extended its influence in Sarawak under the rule of the White Rajahs, the impact on the timber industry became increasingly pronounced (Kaur; 1998; Mead, 1925; Porter, 1967; Smythies, 1963). The establishment of a more organized legal framework facilitated the regulation of timber-related activities. Subsequently, numerous Western companies were granted exclusive monopoly rights pertaining to forest products (Porter, 1967). This monopolistic control allowed these companies to wield considerable influence over the extraction, processing, and trade of timber resources, further solidifying their dominance in the burgeoning timber industry (Kaur; 1998; Smythies, 1963). The convergence of law and commercial interests in the timber sector during this period shaped the trajectory of resource exploitation and laid the foundation for the economic landscape in the region (Bevis, 1995, Jomo et al., 2004; Kaur; 1998; Smythies, 1963).

In 1886, the initiation of timber extractions by the Borneo Company Limited in Rajang marked the commencement of a significant chapter (Kaur, 1998). However, this enterprise faced a severe setback when the harvested logs succumbed to infestations by teredo, commonly known as naval shipworms, resulting in disastrous consequences (Smythies, 1963). In response to these challenges, the venture shifted its focus to exporting Belian wood to cater to the demands of the Indian railways (Jomo et al., 2004). Nevertheless, this phase was relatively short-lived as well (Smythies, 1963).

During this era, the governance of timber and forest products in Borneo operated in a virtually unregulated manner, although the imposition of substantial export duties prevailed. Recognizing the need for control and sustainability, the second Rajah, Sir Charles Brooke, issued three orders regulating the felling of Jelutong and Gutta trees (Jomo et al., 2004; Kaur, 1998; Smythies, 1963). This regulatory intervention aimed to manage the extraction of these valuable resources and safeguard against overexploitation. The implementation of these orders, serving as a precursor to more comprehensive forestry regulations, marked a pivotal moment in the evolving relationship between economic pursuits and environmental considerations in Borneo (Jomo et al., 2004; Kaur, 1998; Smythies, 1963, Porter, 1967). This period witnessed the acknowledgement of the need for responsible resource management, setting the stage for the formulation of policies that sought to balance economic interests with the preservation of the region's natural resources (Jomo et al., 2004; Kaur, 1998; Smythies, 1963).

Mr. J.P. Mead became the first Conservator of Forests in 1919, with the establishment of Sarawak Forestry Department (Kaur, 1998; Mead, 1925; Smythies, 1963). As the commercial importance of timber was only growing, the Department embarked on a mission with twin objectives: to effectively manage and conserve the extensive forest resources within the State. This undertaking found its operational framework in the implementation of *The Forest Rules* (Kaur, 1998; Mead, 1925). These rules regulated the taking of timber, firewood, charcoal and certain other forest products and imposed penalties for any infractions. This marked a crucial step in the evolution of forestry governance, as it aimed to strike a delicate balance between the imperative need for resource utilization and for sustainable conservation practices.

Building upon the foundation laid by the Forest Rules, the year 1920 witnessed the introduction of the Forest Reservation Order (Kaur, 1998; Smythies, 1963). This pivotal order was crafted with the primary objective of reserving adequate forest areas essential for meeting the community's needs arising from timber production. The foresight behind this measure recognized the intrinsic link between safeguarding designated forest reserves and the sustenance of vital community requirements (Kaur, 1998; Smythies, 1963).

Together, the Forest Rules and the subsequent Forest Reservation Order constituted a comprehensive regulatory framework that not only acknowledged the surging importance of timber commercially but also laid the groundwork for responsible and sustainable forest management practices in Sarawak (Kaur, 1998; Smythies, 1963). This period represented a watershed moment in the history of Sarawak's forestry governance, setting the trajectory for future conservation efforts and prudent resource utilization (Jomo et al., 2004; Kaur, 1998; Smythies, 1963).

Mr. Mead concluded his tenure in Sarawak in 1928, yet the enduring legacy of his reserve-centric approach persisted. In 1934, the introduction of Order F-1, commonly known as the Forest Order, ushered in a novel category of forest, termed the Protected Forest (Cooke, 2006, 2013; Kaur, 1998; Smythies, 1963). This innovative classification permitted citizens to freely harvest any produce or forest product from unreserved State land, while restrictions were imposed within reserved forests. Subsequent minor amendments to the Forest Order ensued, culminating in Order F-1D in 1940, introducing a third permanent forest type called the Communal Forest (Cooke, 2013; Jomo et al., 2004; Kaur, 1998; Sellato, 2001; Smythies, 1963). The concept of the Communal Forest deviates from the Protected Forest and the Forest Reserve, representing a distinct category with unique characteristics. The Communal Forest signifies an area where local communities hold collective rights to utilize and manage forest resources sustainably, fostering a shared approach to conservation and utilization. This distinct classification aims to facilitate a balance between communal needs, environmental preservation, and responsible resource utilization.

By 1940, the proliferation of sawmills had surged to a total of 16, indicative of a heightened emphasis on timber-related activities (Jomo et a., 2004; Kaur, 1998; Smythies, 1963). However, this period was marred by significant disruptions, including the Japanese occupation in 1941 and the subsequent entry of other foreign timber concessionaries during the postwar era.

In the aftermath of World War II, the Forestry Department underwent a transitional phase as it came under the crown's jurisdiction in 1946 (Cooke, 2013; Jomo et al., 2004; Kaur, 1998; Smythies, 1963). This period was characterized by colonial rule, ushering in economic transformations driven by the strategic exploitation of natural resources. The implementation of development schemes, backed by both the colonial government and the private sector, played a pivotal role in shaping the landscape of resource utilization during this era (Cooke, 2013; Jomo et al., 2004).

In the pivotal year of 1963, Sarawak, along with Sabah, Singapore, and Peninsular Malaysia formed the newly independent Federation of Malaysia. This marked the end of direct colonial rule in Sarawak, as the state became a part of a larger political entity with self-governance. In accordance with the Federal Constitution, state governments hold complete jurisdiction over their respective forest resources, as with land and other natural resources besides petroleum (FCM, 1957; Jomo et al., 2004). The federal government holds the capacity to impact local policies, particularly through fiscal measures.

During the 1970s, Malaysia's forestry management was influenced by a combination of government policies and international pressures, particularly the National Forestry Council (NFC), global environmental movements, and collaborative efforts with international organizations. The NFC, established by the federal government, acted as a platform for coordinating forestry policies among the states in Malaysia, comprised of chief ministers and federal ministers. Notably, Sabah and Sarawak chose to maintain observer status rather than full NFC membership, signifying a lesser commitment to adhering strictly to policies set by the NFC. During this time, the advent of reliable heavy machinery and the invention of the one-man chain saw acted as catalysts, propelling the timber market to eclipse other forest products from Sarawak (Jomo et al., 2004). During this time, most forests in rural areas were logged at least once.

In the late 1970s, escalating concern regarding extensive logging practices and their environmental unsustainability prompted the NFC to establish the National Forestry Policy (NFP) in 1978. This policy, later translated into the National Forestry Act of 1984, highlighted concerns about deforestation's environmental impact and proposed initiatives to protect watersheds and other areas vulnerable to soil erosion, flooding, and other natural elements. Significantly, Sarawak and Sabah chose not to join (Jomo et al., 2004).

In the early 1980s, the region grappled with the Borneo fires of 1982-1983, which posed severe challenges to the ecological balance (Leighton, 1984; Lennert & Panzer, 1984; Malingreau et al., 1985; Sloan et al., 2017; Woods, 1989). These fires were primarily caused by a combination of factors, including land clearance through slash-and-burn methods, prolonged drought conditions, and the ignition of peat deposits. The fires led to widespread environmental and ecological damage, impacting both natural habitats and human communities. This period underscored the necessity for stringent conservation measures and sustainable forestry practices to mitigate the environmental impact of such events. The dynamic interplay between historical events and evolving forestry practices has left an indelible mark on Sarawak's forestry legacy.

The advent of large-scale industrial logging in the 1980's positioned Sarawak as a focal point in a heated global conversation regarding the implications of logging on rampant tropical deforestation. By the end of the decade, this debate underscored concerns about the detrimental effects of logging on biodiversity, as well as its impact on the rights and livelihoods of indigenous communities dependent on the forest (Jomo et al., 2004). In 1989, the International Tropical Timber Organization (ITTO), an intergovernmental body created to enhance the management and trade of tropical timber, appointed a distinguished panel to evaluate the consequences of tropical timber logging in Sarawak. The assessment, referred to as "The Cranbrook Report," supported a definition of sustainable forest management (SFM) that emphasized state dominance, offering limited consideration for ecological integrity and confining indigenous rights to those accorded by the State under the law. By 1990, ITTO had transitioned its focus towards endorsing continual industrial-scale logging in Sarawak and aiding international trade in tropical timber, with a notable emphasis on Japan. Japan served as Sarawak's principal timber client and hosted both the ITTO's Secretariat and acted as its major financial supporter (GW, 2013).

During this time, consumer driven demands for sustainable forestry practices were becoming popular. Following unsuccessful endeavors to cooperate with the Forest Stewardship Council (FSC; a global sustainable forest certification system) on a forest certification initiative in the late 1990s, Malaysia chose an independent trajectory for certifying the forest management practices of its forest management units (FMUs) (Jomo et al., 2004; Lewis, 2011; Lewis & Davis, 2015). In 1998, the Malaysian Timber Certification Council (MTCC) was instituted with the aim of creating, executing, and overseeing a location-specific timber certification framework in Malaysia (NTCC, 1999). In theory, timber is considered a renewable resource, overlooking biodiversity considerations; however, its sustainability is contingent upon the extraction and restoration practices (Johns, 1988; Nicholson, 1958, 1979; Pinard & Putz, 1996; Sist et al., 2003). Based on assessments during this time by ITTO (1990) and the World Bank (1991), levels of extraction remained in excess of estimated sustainable levels.

The emergence of certification standards, such as the MTCS, underscores an increasing global priority on responsible resource management. These standards are designed to guarantee sustainable forestry practices and have become integral to international trade. Currently, the worldwide emphasis on environmental conservation, adherence to certification standards, and responsible resource management has further intensified. Consequently, Sarawak has adjusted its policies to conform to these evolving standards, demonstrating a dedication to environmentally sustainable forestry. Over the past decade, Malaysia has observed a decline in tropical log exports, indicative of constraints in the availability of tropical roundwood, a log export prohibition in Sabah, and log export limitations in Sarawak. This downward trend in exports has been consistently observed each year since the 1990's (ITTO, 2018; Koh et al., 2023).

The Sarawak Forest Policy 2019 continues the ethos of the Forest Policy of Sarawak 1954, with a succinct mission statement: "to manage and develop forest resources for socio-economic and environmental sustainability" (FDS, 2021). The policy defines categories of forested and non-forested land (Table 1). Forested land includes Permanent Forest Estates (PFEs; Protected Forest, Forest Reserve and Communal Forest), Totally Protected Areas (TPAs), and State Land Forests (SLFs). The state management of forest land in Sarawak is within the Permanent Forest Estate (Protected Forest, Forest Reserve and Communal Forest). PFE is dedicated to production forestry (primarily of timber); TPA encompasses national parks and wildlife sanctuaries; and SLF is potentially available for conversion to other uses (often agriculture) (Jomo et al., 2004; Koh et al., 2023). Non-forested or non-titled land includes Native Customary Rights land (NCR), belonging to the Indigenous peoples of the region. To be recognized as such land, rights had to be first registered, and the holder occupies the land as a licensee of the state (Jomo et al., 2004).

Totally Protected Area	**Permanent Forest Estates**			**State Land Forest**
	Forest Reserve	Protected Forest	Communal Forest	
Conservation areas including national parks, nature reserves and wildlife sanctuaries. No logging, restricted usufruct.	Production forest. Allow usufructuary rights for specific communities only.	Production forest. Allow usufructuary rights for all communities.	Not for commercial logging. Managed by specified communities.	Can be converted to other land use.

Table 1. Sarawak forest designations. Taken from Koh et al., 2023.

FOREST CONVERSION

While Sarawak has witnessed a downward trend of log exports, there has been a massive increase in other crops, specifically palm oil. There is a short-term economic advantage in clearing and converting forests for alternative land use. Harvesting mature forests for timber generates immediate monetary value. Although forests can regenerate naturally (Blackham et al., 2014; Chazdon & Guariguata, 2016; Martínez-Ramos et al., 2016; Sodhi et al., 2010), alternative industrial crops like fast-growing timber species, rubber, and oil palm exhibit quicker growth rates and offer superior economic returns for the land. Replacing large areas of logged forest, the extensive spread of oil palm cultivation in Sarawak over the last three decades, stands as the most rapid and transformative alteration of the rural landscape in the state (Cramb, 2016, Jomo et al., 2004). Expanding from a modest 23,000 ha in 1980, the land dedicated to oil palm cultivation has surged to over 5.9 million hectares at present (Cramb, 2016, Gaveau et al., 2014, 2016, 2019; Jomo et al., 2004).

The expansion of oil palm in Sarawak has not only brought about changes in land use but has also resulted in a fundamental transformation of the agricultural economy (Cramb, 2016; Cramb & Sujang, 2016). Historically, Sarawak's agriculture was characterized by semi-subsistence smallholdings, particularly through swidden cultivation practiced by the Indigenous population on their customary lands. However, the post-1980 expansion of industrial oil palm plantations has shifted from this smallholder-dominated model to one dominated by large-scale private estates. While it might be tempting to attribute this transformation solely to market forces responding to increased global palm oil demand and the perceived efficiency of large-scale estates, this perspective overlooks the influential role of government policies. Government policies have actively restricted smallholder development while facilitating the allocation of substantial public and customary lands to a select group of powerful private plantation companies (Cramb, 2016; Cramb & Sujang, 2016; Ngidang, 2002; Cramb & Ferraro, 2012). Therefore, the shift in Sarawak's agricultural landscape is not merely a spontaneous market response but a result of deliberate government interventions favoring large-scale plantations over smallholder agriculture.

