SOUNDSCAPE, HABITAT AND BIRD SPECIES AS INDICATORS OF MANGROVE HEALTH IN SELANGOR, MALAYSIA

By

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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Mangrove forests are critical ecosystems that require conservation and restoration efforts to mitigate global logging trends, shoreline ingression and sea level rise, while serving as essential nurseries that support the biodiversity in mangrove ecosystem. Mangrove restoration is frequently undertaken via tree planting without subsequent monitoring of the sapling survival. Besides plant regeneration, the recovery of other biotic communities may serve as an indicator of mangrove recovery and health. By using bioacoustic approach, this study aimed to assess the diel activity patterns of birds, examine the relationship between mangrove habitat variables and bird species, and evaluate acoustic niche partitioning among bird species in four different mangrove forests of varying ages with different types of habitat disturbance in Selangor, Malaysia. Five bioacoustic audio recorders were set up in each forest to collect data on bird vocalisations, and acoustic indices were derived to identify temporal patterns and variations in soundscapes. The study revealed that higher species richness was recorded using bioacoustic method compared to mist-netting. This study also indicated clear diel patterns in soundscapes. Almost all the measured acoustic indices exhibited similar temporal patterns with a peak at the beginning of dawn and dusk. Differences in soundscapes among the study sites were found to linked to variations in habitat structure and size of the mangrove forests. A significant positive correlation was found between mangrove habitat variables and bird species richness, highlighting the importance of certain habitat variables in supporting avian populations in such habitat. Additionally, the interaction among nectarivores, as a focal family revealed the presence of acoustic niche partitioning which highlights the need to understand the response of mangrove specialists and generalists towards the condition of the mangrove ecosystem. The findings emphasize the importance of preserving and restoring mangrove forests, incorporating diverse habitat structure and size in restoration programmes, and implementing well-managed restoration or replanting programmes that consider various aspects to enhance bird populations and promote mangrove biodiversity in the long run. Through bioacoustics approach,

this study demonstrated the potential of using birds as indicators of mangrove health.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

RUANG BUNYI, HABITAT DAN SPESIES BURUNG SEBAGAI PENUNJUK KESIHATAN BAKAU DI SELANGOR, MALAYSIA

Oleh

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Hutan bakau merupakan ekosistem kritikal yang memerlukan usaha pemuliharaan dan pemulihan untuk mengurangkan pembalakan hutan secara global, kemasukan garis pantai dan kenaikan paras laut, disamping berfungsi sebagai tapak semaian penting yang menyokong kepelbagaian biologi dalam ekosistem bakau. Pemulihan hutan paya bakau sering dilakukan tanpa pemantauan selanjutnya terhadap kemandirian anak pokok. Selain daripada pertumbuhan semula tumbuhan, pemulihan komuniti biotik lain juga memainkan peranan sebagai petunjuk pemulihan dan kesihatan hutan paya bakau. Melalui pendekatan bio-akustik, kajian ini bertujuan menilai corak aktiviti harian burung, mengkaji hubungan antara struktur habitat bakau dan kekayaan spesies burung dan menilai pembahagian ceruk akustik di antara spesies burung di empat hutan bakau berbeza dari peringkat umur dan gangguan habitat di Selangor, Malaysia. Lima perakam audio bio-akustik telah dipasang di setiap hutan bakau untuk mengumpul data mengenai bunyi burung dan indeks akustik telah dihasilkan bagi mengenal pasti corak temporal serta variasi dalam ruang bunyi. Kajian ini menunjukkan bahawa kekayaan spesies direkodkan adalah lebih tinggi dengan kaedah bioakustik berbanding dengan jaring kabus. Kajian ini turut menunjukkan corak harian yang jelas dalam ruang bunyi. Hampir kesemua indeks akustik yang dikira mempamerkan corak temporal yang sama, dengan puncak pada waktu awal subuh dan senja. Perbezaan dalam ruang bunyi di antara kawasan kajian didapati berkait dengan variasi dari segi struktur dan saiz habitat hutan bakau. Korelasi positif yang ketara antara pembolehubah habitat bakau dan kekayaan spesies burung menunjukkan kepentingan pembolehubah habitat tertentu dalam menyokong populasi burung di dalam habitat tersebut. Interaksi antara pemakan nektar telah mendedahkan kewujudan pembahagian nic akustik yang menunjukkan keperluan memahami respon kumpulan burung habitat khas dan am kepada keadaan ekosistem bakau. Penemuan ini menekankan kepentingan memelihara dan memulihkan hutan bakau, menggabungkan pembolehubah habitat yang pelbagai dari segi struktur dan saiz dalam program pemulihan, dan melaksanakan program pemulihan atau penanaman semula yang diurus dengan