CONSERVATION EFFORTS

In 1992, Malaysia committed at the Earth Summit to maintain a minimum of 50% of its terrestrial area under forest cover, known as the 'Rio Pledge' (Koh et al., 2023). While not legally binding, Malaysia has consistently reaffirmed this commitment, including at the recent COP26 where it endorsed the Glasgow Forest Declaration, aiming to halt and reverse forest loss by 2030 (Tuan Man, 2021). In Sarawak, log production and exports have become increasingly restricted, with production affected by ongoing crackdowns on illegal logging and corrupt trade practices (ITTO, 2018). The Sarawak Forestry Corporation plays a crucial role in managing and conserving the state's forests. It is responsible for implementing conservation policies, sustainable forestry practices, and wildlife protection measures.

In addition to establishing Protected and Totally Protected Areas, Sarawak is part of the Heart of Borneo project, a transboundary conservation initiative involving Malaysia, Indonesia, and Brunei. The goal is to protect and sustainably manage a large area of rainforest in the interior of Borneo to conserve biodiversity and promote sustainable development. Furthermore, efforts have been made to protect and rehabilitate endangered species. The Bornean orangutan, for example, is the focus of conservation programs, and sanctuaries such as Semenggoh Wildlife Centre work towards rehabilitating and releasing orangutans back into the wild.

HIGH CONSERVATION VALUE FOREST

In the current environmental movement, consumer preference for green labeled and sustainable goods can be used as a tool to influence the practices of corporations when local governments are reluctant to improve environmental laws (Edwards & Laurance, 2012). One example of this approach is the High Conservation Value Forest (HCV/HCVF) concept, developed by the Forest Stewardship Council (FSC) in 1999 as Principle 9 in its criteria for timber companies seeking sustainable forest certification. The HCV concept was initially designed, in the context of selective logging, as a tool to enable forest managers to voluntarily develop sustainable forest management decisions, based on the preservation or enrichment of biodiversity within a given ecosystem (Brown et al., 2013; Jennings et al., 2003). Although a selectively logged forest and oil palm plantation will impact biodiversity very differently (Edwards et al., 2010), the Roundtable for Sustainable Palm Oil (RSPO) has adopted HCV for certification schemes and claims that the negative aspects of cultivation are mitigated when using this approach (RSPO, 2007; Senior et al., 2014).

High Conservation Value Areas (HCVAs) are areas considered critically important due to their concentrations of biological, ecological, social or cultural values (Jennings et al., 2003). The guidelines provide a set of environmental and social criteria with which companies must comply to produce certified sustainable products. Certification is intended to ensure that HCVs and the forests that contain them will be managed in a way that maintains or enhances their identified value. The Roundtable for Sustainable Palm Oil (RSPO) claims that the negative environmental and social impacts of palm oil cultivation are minimized when using this approach (RSPO, 2007). ProForest, a non-profit advocating for agricultural and forest responsibility, developed a global HCV toolkit in 2003. This toolkit provides the framework from which national toolkits are developed, specific to each country or region (Jennings et al., 2003) In 2009, the HCV Malaysia Toolkit was developed to provide technical advice in accordance with three distinct geographical regions in Malaysia; Sabah, Sarawak, and Peninsular Malaysia (HCV Malaysia, 2018). These toolkits have gone through various revisions with input from numerous contributors throughout their existence.

The three main steps in the HCV process include: (i) the identification of HCVs present within an exact area of a plantation, (ii) development and implementation of management plans, and (iii) monitoring the effectiveness of management plans. This process is region specific, requires describing what local values are, and necessitates parameters and thresholds for detecting these values (Jennings et al., 2003).

There are six categories used to identify areas of HCV, described in Table 2. HCVs 1 – 3 incorporate species diversity, landscape-level ecosystems, and critical habitats with a focus on rare, threatened, endangered and endemic species or ecosystems. The remaining HCVs 4 – 6 encompass ecosystem services, community needs, and cultural values (Jennings et al., 2003; Brown et al., 2013).

HCV1. Forest areas containing globally, regionally or nationally significant concentrations of biodiversity values (e.g. endemism, endangered species, refugia.) For example, the presence of several globally threatened bird species within a Kenyan montane forest.	HCV4. Forest areas that provide basic services of nature in critical situations (e.g. watershed protection, erosion control). For example, forest on steep slopes with avalanche risk above a town in the European Alps.
HCV2. Forest areas containing globally, regionally, or nationally significant large landscape level forests, contained within, or containing the management unit, where viable populations of most if not all naturally occurring species exist in natural patterns of distribution and abundance. For example, a large tract of Mesoamerican lowland rainforest with healthy populations of jaguars, tapirs, harpy eagles and caiman as well as most smaller species.	HCV5. Forest areas fundamental to meeting basic needs of local communities (e.g. subsistence, health). For example, key hunting or foraging areas for communities living at subsistence level in a Cambodian lowland forest mosaic.
HCV3. Forest areas that are in or contain rare, threatened or endangered ecosystems. For example, patches of a regionally rare type of freshwater swamp forest in an Australian coastal district.	HCV6. Forest areas critical to local communities' traditional cultural identity (areas of cultural, ecological, economic or religious significance identified in cooperation with such local communities). For example, sacred burial grounds within a forest management area in Canada.

Table 2. The six High Conservation Value types. (Brown et al., 2013).

BIRDS AS INDICATORS OF FOREST HEALTH

Biodiversity assessments play a pivotal role in shaping conservation and management strategies by offering valuable insights into the ecological integrity of diverse habitats. The use of employing "indicator" species to estimate species richness has gained prominence (i.e., Pearson, 1994; Scott 1998; Gustafsson 2000). This strategy involves selecting a subset of species whose presence and behavior serve as proxies for the overall biodiversity within an ecosystem (Fleishman et al., 2005). However, the utilization of indicator species has not been without controversy (Thomas 1972; Zoneveld 1983; Morrison 1986; Landres et al., 1988). Landres (1988) critically examines the assumption that maintaining habitat quality for indicator species automatically extends to suitability for other species. Species that coexist often diverge in their habitat requirements and life trajectories (Martin & Li, 1992; Martin,1996), displaying a propensity to react independently to fluctuations in environmental conditions (e.g., James et al. 1984). Consequently, relying on individual species as reliable indicators of broader community responses becomes a matter of contention. The concept gains traction when species are viewed as indicators of specific guilds, defined as groups exploiting similar environmental resources (Canterbury et al., 2000; Fleishman et al., 2005). This refined perspective acknowledges the diversity within guilds while emphasizing the potential of certain species to indicate specific components of community responses, contributing to a more nuanced understanding of ecological conditions.

Birds are often employed as indicator species in ecological monitoring to assess the health of ecosystems and detect environmental changes. Their diverse responses to alterations in habitat, climate, and resource availability make them valuable indicators, reflecting the overall well-being of ecosystems (Canterbury et al., 2000; Fleishman et al., 2005). This method was formulated to serve as a comprehensive metric indicating the overall impact of forest disturbance on the avian community, emphasizing a broader perspective rather than delving into the intricacies of habitat utilization by individual bird species. Despite this, the index retains species-specific information, enabling the interpretation of values in the context of the diverse responses exhibited by individual species. The ecological indices encapsulate a crucial dimension of disturbance, offering valuable insights into the ecological condition concerning the biodiversity conservation and ecological resources, helping scientists and conservationists make informed decisions about habitat conservation and management. (Angermeier & Karr 1994; Canterbury et al., 2000; Fleishman et al., 2005).

BABBLERS

Babblers are a predominately Asian group of passerines. The systematics of babblers was once a much more inclusive family, now separated into distinct family groups, Pellorneidae (ground babblers) and Timaliidae (tree babblers) (Cibois, 2003; Moyle et al., 2012). Both families demonstrate high levels of sympatry. As their name would suggest, babblers make a lot of noise and their vocalizations are distinct, complex, and often heard. (Myers, 2016; Phillipps, 2011; Smythies, 1999; Styring et al., 2016).

Timaliid babblers inhabit various environments, occupying all levels of Asian forests, but only a few spend time on the ground. They are primarily insectivorous, gleaning from leaves and branches (Winkler et al., 2020).

Pellorneid babblers spend most of their time on the ground or in lower, dense vegetation. They mainly forage on the ground, probing soil and picking through leaf litter, feeding almost exclusively on insects, although some eat berries and seeds (Winkler et al., 2020).

PASSIVE ACOUSTIC MONITORING

The evolution of advanced technologies has ushered in a paradigm shift, enhancing our capacity for biodiversity assessment and ecological exploration. Innovations like remote sensing, camera trapping, and DNA barcoding have enabled more effective tracking of biodiversity responses to dynamic environmental changes, encompassing factors such as habitat loss, species introductions, and climate shifts (Janzen et al., 2009; Rowcliffe et al., 2014; Trolliet et al., 2014; Turner et al., 2003). Notably, automated recording units (ARUs) have emerged as transformative tools, reshaping conventional survey methodologies centered on auditory detection. These devices have become instrumental in capturing the intricate soundscape of terrestrial environments, teeming with signals from diverse sources, particularly the rich repertoire of animal sounds (Acevedo & Villanueva-Rivera, 2006; Anderson et al., 1996; Brandes, 2008; Chesmore & Ohya, 2004; Kogan & Margoliash, 1998; Marques et al., 2013; Parsons & Jones, 2000; Sugai et al., 2019; Walters et al., 2012).

The significance of animal sounds extends beyond mere species identification, offering valuable insights into abundance, spatial positioning, and behavior. Unlike visual observations, sounds are more readily detectable over longer distances (Bobay et al., 2018; Campos-Cerqueira & Aide 2016; Heinicke et al., 2015; Rosenthal & Ryan, 2000). Auditory surveys, exemplified by initiatives investigating birds (Anderson et al., 1996; Brandes, 2008; Kogan & Margoliash, 1998), bats (Parsons & Jones, 2000; Walters et al., 2012), insects (Chesmore & Ohya, 2004) and other study organisms (Acevedo & Villanueva-Rivera, 2006; Marques et al., 2013) are increasingly used for biodiversity assessments. The evolution from portable tape recorders to digital audio recorders has further revolutionized field recordings, providing researchers with more affordable, compact, and efficient tools. The advent of ARUs has propelled the capabilities of passive acoustic monitoring, enabling unattended recording over extended periods, reducing observer bias, and facilitating the long-term storage of field recordings for subsequent digital analysis (Lahoz-Monfort & Magrath, 2021; Sugai et al., 2019). This metamorphosis positions Passive Acoustic Monitoring (hereafter, PAM) as a potent and versatile instrument in biodiversity monitoring, fostering applications in ecology, behavior, and conservation endeavors.

Recently, machine learning has played a crucial role in advancing the automated recognition of species in acoustic recordings (Bermant et al., 2019; Campos-Cerqueira & Aide, 2017; Gan et al., 2021). The availability of various software packages (Arbimon, 2023; Batsound, 2023) equipped with embedded classification algorithms and libraries tailored for the automated recognition of species. Machine learning algorithms can extract relevant features from acoustic recordings, such as frequency patterns, temporal characteristics, and amplitude variations (Aide et al., 2013). These features serve as input data for the machine learning models. Machine learning models excel at recognize complex patterns within large datasets. In the context of acoustic recordings, these models can learn intricate patterns associated with different species' vocalizations (Aide et al., 2013). Furthermore, these models can be continuously improved through iterative processes. As more acoustic data becomes available, models can be retrained to enhance their accuracy and adaptability to new conditions. Overall, the application of machine learning in automated species recognition from acoustic recordings has significantly improved the efficiency, accuracy, and scalability of monitoring efforts in ecological and conservation research (Aide et al., 2013; Campos-Cerqueira & Aide, 2017; Gan et al., 2021; Lahoz-Monfort & Magrath, 2021).

RESEARCH MANUSCRIPT

This research aims to provide a better understanding of the relationships between babblers and their habitat preferences within native and planted forest in Sarawak. Through a bioacoustics analysis, this research aims to identify and understand the ecological factors influencing the occupancy patterns of these bird species, shedding light on the dynamics of their habitat preferences across different forest types. I hypothesize that bird and plant community complexity are correlated and connect species occupancy to the physical structure of the respective sites (MacArthur & MacArthur 1961; Hanowski et al., 1997). This exploration not only contributes to our understanding of the ecological interplay within these forested landscapes but also holds the potential to inform targeted conservation strategies and sustainable land-use practices for the benefit of both avian biodiversity and ecosystem health.

STUDY AREA

This study took place in the Sarawak PFZ, located ca. 40 km southeast of Bintulu in the Tatau District of central Sarawak (Figure 1). Run by the Forest Department of Sarawak, Samarakan Nursery (2°56’N, 113°07’E) serves as the administrative center for plantation operations, contracted through Grand Perfect Sdn. Bhd (GP). Planted groves at Samarakan consist primarily of acacia *(Acacia mangium),* eucalyptus *(Eucalyptus pellita),* and albizia *(Paraserianthes falcataria)* crops. The remaining areas consist of Native Customary Rights land, Protected and Totally Protected conservation areas, and native forest fragments or stream buffer areas, which are intended to serve as reservoirs and corridors for wildlife (Stuebing, 2007).

The native forest at Samarakan consists of secondary mixed-dipterocarp and heath forest (kerangas). Secondary forest refers to native forest that has undergone selective logging and is characterized by regrowth and re-establishment of vegetation following disturbance, with these particular forests having been subjected to extraction practices since the early 1970s (Jomo et al., 2004; J. Unggang, personal communication, 2022).