baik yang mempertimbangkan pelbagai aspek untuk meningkatkan populasi burung dan menggalakkan biodiversiti bakau pada jangkamasa panjang. Melalui pendekatan bio-akustik, kajian ini menunjukkan potensi menggunakan burung sebagai penunjuk pemulihan hutan bakau.

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LIST OF ABBREVIATIONS

ACI	Acoustic Complexity Index
ADI	Acoustic Diversity Index
AEve	Acoustic Evenness Index
AIC	Akaike Information Criteria
ARUs	Autonomous Recording Units
BI	Bioacoustics Index
DBH	Diameter at Breast Height
GLMM	Generalised Linear Mixed Models
HMM	Hidden Markov Model
NDSI	Normalized Difference Soundscape Index
NGOs	Non-Governmental Organisations
NMDS	Non-Metric Multidimensional Scaling
PAM	Passive Acoustic Monitoring
PCA	Principal Component Analysis
PERMANOVA	Permutational Multivariate Analysis of Variance
SES	Standard Effect Size

CHAPTER 1

INTRODUCTION

1.1 General Background

Mangroves are the only trees amongst a small group of halophytic higher plants found in the coastal areas throughout the world. These trees form a unique group of vegetation that is capable of growing and surviving in intertidal zone under the harsh environment. In fact, there are no other trees that can endure the amount of salinity more than the mangrove trees do (Alongi, 2009). Mangroves can prevent erosion, trap sediments, and provide wind protection for coastal biotic communities (Warren-Rhodes et al., 2011). Their functions of protecting the coastlines and preserving the ecological balance of estuaries are significantly contributing to both forestry and fishery sectors (Eganathan et al., 2000), in addition to improving water quality (Wang et al., 2010). Due to anthropogenic pressures such as logging, and drastic developments, mangrove forests are being destroyed and are declining every year; their disappearance is faster compared to inland tropical rainforests (Singh et al., 2014). Mangroves are now threatened worldwide, yet they are essential habitats for fauna. Mangrove forests sustain important nursery habitats for a wide range of organisms, including marine vertebrates and invertebrates (Lee et al., 2014; Nagelkerken et al., 2008; Serafy et al., 2015). Unfortunately, most of the mangrove forests in Southeast Asia and Africa have been converted for agriculture, aquaculture activities such as hatcheries, development of port facilities, and industrial areas (United Nations Environment Programme, 1994). Consequently, mangroves are experiencing rapid degradation as a result of human activities. These activities have been recognized as major causes of biodiversity loss and disturbance in coastal habitats. These human-induced activities in the coastal zone have caused animals from various taxa within mangroves to become vulnerable or threatened (Nagelkerken et al., 2008).