Planted production forests throughout the PFZ are dominated by acacia, eucalyptus, and albizia, harvested on ~10-year cycles. These fast-growing species can achieve heights exceeding 20 meters when mature (Cockburn, 1976; Jusoh & Tiong, 2016; Lee, 2018; Pedley, 1975; Rahman & Suratman, 2016; Yahya, 2020). Throughout the first 2–3 years after planting, groves undergo intensive management and trimming. Once young trees have been established, there is little to no management and the understory is allowed to regenerate (J. Unggang, personal communication, 2022).

AUDIO SURVEYS

From 23 June to 26 July 2022, I used commercially available ARUs, AudioMoths (https://www.openacousticdevices.info/audiomoth,) to survey for bird song within planted and native secondary forest (Figure 3). I examined random and systematic random sampling designs for establishing ARU sites, however, COVID-19 impacted workflow at Samarakan, and desired forest fragments were not accessible. Additionally, poor road conditions made ideal sites impossible to access, and I adjusted to place ARUs randomly at accessible sites. Devices were placed in 11 planted forests and 11 native forest sites, where no active maintenance was scheduled, at least 200m from roads or other recording units, and positioned approximately 1.5m above the ground. Devices were programmed to collect recordings of dawn and dusk chorus when birds are most active (Gil & Llusia, 2020). Units began collecting data 30 minutes before sunrise to two hours after (06:00-08:30) and again two hours before sunset to 30 minutes after (16:30-19:00) at a sample rate of 48000kHz and high gain. Recording duration was programmed to 595 seconds (~9.9 minutes) and the device rested for 5 seconds before beginning the next recording. Units were left in the environment for 10 days, although some ran longer (~16 days). Habitat surveys were also completed at each site and included metrics of canopy height, number of forest layers, adjacent land use, etc (Appendix 1).

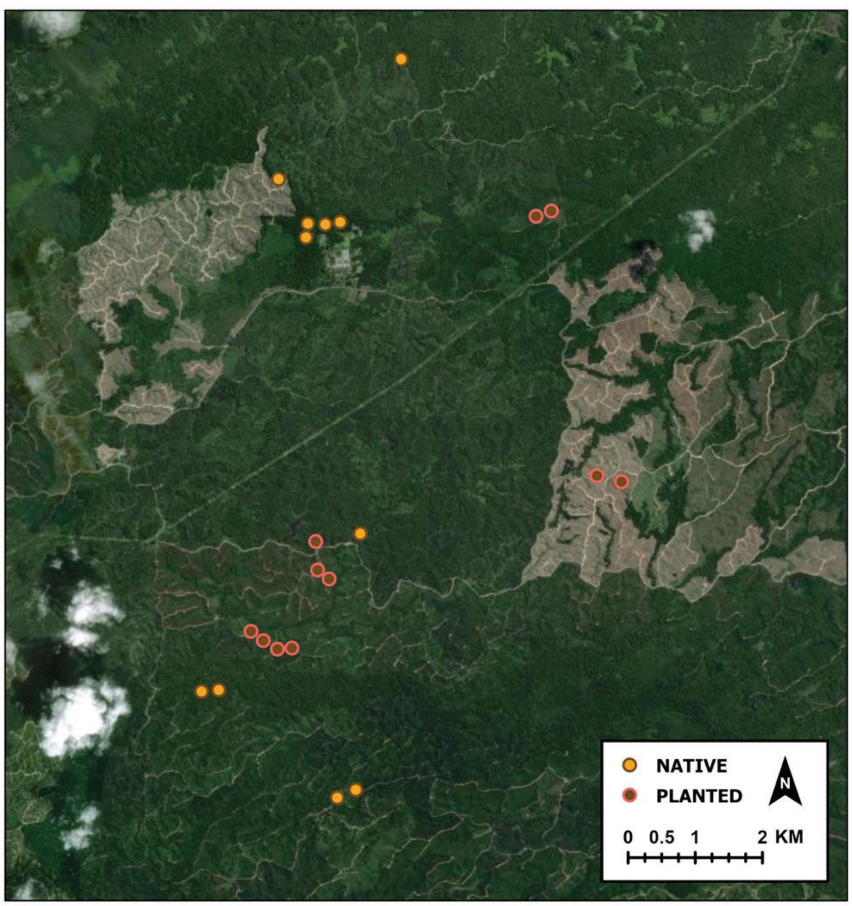

Figure 4. Autonomous recorder sites at Samarakan, 2022

DATA PROCESSING

Audio files were named based on site, date, and time (A0101dt20220725_073000.wav) and uploaded to a project in Arbimon (https://arbimon.rfcx.org/). Arbimon provides users with the tools necessary to analyze large amounts of acoustic data. The platform uses pattern matching recognition and analysis techniques to identify species present in recorded audio. Templates were created from xeno-canto recordings (https://xeno-canto.org/) of target species vocalizations for pattern matching analysis and ran for each species at individual sites. Matches were sorted chronologically, and detected spectrograms were visually and aurally investigated before being validated as “present” or “absent” detection. Multiple templates were created for each species. A presence/absence matrix for each species was generated from survey data.

SINGLE-SEASON OCCUPANCY MODELS

This study uses single-season occupancy modeling, and a logistic regression model was used to compare the influence of environmental variables on babbler occupancy at native forest fragments (n = 11) and planted forest fragments (n = 11). Site-level covariates do not change through time but differ between each site. For example, measures of canopy height or other landscape metrics like the straight-line distance to a river. Models were ranked based on Akaike’s information criterion (AIC) score and a MacKenzie-Bailey test was used to test the goodness-of-fit (MacKenzie & Bailey 2004).

To evaluate the effect of habitat variables on the distribution of babbler species, I created an ordination using a non-parametric multidimensional scaling (NMDS) and the Bray-Crutis dissimilarity with the *MetaMDS* function in the "Vegan" package (Oksanen, 2015). In addition to the ordination analysis, I also ran a PERMANOVA (Anderson, 2014) with the functions *adonis* and *betadisper* with 1000 permutations to test for significant difference.

RESULTS

Autonomous recording units collected 67,900 minutes of bio-acoustics data. In Arbimon, I created 38 species templates and 440 pattern matching jobs, resulting in 135,747 detections. Two of the autonomous recording units failed after deployment (A01 and A11). and those sites have not been included in this analysis.

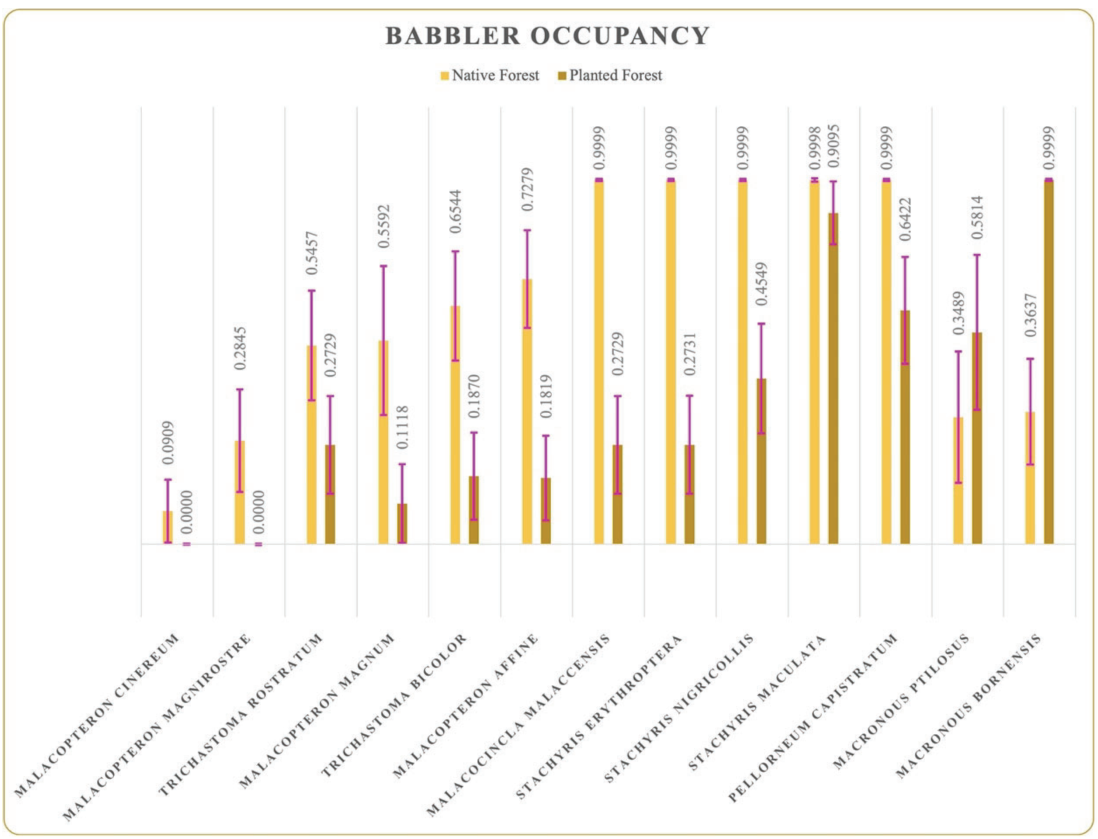

Figure 5. Babbler occupancy estimates across all sites. Occupancy values shown above bars. Standard error bars are indicated in pink.

Figure 5 and Table 3 show occupancy estimates across Native Forest (NF) and Planted Forest (PF) sites. Scaly-crowned Babbler (NF = 0.0909; PF = 0.0000), stands out as the rarest find, occupying just one native forest site. Moustached Babbler (NF = 0.2845; PF = 0.0000), is similarly reliant on native forest and notably absent in planted forest sites. Contrary to sporadic daily appearances, Chestnut-rumped Babbler (NF = 0.9998; PF = 0.9095) emerges as the most ubiquitous species across all sites, displaying no significant preference for either planted or native forest habitats. Black-capped Babbler (NF = 0.9999; PF = 0.6422) and Black-throated Babbler (PF = 0.9999; NF = 0.4549) frequent multiple sites, although more common in native forests. Meanwhile, Bold-striped Tit-babbler (NF = 0.3637; PF = 0.9999) and Fluffy-backed Tit-babbler (NF = 0.3489; PF = 0.5814) occupy both habitat types, favoring the planted forest landscapes.

Species	Habitat	Occupancy Estimate	Standard Error	Lower CI	Upper CI
Scaly-crowned Babbler (Malacopteron cinereum)	Native	0.0909	0.0867	0.0126	0.4386
	Planted	0.0000	0.0013	0.0000	1.0000
	Detection Probability	0.7142	0.1710	0.3261	0.9281
Moustached Babbler (Malacopteron magnirostre)	Native	0.2845	0.1409	0.0929	0.6070
	Planted	0.0000	0.0018	0.0000	1.0000
	Detection Probability	0.3651	0.1132	0.1809	0.5996
Rufous-crowned Babbler (Malacopteron magnum)	Native	0.5592	0.2041	0.2002	0.8654
	Planted	0.1118	0.1080	0.0147	0.5149
	Detection Probability	0.2129	0.0758	0.1002	0.3963
White-chested Babbler (Trichastoma rostratum)	Native	0.5457	0.1502	0.2681	0.7975
	Planted	0.2729	0.1343	0.0905	0.5859
	Detection Probability	0.6664	0.0596	0.5415	0.7715
Ferruginous Babbler (Trichastoma bicolor)	Native	0.6544	0.1498	0.3407	0.8740
	Planted	0.1870	0.1197	0.0469	0.5182
	Detection Probability	0.4013	0.0654	0.2822	0.5333
Sooty-capped Babbler (Malacopteron affine)	Native	0.7279	0.1344	0.4144	0.9100
	Planted	0.1819	0.1164	0.0458	0.5073
	Detection Probability	0.6424	0.0575	0.5237	0.7458
Fluffy-backed Tit-babbler (Macronous ptilosus)	Native	0.3489	0.1803	0.1016	0.7174
	Planted	0.5814	0.2126	0.2004	0.8850
	Detection Probability	0.1954	0.0646	0.0979	0.3522
Short-tailed Babbler (Malacocincla malaccensis)	Native	0.9999	0.0031	0.0000	1.0000
	Planted	0.2729	0.1343	0.0905	0.5858
	Detection Probability	0.6836	0.0470	0.5853	0.7679
Chestnut-winged Babbler (Stachyris erythroptera)	Native	0.9999	0.0031	0.0000	1.0000
	Planted	0.2731	0.1345	0.0906	0.5863
	Detection Probability	0.6121	0.0493	0.5123	0.7033
Bold-striped Tit-babbler (Macronous bornensis)	Native	0.3637	0.1450	0.1433	0.6613
	Planted	0.9999	0.0024	0.0000	1.0000
	Detection Probability	0.8476	0.0351	0.7656	0.9045
Black-throated Babbler (Stachyris nigricollis)	Native	0.9999	0.0029	0.0000	1.0000
	Planted	0.4549	0.1502	0.2029	0.7322
	Detection Probability	0.7232	0.0423	0.6333	0.7981
Black-capped Babbler (Pellorneum capistratum)	Native	0.9999	0.0033	0.0000	1.0000
	Planted	0.6422	0.1464	0.3399	0.8622
	Detection Probability	0.4903	0.0450	0.4033	0.5779
Chestnut-rumped Babbler (Stachyris maculata)	Native	0.9998	0.0046	0.0000	1.0000
	Planted	0.9095	0.0866	0.5610	0.9875
	Detection Probability	0.7005	0.0378	0.6216	0.7691

Table 3. Babbler occupancy estimates and detection probability.

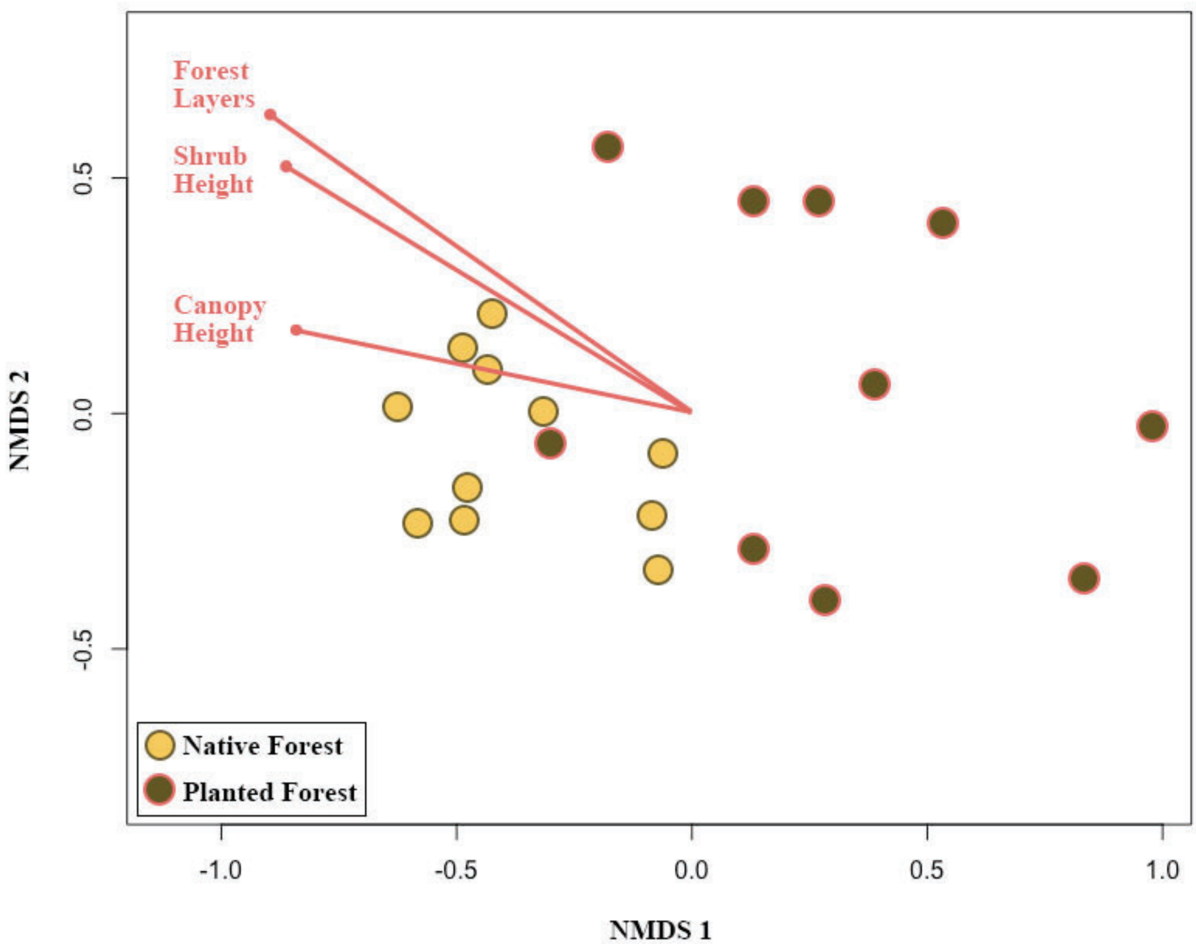

Figure 6. Ordination plot of native forest and planted forest habitat variables

The occupancy model and NMDS (Figure 6) identified primary canopy height (R^2 = 0.3145; p = 0.0329), shrub layer height (R^2 = 0.4362; p = 0.0049), and number of forest layers (R^2 = 0.5067; p=0.0019) correlated significantly with occupancy by forest type. No other environmental variables tested were significant. Canopy height was significantly influential as an inverse relationship with Bold-striped Tit-babbler (β= -0.1580; SE = .0753; Z = -2.1000; P(>|z|) = 0.0357) and Sooty-capped Babbler (β= -0.1310; SE = .0619; Z = 2.1200; P(>|z|) = 0.0339). Number of forest layers was a significant predictor for Black-capped Babbler (β=

3.810; SE = 1.6300; Z = 2.3300; P(>|z|) = 0.0197) as a positive relationship with occupancy of these species.

DISCUSSION

The logistic regression occupancy model and NMDS analysis identify primary canopy height, shrub layer height, and the number of forest layers as significant predictor variables influencing babbler occurrence. This highlights the importance of structural complexity in the environment for these bird species and emphasizes the potential of regenerated forest fragments within plantations to support biodiversity. The preference for complex native forest structures by certain species suggests the need for maintaining or restoring such features through conservation efforts. Most species used planted forest less frequently than native secondary forest, possibly for transit or foraging, with the exception of Bold-striped Tit-babbler and Fluffy-backed Tit-babbler, which were more common in planted stands. This suggests that, under specific conditions, plantations can serve as viable habitats for some bird species.

It is essential to acknowledge the limitations of the study, including the small sample sizes in each habitat type, and large standard errors leading to uncertainty in estimates. Future research could benefit from expanding the study duration and incorporating multi-season data to explore dynamic occupancy patterns. Additionally, continuous monitoring using ARUs over longer periods would provide more comprehensive insights into temporal variations in bird populations.

Autonomous recording units play a pivotal role in environmental monitoring by providing continuous and unobtrusive data collection in remote or sensitive areas. These devices enable researchers to gather crucial information on wildlife behavior, biodiversity, and habitat health, fostering a deeper understanding of ecosystems and supporting informed conservation efforts. Furthermore, they offer a cost-effective and efficient means to track environmental changes over time.

These investigations are intended to contribute to conservation initiatives by providing managers with insights into community ecology. This information can then be applied to the plantation design and management to promote biodiversity conservation (Hanowski et al., 1997; Nasi et al., 2009; Stuebing, 2007).

In conclusion, this research significantly contributes to our understanding of avian ecology in the face of habitat transformation. However, we are still far from a complete understanding of the intricacies influencing species abundance, richness, distribution and movements, and basic elements of life history cycles. The integration of advanced monitoring techniques and a comprehensive analysis of habitat variables enriches our knowledge base, providing a foundation for informed conservation strategies in regions grappling with complex socio-economic and ecological challenges.

LITERATURE CITED

Abdullah, M. T., Hall, L. S., Tissen, O. B., Tuuga, A., & Cranbrook, S. (2007). The large bat caves of Malaysian Borneo. Bat Research News, 48(3), 99-100.

Acevedo, M. A., & Villanueva-Rivera, L. J. (2006). From the field: Using automated digital recording systems as effective tools for the monitoring of birds and amphibians. Wildlife Society Bulletin, 34(1), 211-214.

Aiba, S. I., Kitayama, K., & Takyu, M. (2004). Habitat associations with topography and canopy structure of tree species in a tropical montane forest on Mount Kinabalu, Borneo. Plant Ecology, 174, 147-161.

Aide, T. M., Corrada-Bravo, C., Campos-Cerqueira, M., Milan, C., Vega, G., & Alvarez, R. (2013). Real-time bioacoustics monitoring and automated species identification. PeerJ, 1, e103.

Ali, J. R., & Heaney, L. R. (2021). Wallace's line, Wallacea, and associated divides and areas: history of a tortuous tangle of ideas and labels. Biological Reviews, 96(3), 922-942.

Ancrenaz, M., Oram, F., Nardiyono, N., Silmi, M., Jopony, M. E., Voigt, M., ... & Meijaard, E. (2021). Importance of small forest fragments in agricultural landscapes for maintaining orangutan metapopulations. Frontiers in Forests and Global Change, 4, 560944.

Anderson, J. A. R., & Muller, J. (1975). Palynological study of a Holocene peat and a Miocene coal deposit from NW Borneo. Review of Palaeobotany and Palynology, 19(4), 291-351.

Anderson, S. E., Dave, A. S., & Margoliash, D. (1996). Template-based automatic recognition of birdsong syllables from continuous recordings. The Journal of the Acoustical Society of America, 100(2), 1209-1219.

Anderson, J. A. R. (1961). The ecology and forest types of the peat swamp forests of Sarawak and Burnei in relation to their silviculture. PhD Thesis, University of Edinburgh.

Anderson, M. J. (2014). Permutational multivariate analysis of variance (PERMANOVA). Wiley statsref: statistics reference online, 1-15.

Andriesse, J. P. (1988). Nature and management of tropical peat soils (No. 59). Food & Agriculture Organization of the United Nations.

Angermeier, P. L., & Karr, J. R. (1994). Biological integrity versus biological diversity as policy directives. BioScience, 44(10), 690-697.

Arbimon. https://arbimon.rfcx.org/

Ashton, P. S., & Hall, P. (1992). Comparisons of structure among mixed dipterocarp forests of north-western Borneo. Journal of Ecology, 459-481.

Ashton, P. S., Givnish, T. J., & Appanah, S. (1988). Staggered flowering in the Dipterocarpaceae: new insights into floral induction and the evolution of mast fruiting in the aseasonal tropics. The American Naturalist, 132(1), 44-66.

Barker, G., & Badang, D. (2013). Rainforest foraging and farming in Island Southeast Asia. The Archaeology of the Niah Caves, Sarawak. McDonald Institute of Archaeological Research, Cambridge.

Barker, G., Hunt, C., Hill, E., Jones, S., & O'Donnell, S. (2018). 'Rice Needs People to Grow it': Foraging/Farming Transitions and Food Conceptualization in the Highlands of Borneo.

Batsound. https://batsound.com/

Beccari, O. (1904). Wanderings in the great forests of Borneo: travels and researches of a naturalist in Sarawak. A. Constable & Company, Limited.

Bellwood, P. (2007). Prehistory of the Indo-Malaysian Archipelago: revised edition. ANU Press.

Bermant, P. C., Bronstein, M. M., Wood, R. J., Gero, S., & Gruber, D. F. (2019). Deep machine learning techniques for the detection and classification of sperm whale bioacoustics. Scientific reports, 9(1), 12588.

Bevis, W. W. (1995). Borneo log: the struggle for Sarawak's forests. University of Washington Press.

Bird, M. I., Taylor, D., & Hunt, C. (2005). Palaeoenvironments of insular Southeast Asia during the Last Glacial Period: a savanna corridor in Sundaland?. Quaternary Science Reviews, 24(20-21), 2228-2242.

Blackham, G. V., Webb, E. L., & Corlett, R. T. (2014). Natural regeneration in a degraded tropical peatland, Central Kalimantan, Indonesia: Implications for forest restoration. Forest Ecology and Management, 324, 8-15.

Bobay, L. R., Taillie, P. J., & Moorman, C. E. (2018). Use of autonomous recording units increased detection of a secretive marsh bird. Journal of Field Ornithology, 89(4), 384-392.

Brandes, T. S. (2008). Automated sound recording and analysis techniques for bird surveys and conservation. Bird Conservation International, *18*(S1), S163-S173.

Broadbent, E. N., Asner, G. P., Keller, M., Knapp, D. E., Oliveira, P. J., & Silva, J. N. (2008). Forest fragmentation and edge effects from deforestation and selective logging in the Brazilian Amazon. Biological conservation, 141(7), 1745-1757.

Brookfield, H. C., Byron, Y., & Potter, L. M. (1995). In place of the forest: environmental and socio-economic transformation in Borneo and the Eastern Malay Peninsula (Vol. 893). United Nations University Press.

Brooks, T. M., Pimm, S. L., & Collar, N. J. (1997). Deforestation predicts the number of threatened birds in insular Southeast Asia: La extensión de las deforestaciones predice el número de aves amenazadas de extinción en las islas del sureste de Asia. Conservation Biology, 11(2), 382-394.

Brosius, J. P. (1991). Foraging in tropical rain forests: The case of the Penan of Sarawak, East Malaysia (Borneo). Human Ecology, 19, 123-150.

Brown, E., N. Dudley, A. Lindhe, D.R. Muhtaman, C. Stewart, and T. Synnott (eds.). (2013). Common guidance for the identification of high conservation values. HCV Resource Network.

Browning, E., Gibb, R., Glover-Kapfer, P., & Jones, K. E. (2017). Passive acoustic monitoring in ecology and conservation.

Bruenig, E. F., & Droste, H. J. (1995). Structure, dynamics and management of rainforests on nutrient-deficient soils in Sarawak. Ecology, conservation and management of Southeast Asian rainforests, 41-53.

Burner, R. C., Styring, A. R., Rahman, M. A., & Sheldon, F. H. (2019). Occupancy patterns and upper range limits of lowland Bornean birds along an elevational gradient. Journal of Biogeography, 46(11), 2583-2596.

Campos-Cerqueira, M., & Aide, T. M. (2017). Changes in the acoustic structure and composition along a tropical elevational gradient. Journal of Ecoacoustics, 1(1), 4.

Canterbury, G. E., Martin, T. E., Petit, D. R., Petit, L. J., & Bradford, D. F. (2000). Bird communities and habitat as ecological indicators of forest condition in regional monitoring. Conservation Biology, 14(2), 544-558.

Capotondi, A., & Sardeshmukh, P. D. (2015). Optimal precursors of different types of ENSO events. Geophysical Research Letters, 42(22), 9952-9960.

Carlson, K. M., Curran, L. M., Ponette-González, A. G., Ratnasari, D., Ruspita, Lisnawati, N., ... & Raymond, P. A. (2014). Influence of watershed-climate interactions on stream temperature, sediment yield, and metabolism along a land use intensity gradient in Indonesian Borneo. Journal of Geophysical Research: Biogeosciences, 119(6), 1110-1128.

Carnus, J-M., J. Parrotta, E.G. Brockerhoff, M. Arbez, H. Jactel, A. Kremer, D. Lamb, K. O'Hara & B.Walters. (2003). Planted forests and biodiversity. Paper presented at the UNFF Intersessional Experts Meeting on the Role of Planted Forests in Sustainable Forest Management, 24-30 March, 2003, Wellington, New Zealand.

Chan, L.H. (2002). The impact of present forest policies on sustainable forest management in Malaysia. Proceedings of the Forest Policy Workshop Kuala Lumpur, Malaysia 22-24 January, 2002, FAO Regional Office for Asia and the Pacific, Bangkok.

Chapman, S., Syktus, J., Trancoso, R., Salazar, A., Thatcher, M., Watson, J. E., ... & McAlpine, C. A. (2020). Compounding impact of deforestation on Borneo's climate during El Niño events. Environmental Research Letters, 15(8), 084006.

Chazdon, R. L., & Guariguata, M. R. (2016). Natural regeneration as a tool for large-scale forest restoration in the tropics: prospects and challenges. Biotropica, 48(6), 716-730.

Chazdon, R. L., Harvey, C. A., Komar, O., Griffith, D. M., Ferguson, B. G., Martínez-Ramos, M., ... & Philpott, S. M. (2009). Beyond reserves: A research agenda for conserving biodiversity in human-modified tropical landscapes. Biotropica, 41(2), 142-153.

Chen, C. C., Lin, H. W., Yu, J. Y., & Lo, M. H. (2016). The 2015 Borneo fires: What have we learned from the 1997 and 2006 El Niños?. Environmental Research Letters, 11(10), 104003.

Chesmore, E. D., & Ohya, E. (2004). Automated identification of field-recorded songs of four British grasshoppers using bioacoustic signal recognition. Bulletin of entomological research, 94(4), 319-330.

Chin, S. C. (1977). The limestone hill flora of Malaya I.

Chokkalingam, U., & De Jong, W. (2001). Secondary forest: a working definition and typology. The International Forestry Review, 19-26.

Cibois, A. (2003). Mitochondrial DNA phylogeny of babblers (Timaliidae). Auk 120(1): 35–54.

Clements, R., Sodhi, N. S., Schilthuizen, M., & Ng, P. K. (2006). Limestone karsts of Southeast Asia: imperiled arks of biodiversity. Bioscience, 56(9), 733-742.

Cockburn, P. F. (1976). Trees of Sabah, vol. 1. Sabah Forest Record No. 10, Borneo Literature Bureau, Kuching, Sarawak.

Cooke, F. M., (2006). State, communities, and forests in contemporary Borneo (p. 208). ANU press.

Cooke, F. M. (2013). Scientific forestry: history, boundary. Reading Asia: New Research in Asian Studies, 128.

Corlett, R. T. (2007). What's so special about Asian tropical forests?. Current Science, 1551-1557.

Cramb, R. A., & Ferraro, D. (2012). Custom and capital: A financial appraisal of alternative arrangements for large-scale oil palm development on customary land in Sarawak, Malaysia. Malaysian Journal of Economic Studies, 49(1), 49-69.

Cramb, R., & Sujang, P. S. (2016). Oil palm smallholders and state policies in Sarawak. The Oil Palm Complex: Smallholders, Agribusiness and the State in Indonesia and Malaysia, 247-282.

Cramb, R. (2016). The political economy of large-scale oil palm development in Sarawak. The oil palm complex: Smallholders, agribusiness and the state in Indonesia and Malaysia, 189-246.

Cranbrook, E., & Edwards, D. S. (1994). A tropical rainforest: the nature of biodiversity in Borneo at Belalong. Brunei Sun Tree Publishing, London UK and Singapore.

Cropper Jr, W. P., & Putz, F. E. (2017). Effects of silvicultural intensification on timber yields, carbon dynamics, and tree species composition in a dipterocarp forest in Kalimantan, Indonesia: An individual-tree-based model simulation. Forest Ecology and Management, 390, 104-118.

Curran, L. M., & Leighton, M. (2000). Vertebrate responses to spatiotemporal variation in seed production of mast-fruiting Dipterocarpaceae. Ecological Monographs, 70(1), 101-128.

Curran, L. M., Caniago, I., Paoli, G. D., Astianti, D., Kusneti, M., Leighton, M., ... & Haeruman, H. (1999). Impact of El Nino and logging on canopy tree recruitment in Borneo. Science, 286(5447), 2184-2188.

Das, S. C., Alam, M. S., & Hossain, M. A. (2018). Diversity and structural composition of species in dipterocarp forests: a study from Fasiakhali Wildlife Sanctuary, Bangladesh. Journal of forestry research, 29, 1241-1249.

De Bruyn, M., Stelbrink, B., Morley, R. J., Hall, R., Carvalho, G. R., Cannon, C. H., ... & Von Rintelen, T. (2014). Borneo and Indochina are major evolutionary hotspots for Southeast Asian biodiversity. Systematic Biology, 63(6), 879-901.

Dommain, R., Dittrich, I., Giesen, W., Joosten, H., Rais, D. S., Silvius, M., & Wibisono, I. T. C. (2016). Ecosystem services, degradation and restoration of peat swamps in the Southeast Asian tropics. Peatland restoration and ecosystem services: Science, policy and practice, 253-288.

Donato, D. C., Kauffman, J. B., Murdiyarso, D., Kurnianto, S., Stidham, M., & Kanninen, M. (2011). Mangroves among the most carbon-rich forests in the tropics. Nature geoscience, 4(5), 293-297.

Dove, M. R. (1981). Symbiotic relationships between human populations and Imperata cylindrica: The question of ecosystemic succession and preservation in South Kalimantan. Faculty of Science Universiti Kebangsaan Malaysia.

Drescher, J., Rembold, K., Allen, K., Beckschäfer, P., Buchori, D., Clough, Y., ... & Scheu, S. (2016). Ecological and socio-economic functions across tropical land use systems after rainforest conversion. Philosophical Transactions of the Royal Society B: Biological Sciences, 371(1694), 20150275.

Drummond, I., & Taylor, D. (1997). Forest utilisation in Sarawak, Malaysia: a case of sustaining the unsustainable. Singapore Journal of Tropical Geography, 18(2), 141-162.

Eaton, J. A., van Balen, B., Brickle, N. W., & Rheindt, F. E. (2017). BIRDS OF THE INDONESIAN ARCHIPELAGO. GREATER SUNDAS AND WALLACEA.
Edwards, D.P., and Laurance, S.G. (2012). Green labelling, sustainability and the expansion of tropical agriculture: critical issues for certification schemes. Biological Conservation, 151, 60-64.

Edwards,P.J. & Parish, D. 1988. The distribution of migratory waders in south-west Sarawak. Wader Study Group Bull. 54: 36-40.

Edwards, D. P., Magrach, A., Woodcock, P., Ji, Y., Lim, N. T. L., Edwards, F. A., ... & Yu, D. W. (2014). Selective-logging and oil palm: Multitaxon impacts, biodiversity indicators, and trade-offs for conservation planning. Ecological Applications, 24(8), 2029-2049.

Esselstyn, J. A., Oliveros, C. H., Moyle, R. G., Peterson, A. T., McGuire, J. A., & Brown, R. M. (2010). Integrating phylogenetic and taxonomic evidence illuminates complex biogeographic patterns along Huxley's modification of Wallace's Line. Journal of Biogeography, 37(11), 2054-2066.

Estrada, A., Coates-Estrada, R., & Meritt, D. A. (1997). Anthropogenic landscape changes and avian diversity at Los Tuxtlas, Mexico. Biodiversity & Conservation, 6, 19-43.

Eve, R., & Guigue, A. M. (1989). Survey of the Mahakam river delta, East Kalimantan with special reference to its waterbirds. Asian Wetland Bureau (AWB).

Federal Constitution of Malaysia. 1957. Available online: https://lom.agc.gov.my/federal-constitution.php

FDS. Forest Department Sarawak. (2021). Forest Department Sarawak Strategic Plan 2021-2025; Forest Department Sarawak: Kuching, Malaysia.

Fimbel, R. A., Robinson, J., & Grajal, A. (Eds.). (2001). The cutting edge: conserving wildlife in logged tropical forests. Columbia University Press.

Fitzherbert, E. B., Struebig, M. J., Morel, A., Danielsen, F., Brühl, C. A., Donald, P. F., & Phalan, B. (2008). How will oil palm expansion affect biodiversity?. Trends in ecology & evolution, 23(10), 538-545.

Fleishman, E., Thomson, J. R., Mac Nally, R., Murphy, D. D., & Fay, J. P. (2005). Using indicator species to predict species richness of multiple taxonomic groups. Conservation biology, 19(4), 1125-1137.

Freeman, D. (1955). Iban agriculture: a report on the shifting cultivation of hill rice by the Iban of Sarawak.

Freemark, K. E., & Merriam, H. G. (1986). Importance of area and habitat heterogeneity to bird assemblages in temperate forest fragments. Biological conservation, 36(2), 115-141.

Gaither Jr, J. C. (1994). Understory avifauna of a Bornean peat swamp forest: Is it depauperate?. The Wilson Bulletin, 381-390.

Gan, H., Zhang, J., Towsey, M., Truskinger, A., Stark, D., Van Rensburg, B. J., ... & Roe, P. (2021). A novel frog chorusing recognition method with acoustic indices and machine learning. Future Generation Computer Systems, 125, 485-495.

Garrity, D. P., Soekardi, M., Van Noordwijk, M., De La Cruz, R., Pathak, P. S., Gunasena, H. P. M., ... & Majid, N. M. (1996). The Imperata grasslands of tropical Asia: area, distribution, and typology. Agroforestry Systems, 36, 3-29.

Gaveau et al. (2016) Rapid conversions and avoided deforestation: examining four decades of industrial plantation expansion in Borneo. Scientific Reports. doi: 10.1038/srep32017

Gaveau, D. L., Locatelli, B., Salim, M. A., Yaen, H., Pacheco, P., & Sheil, D. (2019). Rise and fall of forest loss and industrial plantations in Borneo (2000–2017). Conservation Letters, 12(3), e12622.

Gaveau, D. L., Sloan, S., Molidena, E., Yaen, H., Sheil, D., Abram, N. K., ... & Meijaard, E. (2014). Four decades of forest persistence, clearance and logging on Borneo. PloS one, 9(7), e101654.

Gawin, D. F., Rahman, M. A., Ramji, M. F. S., Smith, B. T., Lim, H. C., Moyle, R. G., & Sheldon, F. H. (2014). Patterns of avian diversification in Borneo: the case of the endemic Mountain Black-eye (Chlorocharis emiliae). The Auk: Ornithological Advances, 131(1), 86-99.

GFW. Global Forest Watch. (2022). https://data.globalforestwatch.org/datasets/78f995f7dda8451dbc3253c466375766_5/explore?location=3.149570%2C112.765827%2C7.94

Gibbs, H. K., A. S. Ruesch, F. Achard, M. K. Clayton, P. Holmgren, N. Ramankutty, and J. A. Foley. (2010). Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s. Proceedings of the National Academy of Sciences USA 107: 16732–16737.

Gil, D., & Llusia, D. (2020). The bird dawn chorus revisited. Coding strategies in vertebrate acoustic communication, 45-90.

Giri, C., Ochieng, E., Tieszen, L. L., Zhu, Z., Singh, A., Loveland, T., ... & Duke, N. (2011). Status and distribution of mangrove forests of the world using earth observation satellite data. Global Ecology and Biogeography, 20(1), 154-159.

Giri, C., Long, J., Abbas, S., Murali, R. M., Qamer, F. M., Pengra, B., & Thau, D. (2015). Distribution and dynamics of mangrove forests of South Asia. Journal of environmental management, 148, 101-111.

Gomyo, M., & Kuraji, K. (2009). Spatial and temporal variations in rainfall and the ENSO-rainfall relationship over Sarawak, Malaysian Borneo. Sola, 5, 41-44.

Gregory, R. D., Noble, D., Field, R., Marchant, J., Raven, M., & Gibbons, D. W. (2003). Using birds as indicators of biodiversity. Ornis hungarica, 12(13), 11-24.

Gruwier, B., de Vos, J., & Kovarovic, K. (2015). Exploration of the taxonomy of some Pleistocene Cervini (Mammalia, Artiodactyla, Cervidae) from Java and Sumatra (Indonesia): a geometric-and linear morphometric approach. Quaternary Science Reviews, 119, 35-53.

Grytnes, J. A., & Beaman, J. H. (2006). Elevational species richness patterns for vascular plants on Mount Kinabalu, Borneo. Journal of biogeography, 33(10), 1838-1849.

Gustafsson, L. (2000). Red-listed species and indicators: vascular plants in woodland key habitats and surrounding production forests in Sweden. Biological Conservation, 92(1), 35-43.

Hall, R., & Morley, C. K. (2004). Sundaland basins. Continent-ocean interactions within East Asian marginal seas, 149, 55-85.

Hanebuth, T., Stattegger, K., & Grootes, P. M. (2000). Rapid flooding of the Sunda Shelf: a late-glacial sea-level record. Science, 288(5468), 1033-1035.

Hanebuth, T. J., Stattegger, K., & Bojanowski, A. (2009). Termination of the Last Glacial Maximum sea-level lowstand: The Sunda-Shelf data revisited. *Global and Planetary Change*, *66*(1-2), 76-84.

Hanowski, J. M., Niemi, G. J., & Christian, D. C. (1997). Inf luence of Within-Plantation Heterogeneity and Surrounding Landscape Composition on Avian Communities in Hybrid Poplar Plantations: Influencia de la Heterogeneidad Intra-plantación y de la Composición del Paisaje Circundante Sobre Comunidades de Aves en Plantaciones de Alamo Híbrido. Conservation Biology, 11(4), 936-944.

Hanya, G., Kanamori, T., Kuze, N., Wong, S. T., & Bernard, H. (2020). Habitat use by a primate community in a lowland dipterocarp forest in Danum Valley, Borneo. American Journal of Primatology, 82(8), e23157.

HARRISSON, T. (1970). The prehistory of Borneo. Asian Perspectives, 13, 17-45.

Heaney, Lawrence R. (1984). "Mammalian Species Richness on Islands on the Sunda Shelf, Southeast Asia". Oecologia. 61 (1): 11–17. Bibcode:1984Oecol..61...11H. CiteSeerX 10.1.1.476.4669. doi:10.1007/BF00379083. JSTOR 4217198. PMID 28311380. S2CID 4810675.

Heaney, L. R. (1986). Biogeography of mammals in SE Asia: estimates of rates of colonization, extinction and speciation. Biological journal of the Linnean Society, 28(1-2), 127-165.

Heaney, L.R. (1991) A synopsis of climatic and vegetational change in Southeast Asia. Climatic Change, 19, 53–61.

Heinicke, S., Kalan, A. K., Wagner, O. J., Mundry, R., Lukashevich, H., & Kühl, H. S. (2015). Assessing the performance of a semi-automated acoustic monitoring system for primates. Methods in Ecology and Evolution, 6(7), 753-763.

Henders, S., Persson, U. M., & Kastner, T. (2015). Trading forests: land-use change and carbon emissions embodied in production and exports of forest-risk commodities. Environmental Research Letters, 10(12), 125012.

Hidayat, R., Juniarti, M. D., & Ma'Rufah, U. (2018). Impact of la Niña and la Niña Modoki on Indonesia rainfall variability. In IOP Conference Series: Earth and Environmental Science (Vol. 149, No. 1, p. 012046). IOP Publishing.

Hill, A. P., Prince, P., Piña Covarrubias, E., Doncaster, C. P., Snaddon, J. L., & Rogers, A. (2018). AudioMoth: Evaluation of a smart open acoustic device for monitoring biodiversity and the environment. Methods in Ecology and Evolution, 9(5), 1199-1211.

Holmes, D. A., & Wall, J. R. D. (1989). Letter: Setornis criniger, Malacopteron albogulare and conservation in Indonesia. Forktail, 4, 123-125.

Hon, J., & Shibata, S. (2013). A review on land use in the Malaysian state of Sarawak, Borneo and recommendations for wildlife conservation inside production forest environment. Borneo Journal of Resource Science and Technology, 3(2), 22-35.

Hopkins, D. M. (1982). Aspects of the paleoecology of Beringia during the late Pleistocene. Paleoecology of Beringia, 33-28.

Hose, C. (1894). The natives of Borneo. The Journal of the Anthropological Institute of Great Britain and Ireland, 23, 156-172.

Hunt, C. O., & Premathilake, R. (2012). Early Holocene vegetation, human activity and climate from Sarawak, Malaysian Borneo. Quaternary International, 249, 105-119.

Ichikawa, M. (2007). Degradation and loss of forest land and land-use changes in Sarawak, East Malaysia: a study of native land use by the Iban. In Sustainability and Diversity of Forest Ecosystems (pp. 403-413). Springer, Tokyo.

ITTO. International Tropical Timber Organization.(2018) Biennial Review and Assessment of the World Tropical Timber Situation 2017-2018

IUCN. (2023). The IUCN Red List of Threatened Species. Version 2023-1. https://www.iucnredlist.org.

James, F. C., Johnston, R. F., Wamer, N. O., Niemi, G. J., & Boecklen, W. J. (1984). The Grinnellian niche of the wood thrush. The American Naturalist, 124(1), 17-47.

Janzen, D. H., Hallwachs, W., Blandin, P., Burns, J. M., CADIOU, J. M., Chacon, I., ... & Wilson, J. J. (2009). Integration of DNA barcoding into an ongoing inventory of complex tropical biodiversity. Molecular ecology resources, 9, 1-26. Krishnamurthy, P., & Francis, R. A. (2012). A critical review on the utility of DNA barcoding in biodiversity conservation. Biodiversity and conservation, 21, 1901-1919.

Janzen, D. H. (1974). Tropical blackwater rivers, animals, and mast fruiting by the Dipterocarpaceae. Biotropica, 69-103.

Jennings, S., Nussbaum, R., Judd N. et al. (2003). The high conservation value forest toolkit. Part 2. Defining high conservation values at a national level: a practical guide. Proforest, Oxford, UK.

Johns, A. D. (1988). Effects of" selective" timber extraction on rain forest structure and composition and some consequences for frugivores and folivores. Biotropica, 31-37.

Jomo, K. S., Chang, Y. T., & Khoo, K. J. (2004). Deforesting Malaysia: the political economy and social ecology of agricultural expansion and commercial logging. Zed Books.

Jusoh, I., & Tiong, S. L. (2016). Growth and yield of an Acacia mangium plantation in Sarawak. Sustainable Forest Development in view of Climate Change (SFDCC2016), 145.

Katagiri, S., Yamakura, T., & Lee, S. H. (1991). Properties of soils in kerangas forest on sandstone at Bako National Park, Sarawak, East Malaysia. Japanese Journal of Southeast Asian Studies, 29(1), 35-48.

Kathiresan, K., & Bingham, B. L. (2001). Biology of mangroves and mangrove ecosystems.

Kaur, A. (1998). A history of forestry in Sarawak. *Modern Asian Studies*, *32*(1), 117-147.

Kawabe, M., & Mano, T. (1972). Ecology and behavior of the wild proboscis monkey, Nasalis larvatus (Wurmb), in Sabah, Malaysia. Primates, 13, 213-227.

Kelly, D., & Sork, V. L. (2002). Mast seeding in perennial plants: why, how, where?. Annual review of ecology and systematics, 33(1), 427-447.

Kelly, D. (1994). The evolutionary ecology of mast seeding. Trends in ecology & evolution, 9(12), 465-470.

Kendawang, J. J., Tanaka, S., Soda, R., SEMAN, L., WASLI, M. E., & SAKURAI, K. (2005). Difference of rice farming practices of the Iban in a national boundary area in Borneo and its socio-economic background. Tropics, 14(4), 295-307.

Kinnaird, M. F., O'Brien, T. G., & Suryadi, S. (1996). Population fluctuation in Sulawesi Red-knobbed Hornbills: tracking figs in space and time. The Auk, 113(2), 431-440.

Kogan, J. A., & Margoliash, D. (1998). Automated recognition of bird song elements from continuous recordings using dynamic time warping and hidden Markov models: A comparative study. *The Journal of the Acoustical Society of America*, *103*(4), 2185-2196.

Koh, L. P., & Wilcove, D. S. (2008). Is oil palm agriculture really destroying tropical biodiversity?. Conservation letters, 1(2), 60-64.

Koh, J., Johari, S., Shuib, A., Siow, M. L., & Matthew, N. K. (2023). Malaysia's forest pledges and the Bornean state of Sarawak: A policy perspective. Sustainability, 15(2), 1385.

Kummer, D. M., & Turner, B. L. (1994). The human causes of deforestation in Southeast Asia. Bioscience, 44(5), 323-328.

Kurokawa, H., Yoshida, T., Nakamura, T., Lai, J., & Nakashizuka, T. (2003). The age of tropical rain-forest canopy species, Borneo ironwood (Eusideroxylon zwageri), determined by 14C dating. Journal of Tropical Ecology, 19(1), 1-7.

Kurokawa, H., Yoshida, T., Nakamura, T., Lai, J., & Nakashizuka, T. (2003). The age of tropical rain-forest canopy species, Borneo ironwood (Eusideroxylon zwageri), determined by 14C dating. Journal of Tropical Ecology, 19(1), 1-7.

Lahoz-Monfort, J. J., & Magrath, M. J. (2021). A comprehensive overview of technologies for species and habitat monitoring and conservation. BioScience, 71(10), 1038-1062.

Lambert, F. R., & Collar, N. J. (2002). The future for Sundaic lowland forest birds: long-term effects of commercial logging and fragmentation. Forktail, 18(2002), 127-146.

Lambert, F. (1989). Fig-eating by birds in a Malaysian lowland rain forest. Journal of Tropical Ecology, 5(4), 401-412.

Landres, P. B., Verner, J., & Thomas, J. W. (1988). Ecological uses of vertebrate indicator species: a critique. Conservation biology, 2(4), 316-328.

Langub, J., & Ishikawa, N. (2017). Community, river and basin: Watersheds in northern Sarawak as a social linkage. Borneo studies in history, society and culture, 365-384.

Langub, J. (2020). The Penan of Jelalong River, Sarawak: A Narrative of Migration and Adaptation. Anthropogenic Tropical Forests: Human–Nature Interfaces on the Plantation Frontier, 123-145.

Laurance, W.F. (2007). Forest destruction in tropical Asia. Curr. Sci. 93 (11), 1544–1550. http://www.jstor.org/stable/24099083

Lee, S. S. (2018). Observations on the successes and failures of acacia plantations in Sabah and Sarawak and the way forward. Journal of Tropical Forest Science, 30(5), 468-475.

Leighton, M. (1984). The El Nino-southern oscillation event in Southeast Asia: effects of drought and fire in tropical forest in Eastern Borneo. WWF report, 31.

Lennertz, R., & Panzer, K. F. (1984). Preliminary assessment of the drought and forest fire damage in Kalimantan Timur. Report by DFS German Forest Inventory Service Ltd. for Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), 45.

Lewis, R. A., & Davis, S. R. (2015). Forest certification, institutional capacity, and learning: An analysis of the impacts of the Malaysian Timber Certification Scheme. Forest Policy and Economics, 52, 18-26.

Lewis, R. A. (2011). Networked knowledge (s)?: Forest certification and the politics of expertise in Malaysia (Doctoral dissertation, School of Geography & Development, The University of Arizona).

Lim, H.C., Sheldon, F.H. (2011). Multilocus analysis of the evolutionary dynamics of rainforest bird populations in Southeast Asia. Mol. Ecol. 20, 3414–3438.

Lim, H. C., Rahman, M. A., Lim, S. L., Moyle, R. G., & Sheldon, F. H. (2011). Revisiting Wallace's haunt: Coalescent simulations and comparative niche modeling reveal historical mechanisms that promoted avian population divergence in the Malay Archipelago. Evolution: International Journal of Organic Evolution, 65(2), 321-334.

Lohman, D. J., de Bruyn, M., Page, T., von Rintelen, K., Hall, R., Ng, P. K., ... & von Rintelen, T. (2011). Biogeography of the Indo-Australian archipelago. Annual Review of Ecology, Evolution, and Systematics, 42, 205-226.

MacArthur, R. H., & MacArthur, J. W. (1961). On bird species diversity. Ecology, 42(3), 594-598.

MacKenzie, D. I., Bailey, L. L., & Nichols, J. D. (2004). Investigating species co-occurrence patterns when species are detected imperfectly. Journal of Animal Ecology, 73(3), 546-555.

MacKinnon, K., Hatta, G., Halim, H., & Mangalik, A. (1996). The Ecology of Kalimantan, Periplus Editions.

Malcolm, J. R. (1994). Edge effects in central Amazonian forest fragments. Ecology, 75(8), 2438-2445.

Malingreau, J. P. (1985). Remote sensing of forest fires: Kalimantan and North Borneo in 1982-83. Ambio, 14, 314-321.

Maloney, T. R., Dilkes-Hall, I. E., Setiawan, P., Oktaviana, A. A., Geria, I. M., Effendy, M., ... & Aubert, M. (2022). A late Pleistocene to Holocene archaeological record from East Kalimantan, Borneo. *Quaternary Science Reviews*, *277*, 107313.

Mansor, M. S., Sah, S. A. M., Koon, L. C., & Rahman, M. A. (2011). Bird species diversity in the padawan limestone area, sarawak. Tropical Life Sciences Research, 22(2), 65.

Marques, T. A., Thomas, L., Martin, S. W., Mellinger, D. K., Ward, J. A., Moretti, D. J., ... & Tyack, P. L. (2013). Estimating animal population density using passive acoustics. Biological reviews, 88(2), 287-309.

Martensen, A. C., Ribeiro, M. C., Banks-Leite, C., Prado, P. I., & Metzger, J. P. (2012). Associations of forest cover, fragment area, and connectivity with neotropical understory bird species richness and abundance. Conservation Biology, 26(6), 1100-1111.

Martin, T. E., & Li, P. (1992). Life history traits of open-vs. cavity-nesting birds. Ecology, 73(2), 579-592.

Martin, T. E. (1986). Competition in breeding birds: On the importance of considering processes at the level of the individual. Pages 181–210 in R. F. Johnston, editor. Current Ornithology. Volume 4. Plenum Press, New York , New York .

Martínez-Ramos, M., Pingarroni, A., Rodríguez-Velázquez, J., Toledo-Chelala, L., Zermeño-Hernández, I., & Bongers, F. (2016). Natural forest regeneration and ecological restoration in human-modified tropical landscapes. Biotropica, 48(6), 745-757.

Matos, F. A., Magnago, L. F., Aquila Chan Miranda, C., de Menezes, L. F., Gastauer, M., Safar, N. V., ... & Edwards, D. P. (2020). Secondary forest fragments offer important carbon and biodiversity cobenefits. Global Change Biology, 26(2), 509-522.

Mayr, E. (1944). Wallace's line in the light of recent zoogeographic studies. The Quarterly Review of Biology, 19(1), 1-14.

McConkey, K. R., Aldy, F., Ong, L., Sutisna, D. J., & Campos-Arceiz, A. (2022). Lost mutualisms: Seed dispersal by Sumatran rhinos, the world's most threatened megafauna. Biotropica, 54(2), 346-357.

McPhaden, M. J., Zebiak, S. E., & Glantz, M. H. (2006). ENSO as an integrating concept in earth science. science, 314(5806), 1740-1745.

McShea, W. J., Stewart, C., Peterson, L., Erb, P., Stuebing, R., & Giman, B. (2009). The importance of secondary forest blocks for terrestrial mammals within an Acacia/secondary forest matrix in Sarawak, Malaysia. Biological Conservation, 142(12), 3108-3119.

Mead, J. P. (1925). Forestry in Sarawak. Empire Forestry Journal, 4(1), 92-99.

Meijaard, E., & Nijman, V. (2003). Primate hotspots on Borneo: predictive value for general biodiversity and the effects of taxonomy. Conservation Biology, 17(3), 725-732.

Meijaard, E., Sheil, D., Nasi, R., Augeri, D., Rosenbaum, B., Iskandar, D., ... & O'Brien, T. (2005). Life after logging: reconciling wildlife conservation and production forestry in Indonesian Borneo. Cifor.

Meijaard, E., Abram, N. K., Wells, J. A., Pellier, A. S., Ancrenaz, M., Gaveau, D. L., ... & Mengersen, K. (2013). People's perceptions about the importance of forests on Borneo. PloS one, 8(9), e73008.

Meijaard, E., Brooks, T. M., Carlson, K. M., Slade, E. M., Garcia-Ulloa, J., Gaveau, D. L., ... & Sheil, D. (2020). The environmental impacts of palm oil in context. Nature plants, 6(12), 1418-1426.

Metcalfe, I. (2017). Tectonic evolution of Sundaland.

Miettinen, J., Shi, C., & Liew, S. C. (2011). Deforestation rates in insular Southeast Asia between 2000 and 2010. Global Change Biology, 17(7), 2261-2270.

Mishra, S., Page, S. E., Cobb, A. R., Lee, J. S. H., Jovani-Sancho, A. J., Sjögersten, S., ... & Wardle, D. A. (2021). Degradation of Southeast Asian tropical peatlands and integrated strategies for their better management and restoration. Journal of Applied Ecology, 58(7), 1370-1387.

Mitra, S. S., & Sheldon, F. H. (1993). Use of an exotic tree plantation by Bornean lowland forest birds. The Auk, 110(3), 529-540.

Mittermeier, R. A., N. Myers & C. G. Mittermeier. (1999). Hotspots: earth's biologically richest and most endangered terrestrial ecoregions. CEMEX; Conservation International. 431 pp.

Miyamoto, K., Wagai, R., Aiba, S. I., & Nilus, R. (2016). Variation in the aboveground stand structure and fine-root biomass of Bornean heath (kerangas) forests in relation to altitude and soil nitrogen availability. Trees, 30, 385-394.

Molengraaff, G. A. F. (1921). Modern deep-sea research in the East Indian Archipelago. The Geographical Journal, 57(2), 95-118.

Moore, W. S. (1982). Late Pleistocene sea-level history. In Uranium series disequilibrium: applications to environmental problems.

Morley, R. J. (2000). Origin and evolution of tropical rain forests. John Wiley & Sons.

Morrison, M. L. (1986). Bird populations as indicators of environmental change. Pages 429–451 in R. F. Johnston, editor. Current Ornithology. Volume 3. Plenum Press, New York , New York .

Moyle, R.G., Andersen, M.J., Oliveros, C.H., Steinheimer, F.D. & Reddy, S. (2012). Phylogeny and biogeography of the core babblers (Aves: Timaliidae). Systematic Biology 61(4): 631–651.

Mukhlisi, M., Sayektiningsih, T., & Yassir, I. (2021). Bird Communities in the Karst Forests of Teluk Sumbang, East Kalimantan, Indonesia.

Mulyoutami, E., Rismawan, R., & Joshi, L. (2009). Local knowledge and management of simpukng (forest gardens) among the Dayak people in East Kalimantan, Indonesia. Forest Ecology and Management, 257(10), 2054-2061.

Murcia, C. (1995). Edge effects in fragmented forests: implications for conservation. Trends in ecology & evolution, 10(2), 58-62.

Myers, S. (2016). Birds of Borneo. Bloomsbury Publishing.

Naniwadekar, R., Mishra, C., & Datta, A. (2015). Fruit resource tracking by hornbill species at multiple scales in a tropical forest in India. Journal of Tropical Ecology, 31(6), 477-490.

Nasi, R., Koponen, P., Poulsen, J. G., Buitenzorgy, M., & Rusmantoro, W. (2009). Impact of landscape and corridor design on primates in a large-scale industrial tropical plantation landscape. Plantation Forests and Biodiversity: Oxymoron or Opportunity?, 181-202.

Newbery, D. M., Renshaw, E., & Brünig, E. F. (1986). Spatial pattern of trees in kerangas forest, Sarawak. Vegetatio, 65, 77-89.

Newbery, D. M. (1991). Floristic variation within kerangas (heath) forest: re-evaluation of data from Sarawak and Brunei. Vegetatio, 96, 43-86.

Ngidang, D. (2002). Contradictions in land development schemes: the case of joint ventures in Sarawak, Malaysia. Asia Pacific Viewpoint, 43(2), 157-180.

Nicholson, D. I. (1958). An analysis of logging damage in tropical rain forest, North Borneo. Malayan Forester, 21(4), 235-245.

Nicholson, D. I. (1979). The effects of logging and treatment on the mixed Dipterocarp forests of South East Asia.

Ohsawa, M. (1991). Structural comparison of tropical montane rain forests along latitudinal and altitudinal gradients in south and east Asia. Vegetatio, 97, 1-10.

Ohsawa, M. (1995). The montane cloud forest and its gradational changes in Southeast Asia. In Tropical montane cloud forests (pp. 254-265). Springer US.

Oksanen, J. (2015). Vegan: an introduction to ordination.

Padoch, C. (1988). Agriculture in interior Borneo. Expedition, 30(1), 18.

Page, S, Hoscilo, A., Langner, A., Tansey, K., Siegert, F., Limin, S., & Rieley, J. (2009). Tropical peatland fires in Southeast Asia. In: Cochrane, M. A. (ed.). Tropical fire ecology: climate change, land use, and ecosystem dynamics, 263-287.

Palmiotto, P. A., Davies, S. J., Vogt, K. A., Ashton, M. S., Vogt, D. J., & Ashton, P. S. (2004). Soil-related habitat specialization in dipterocarp rain forest tree species in Borneo. Journal of Ecology, 609-623.

Paoli, G. D., Curran, L. M., & Slik, J. W. F. (2008). Soil nutrients affect spatial patterns of aboveground biomass and emergent tree density in southwestern Borneo. Oecologia, 155, 287-299.

Parsons, S., & Jones, G. (2000). Acoustic identification of twelve species of echolocating bat by discriminant function analysis and artificial neural networks. Journal of experimental biology, 203(17), 2641-2656.

Pearson, D. L. (1994). Selecting indicator taxa for the quantitative assessment of biodiversity. Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences, 345(1311), 75-79.

Pedley, L. (1975). Revision of the extra-Australian species of Acacia subg. Heterophyllum. Contributions from the Queensland Herbarium, 1-24.

Peluso, N. L. (1992). The ironwood problem:(mis) management and development of an extractive rainforest product. Conservation Biology, 6(2), 210-219.

Phillipps, Q. (2011). *Phillipps' field guide to the birds of Borneo*. Oxford, England: John Beaufoy.

Phillipps, Q. (2016). Phillipps' field guide to the mammals of Borneo and their ecology: Sabah, Sarawak, Brunei, and Kalimantan (Vol. 105). Princeton University Press.

Phillips, V. D. (1998). Peatswamp ecology and sustainable development in Borneo. Biodiversity & Conservation, 7, 651-671.

Pinard, M. A., & Putz, F. E. (1996). Retaining forest biomass by reducing logging damage. Biotropica, 278-295.

Porter, A. F. (1967). The Development of Land Administration in Sarawak from the Rule of Rajah James Brooke to the Present Time, 1841-1967, Kuching: Land and Survey Department

Posa, M. R. C., & Marques, D. A. (2012). Peat swamp forest birds of the Tuanan research station, Central Kalimantan, Indonesia, with notes on habitat specialists. Forktail, 28(28), 29-37.

Posa, M. R. C. (2011). Peat swamp forest avifauna of Central Kalimantan, Indonesia: Effects of habitat loss and degradation. Biological conservation, 144(10), 2548-2556.

Raes, N., Roos, M. C., Slik, J. F., Van Loon, E. E., & Steege, H. T. (2009). Botanical richness and endemicity patterns of Borneo derived from species distribution models. Ecography, 32(1), 180-192.

Rahman, I. A., & Suratman, M. N. (2016). Assessments of Growth, Volume and Above Ground Biomass of Four Forest Plantation Species In Sarawak, Malaysia. In Proceedings of the Second International Conference on Science, Engineering & Environment, Osaka, Japan (pp. 21-23).

Reid, W. V. (1998). Biodiversity hotspots. Trends in Ecology & Evolution, 13(7), 275-280.

Reynolds, G., Payne, J., Sinun, W., Mosigil, G., & Walsh, R. P. (2011). Changes in forest land use and management in Sabah, Malaysian Borneo, 1990–2010, with a focus on the Danum Valley region. Philosophical Transactions of the Royal Society B: Biological Sciences, 366(1582), 3168-3176.

Richards, D. R., & Friess, D. A. (2016). Rates and drivers of mangrove deforestation in Southeast Asia, 2000–2012. Proceedings of the National Academy of Sciences, 113(2), 344-349.

Riede, K. (1998). Acoustic monitoring of Orthoptera and its potential for conservation. Journal of Insect Conservation, 2(3-4), 217-223.

Ritzema, H., & Wösten, H. (2002). Hydrology of Borneo's peat swamps. In Strategies for implementing sustainable management of peatlands in Borneo. Proceedings STRAPEAT partners workshop, Palangka Raya, Kalimantan, Indonesia and Sibu, Sarawak, Malaysia.

Robinson, S. K., Thompson III, F. R., Donovan, T. M., Whitehead, D. R., & Faaborg, J. (1995). Regional forest fragmentation and the nesting success of migratory birds. *Science*, *267*(5206), 1987-1990.

Rosenthal, G. G., & Ryan, M. J. (2000). Visual and acoustic communication in non-human animals: a comparison. Journal of biosciences, 25, 285-290.

Rowcliffe, J. M., Kays, R., Kranstauber, B., Carbone, C., & Jansen, P. A. (2014). Quantifying levels of animal activity using camera trap data. Methods in ecology and evolution, 5(11), 1170-1179.

RSPO. Roundtable on Sustainable Palm Oil. (2007). RSPO principles and criteria for sustainable palm oil production including indicators and guidance October 2007. Available from www.rspo.org.

Sada, C., Alas, Y., & Anshari, M. (2019). Indigenous people of Borneo (Dayak): Development, social cultural perspective and its challenges. Cogent Arts & Humanities, 6(1), 1665936.

Salinas, N., Cosio, E. G., Silman, M., Meir, P., Nottingham, A. T., Roman-Cuesta, R. M., & Malhi, Y. (2021). tropical montane forests in a changing environment. Frontiers in plant science, 12, 712748.

Seidl, R., Thom, D., Kautz, M., Martin-Benito, D., Peltoniemi, M., Vacchiano, G., ... & Reyer, C. P. (2017). Forest disturbances under climate change. Nature climate change, 7(6), 395-402.

Şekercioğlu, Ç. H., Ehrlich, P. R., Daily, G. C., Aygen, D., Goehring, D., & Sandí, R. F. (2002). Disappearance of insectivorous birds from tropical forest fragments. Proceedings of the National Academy of Sciences, 99(1), 263-267.

Sellato, B. (2001). Forest, Resources, and People in Bulungan: Elements for a History of Settlement, Trade, and Social Dynamics in Borneo, 1880-2000. Cifor.

Shadbolt, A. B., & Ragai, R. (2010). Effects of habitat fragmentation on the movement patterns and dispersal ability of the brown spiny rat (Maxomys rajah) in the Planted Forest Zone of Sarawak, Eastern Malaysia. Biodiversity and Conservation, 19(2), 531-541.

Sheldon, F. H., & Styring, A. R. (2011). Bird diversity differs between industrial tree plantations on Borneo: Implications for conservation planning. Raffles Bulletin of Zoology, 59(2).

Sheldon, F. H., Styring, A., & Hosner, P. A. (2010). Bird species richness in a Bornean exotic tree plantation: A long-term perspective. Biological conservation, 143(2), 399-407.

Sheldon, F. H., Lim, H. C., & Moyle, R. G. (2015). Return to the Malay Archipelago: the biogeography of Sundaic rainforest birds. Journal of Ornithology, 156(1), 91-113.

Shelford, R. W. C. (1917). A naturalist in Borneo. EP Dutton.

Shim, P. S. (1993). Imperata cylindrica grasslands in Malaysia. Imperata Grasslands in Southeast Asia: Summary Reports from the Philippines, Malaysia, Indonesia, 21-32.

Shonfield, J., & Bayne, E. M. (2017). Autonomous recording units in avian ecological research: current use and future applications. Avian Conservation & Ecology, 12(1).

Siegert, F., Ruecker, G., Hinrichs, A., & Hoffmann, A. A. (2001). Increased damage from fires in logged forests during droughts caused by El Nino. Nature, 414(6862), 437-440.

Siikamäki, J., Sanchirico, J. N., & Jardine, S. L. (2012). Global economic potential for reducing carbon dioxide emissions from mangrove loss. Proceedings of the National Academy of Sciences, 109(36), 14369-14374.

Sist, P., Fimbel, R., Sheil, D., Nasi, R., & Chevallier, M. H. (2003). Towards sustainable management of mixed dipterocarp forests of South-east Asia: moving beyond minimum diameter cutting limits. Environmental conservation, 30(4), 364-374.

Sist, P., Picard, N., & Gourlet-Fleury, S. (2003). Sustainable cutting cycle and yields in a lowland mixed dipterocarp forest of Borneo. Annals of Forest Science, 60(8), 803-814.

Slik, J. W. F., Poulsen, A. D., Ashton, P. S., Cannon, C. H., Eichhorn, K. A. O., Kartawinata, K., ... & Wilkie, P. (2003). A floristic analysis of the lowland dipterocarp forests of Borneo. Journal of Biogeography, 30(10), 1517-1531.

Slik, J. F., Raes, N., Aiba, S. I., Brearley, F. Q., Cannon, C. H., Meijaard, E., ... & Wulffraat, S. (2009). Environmental correlates for tropical tree diversity and distribution patterns in Borneo. Diversity and Distributions, 15(3), 523-532.

Sloan, S., Locatelli, B., Wooster, M. J., & Gaveau, D. L. (2017). Fire activity in Borneo driven by industrial land conversion and drought during El Niño periods, 1982–2010. Global environmental change, 47, 95-109.

Smythies, B. E. (1963). History of forestry in Sarawak. *Malayan forester*, *26*(4), 232-50.

Smythies, B.E. (1999). The Birds of Borneo (4th ed.; G. W. H. Davison, Ed.). Natural History Publications (Borneo) Sdn. Bhd.

Sodhi, N. S., Koh, L. P., Brook, B. W., & Ng, P. K. (2004). Southeast Asian biodiversity: an impending disaster. Trends in ecology & evolution, 19(12), 654-660.

Sodhi, N. S., Posa, M. R. C., Lee, T. M., & Warkentin, I. G. (2008). Perspectives in ornithology: Effects of disturbance or loss of tropical rainforest on birds. The Auk, 125(3), 511-519.

Sodhi, N. S., Koh, L. P., Clements, R., Wanger, T. C., Hill, J. K., Hamer, K. C., ... & Lee, T. M. (2010). Conserving Southeast Asian forest biodiversity in human-modified landscapes. Biological Conservation, 143(10), 2375-2384.

Srikanth, S., Lum, S. K. Y., & Chen, Z. (2016). Mangrove root: adaptations and ecological importance. Trees, 30, 451-465.

Struebig, M. J., Aninta, S. G., Davies, Z. G., Lo, M., & Voigt, M. (2022). Safeguarding imperiled biodiversity and evolutionary processes in the Wallacea center of endemism. BioScience.

Stuebing, R. B., & Gasis, J. (1989). A survey of small mammals within a Sabah tree plantation in Malaysia. Journal of Tropical Ecology, 5(2), 203-214.

Stuebing, R. B. (2005). Wildlife conservation in the planted forests of Sarawak: blind ambition? In An International Conference on Biogeography and Biodiversity. Kota Samarahan, Sarawak, Malaysia: Institute of Biodiversity and Environmental Conservation, Universiti Malaysia Sarawak.

Stuebing, R. B. (2007). Biodiversity conservation in theory and practice: lessons from the Planted Forest Zone, Sarawak. In Proceedings of the Regional Conference of Biodiversity Conservation in Tropical Planted Forests in Southeast Asia. Sarawak Forest Department, Sarawak Forestry Corporation, and Grand Perfect Sdn Bhd, Kuching, Malaysia (pp. 16-30).

Styring, A. R., Ragai, R., Unggang, J., Stuebing, R., Hosner, P. A., & Sheldon, F. H. (2011). Bird community assembly in Bornean industrial tree plantations: effects of forest age and structure. Forest Ecology and Management, 261(3), 531-544.

Styring, A. R., Ragai, R., Zakaria, M., & Sheldon, F. H. (2016). Foraging ecology and occurrence of 7 sympatric babbler species (Timaliidae) in the lowland rainforest of Borneo and peninsular Malaysia. Current zoology, 62(4), 345-355.

Styring, A. R., Unggang, J., Jukie, A., Tateh, O., Megom, N., & Sheldon, F. H. (2018). Bird community structure in native forest fragments and Acacia mangium plantations in Borneo. The Wilson Journal of Ornithology, 130(1), 112-130.

Styring, A. R., Unggang, J., Ragai, R., Kueffner, K., Froehlich, D., Megom, N., ... & James, D. (2022). Determining High Conservation Values in Production Landscapes: Biodiversity and Assessment Approaches. Frontiers in Environmental Science, 1012.

Sugai, L. S. M., Silva, T. S. F., Ribeiro Jr, J. W., & Llusia, D. (2019). Terrestrial passive acoustic monitoring: review and perspectives. BioScience, 69(1), 15-25.

Sukardjo, S., Alongi, D. M., & Kusmana, C. (2013). Rapid litter production and accumulation in Bornean mangrove forests. Ecosphere, 4(7), 1-7.

Sutlive VH, Sutlive J. (2001). The encyclopedia of Iban studies: Iban history, society, and culture. Tun Jugah Foundation.

Takeuchi, Y., Soda, R., Diway, B., Kuda, T. A., Nakagawa, M., Nagamasu, H., & Nakashizuka, T. (2017). Biodiversity conservation values of fragmented communally reserved forests, managed by indigenous people, in a human-modified landscape in Borneo. PLoS One, 12(11), e0187273.

Tangang, F., Farzanmanesh, R., Mirzaei, A., Supari, Salimun, E., Jamaluddin, A. F., & Juneng, L. (2017). Characteristics of precipitation extremes in Malaysia associated with El Niño and La Niña events. International Journal of Climatology, 37, 696-716.

Thomas, W. A. (1972). Indicators of environmental quality: an overview. Indicators of environmental quality, 1-5.

Thorburn, C. C. (2015). The edible nest swiftlet industry in Southeast Asia: Capitalism meets commensalism. Human Ecology, 43(1), 179-184.

Sarachik, E. S., & Cane, M. A. (2010). The El Nino-southern oscillation phenomenon. Cambridge University Press.

Tolentino, P. J., Navidad, J. R. L., Angeles, M. D., Fernandez, D. A. P., Villanueva, E. L. C., Obeña, R. D. R., & BUOT JR, I. E. (2020). Biodiversity of forests over limestone in Southeast Asia with emphasis on the Philippines. Biodiversitas Journal of Biological Diversity, 21(4).

Trolliet, F., Vermeulen, C., Huynen, M. C., & Hambuckers, A. (2014). Use of camera traps for wildlife studies: a review. Biotechnologie, Agronomie, Société et Environnement, 18(3).

Tsuji, K., Ghazalli, M. N. F., Ariffin, Z. U. L. H. A. I. R. I. L., Nordin, M. S., Khaidizar, M. I., Dulloo, M. E., & Sebastian, L. S. (2011). Biological and ethnobotanical characteristics of Nipa Palm (Nypa fructicans wurmb.): A review. Sains Malaysiana, 40(12), 1407-1412.

Tuan Man, T.I. (2021). Statement by Mr. Tuan Ibrahim Tuan Man Honourable Minister of Environment and Water Malaysia for COP-26/CMP-16/CMA-3 Resumed High-Level Segment. In Proceedings of the UNFCCC COP26, Glasgow, UK, 31 October–12 November 2021. (https://unfccc.int/sites/default/files/resource/MALAYSIA_cop26cmp16cma3_HLS_EN.pdf)

Turner, W., Spector, S., Gardiner, N., Fladeland, M., Sterling, E., & Steininger, M. (2003). Remote sensing for biodiversity science and conservation. Trends in ecology & evolution, 18(6), 306-314.

Turvey, N. D. (1994). Afforestation and rehabilitation of Imperata grasslands in Southeast Asia: identification of priorities for research, education, training and extension (No. 436-2016-33817).

Valiela, I., Bowen, J. L., & York, J. K. (2001). Mangrove Forests: One of the World's Threatened Major Tropical Environments: At least 35% of the area of mangrove forests has been lost in the past two decades, losses that exceed those for tropical rain forests and coral reefs, two other well-known threatened environments. Bioscience, 51(10), 807-815.

Verma, M., Symes, W. S., Watson, J. E., Jones, K. R., Allan, J. R., Venter, O., ... & Carrasco, L. R. (2020). Severe human pressures in the Sundaland biodiversity hotspot. *Conservation Science and Practice*, *2*(3), e169.

Visser, M. D., Jongejans, E., van Breugel, M., Zuidema, P. A., Chen, Y. Y., Rahman Kassim, A., & de Kroon, H. (2011). Strict mast fruiting for a tropical dipterocarp tree: a demographic cost–benefit analysis of delayed reproduction and seed predation. Journal of Ecology, 99(4), 1033-1044.

Voris, H. K. (2000). Maps of Pleistocene sea levels in Southeast Asia: shorelines, river systems and time durations. Journal of biogeography, 27(5), 1153-1167.

Wallace, A.R. (1860). On the zoological geography of the Malay Archipelago. J. Proc. Linnean Soc. 4, 172–184.

Walters, C. L., Freeman, R., Collen, A., Dietz, C., Brock Fenton, M., Jones, G., ... & Jones, K. E. (2012). A continental-scale tool for acoustic identification of E uropean bats. *Journal of Applied Ecology*, *49*(5), 1064-1074.

Waltert, M., Mardiastuti, A., & Mühlenberg, M. (2004). Effects of land use on bird species richness in Sulawesi, Indonesia. Conservation Biology, 18(5), 1339-1346.

Wells, D. R., C. J. Hails, and A. J. Hails. (1979). A study of the birds of Gunung Mulu National Park, Sarawak, with special emphasis on those of lowland forests. Royal Geography Society Gunung Mulu Expedition. Royal Geographical Society, London, UK.
Wells, D. R. (1985). The forest avifauna of western Malesia and its conservation. Conservation of tropical forest birds, 213, 232.

Wells, D. R. (2007). Birds of the Thai-Malayan Peninsula. Vol. 2. The Passerine Birds of Southern Thailand, Peninsular Malaysia and Singapore.

Whitmore, T. C. (1975). Tropical Rain Forests of the Far East. Clarendon Press, Oxford.

Whitmore, T. C. (1981). Wallace's line and plate tectonics. Oxford University Press, Oxford

Whitten, T., van Dijk, P.P., Curran, L., Meijaard, E., Wood, P., Supriatna, J. and Ellis, S. (2004). Sundaland. In: R.A. Mittermeier, P. Robles-Gil, M. Hoffmann, C.G. Mittermeier,J. Pilgrim, T. Brooks and G.A.B. Fonseca (eds), Hotspots Revisited: Earth's BiologicallyRichest and Most Endangered Terrestrial Ecoregions, pp. 164-172. CEMEX, MexicoCity, Mexico.

Wicke, B., Sikkema, R., Dornburg, V., & Faaij, A. (2011). Exploring land use changes and the role of palm oil production in Indonesia and Malaysia. Land use policy, 28(1), 193-206.

Widiyono, W. (2021). Biological and economic value of Dipterocarpaceae, the main timber forest product of Indonesia. Applied Environmental Studies, 2(2), 104-112.

Wilcove, D. S., Giam, X., Edwards, D. P., Fisher, B., & Koh, L. P. (2013). Navjot's nightmare revisited: logging, agriculture, and biodiversity in Southeast Asia. Trends in ecology & evolution, 28(9), 531-540.

Winkler, D. W., S. M. Billerman, and I. J. Lovette (2020). Tree-Babblers, Scimitar-Babblers, and Allies (Timaliidae), version 1.0. In Birds of the World (S. M. Billerman, B. K. Keeney, P. G. Rodewald, and T. S. Schulenberg, Editors). Cornell Lab of Ornithology, Ithaca, NY, USA.

Wong, A. H. H., Kim, Y. S., Singh, A. P., & Ling, W. C. (2005, April). Natural durability of tropical species with emphasis on Malaysian hardwoods–variations and prospects. In The international research group on wood preservation, the 36th annual meeting, Bangalore, India (pp. 1-33).

Wong, K. M. (1998). Patterns of plant endemism and parity in Borneo and the Malay Paninsula. Rare, threatened and endangered floras of Asia and the Pacific Rim, 139-169.

Woods, P. (1989). Effects of logging, drought, and fire on structure and composition of tropical forests in Sabah, Malaysia. Biotropica, 290-298.

Wooster, M. J., Perry, G. L. W., & Zoumas, A. (2012). Fire, drought and El Niño relationships on Borneo (Southeast Asia) in the pre-MODIS era (1980–2000). Biogeosciences, 9(1), 317-340.

World Bank. (1991). Malaysia: Forestry subsector study. Report No. 9775-MA, Washington D.C.

Wrege, P. H., Rowland, E. D., Keen, S., & Shiu, Y. (2017). Acoustic monitoring for conservation in tropical forests: examples from forest elephants. Methods in Ecology and Evolution, 8(10), 1292-1301.

Wurster, C. M., Rifai, H., Zhou, B., Haig, J., & Bird, M. I. (2019). Savanna in equatorial Borneo during the late Pleistocene. *Scientific reports*, *9*(1), 6392.

Yahya, A. Z. (2020). Planting of Eucalyptus in Malaysia. Acta Scientific Agriculture, 4(2), 139-140.

Yang, H. and Xie, Z.: (1984). 'Sea-Level Changes in East China over the Past 20 000 Years', in R. O. Whyte (ed.), The Evolution of the EastAsian Environment, Univ. Hong Kong, Cent. Asian Stud., pp. 288-308.

Yong, H. S., Ng, F. S. P., & Lee, E. Y. E. (2004). Sarawak bau limestone biodiversity. Sarawak Museum Journal, 59(6), 1-403.

Zonneveld, I. S. (1983). Principles of bio-indication. In Ecological Indicators for the Assessment of the Quality of Air, Water, Soil, and Ecosystems: Papers Presented at a Symposium held in Utrecht, October 1982 (pp. 207-217). Dordrecht: Springer Netherlands.