Over the last few decades, the interest in forest rehabilitation has rapidly increased (Aronson & Alexander, 2013), including restoration of coastal wetlands (Palmer et al., 2014; Suding et al., 2015). Forest rehabilitation involves restoring a degraded area by replanting trees in an attempt to maintain and restore its biodiversity. According to Nilsson and Aradóttir (2013), climate change effects and the loss of biodiversity can be minimized through forest rehabilitation. However, the rehabilitation process is time-consuming with respect to recovery from a severely degraded area. Previous attempts to restore mangroves often fail entirely or fail to achieve the stated goals (Erftemeijer & Lewis, 1999; Lewis, 2000, 2005). Forest rehabilitation involves multiple stages, which are planning, funding, implementing, and monitoring (Jong, 2010). It requires careful consideration of each stage in advance before attempting the actual rehabilitation to ensure the success of such replanting programme (Lewis, 2009). The targets of mangrove restoration or regeneration may often include biodiversity recovery, coastal protection, producing forests for timber production, or forests of mixed-use for high sustainable yield (Field, 1999; Lewis, 2009).

Birds have been identified as one of the best indicators of ecosystem health, e.g., to assess forest conditions, because of their diverse roles within the trophic webs. Bird communities are key elements for describing the energetics of ecosystems (Adame et al., 2015; Wenny et al., 2011) and they are sensitive and have been demonstrated to respond fast to the changes in environments (Rahim, 2019). Measuring the diversity of birds in an area is the fundamental approach to generate an indicator of the state of a forest. The diversity of birds reflects their evolutionary adaptation to a good diversity of habitats and modes of living. Birds also inhabit forests, deserts, shorelines and almost every environment in-between (Hill, 2017). Even though avian diversity monitoring is a useful tool for assessing the health of wetland ecosystems, it has rarely been used for the assessment of ecological recovery (Catterall et al., 2012; Cui et al., 2009; Gyurácz et al., 2011; Li et al., 2011; Zou et al., 2014). From a conservation perspective, birds can be a relatively an effective starting point for communicating conservation messages with people and to raise awareness towards issues pertaining to biodiversity (Gregory & Strien, 2010).

Birds can be regarded as the most obvious animal group that can be recognised by sound (Frederick et al., 2009) besides other taxa such as frogs (Brandes et al., 2006; Taylor et al., 1996), insects (Dietrich et al., 2003; Farr & Chesmore, 2007), and mammals (Clemins & Johnson, 2006). Almost all bird species rely on vocalisation for communication, such as for territorial defence and attracting a mate. Bird vocalisations can be divided into song and call. Songs are generally associated with males (Langmore, 1998) and often comprise of the sound of longer duration that is always linked to courtship and mating (Fagerlund, 2014). In contrast, calls are shorter and tend to serve other functions such as alarms for territorial defence (Catchpole & Slater, 2003).

For those species that have distinctive and repetitive sound, they can be easier to be located or detected. Depending on the habitat type and level of disturbance, some elusive bird species may remain silent and are seldom being heard. In such cases, by using a continuous recorder in a specific period of time, the probability of detecting the bird's sound is high. Through such an approach, studies have shown that even nocturnal and less vocal bird species could be detected and recorded effectively. In many cases, the monitoring of nocturnal birds can be applied efficiently using acoustic method where a recording device can effectively substitute an observer in the field, or significantly increase the area covered by a single observer who operates a certain number of recording devices (Frommolt & Tauchert, 2014).

In the past two decades, bioacoustics monitoring using autonomous recording units (ARUs) is a rapidly growing method for monitoring bird populations (Bomans, 2018), and bioacoustic approaches have become increasingly popular for monitoring environmental changes (Fristrup & Mennitt, 2012) in recent years in avian ecological research. Bioacoustic monitoring can record data at multiple locations simultaneously in the absence of observers over a long period of time, and a recording requires only a single observer to analyse using a computer (Aide et al., 2013; Klingbeil & Willig, 2015; Steer, 2010). Nowadays, with the advancement of acoustic technology, through the complete equipment and systematic setting, in terms of high battery capacity, large memory card space and stratified 'on-off' time sampling programme (e.g., recording 1 minute in every 10), some recorders may continuously record up to one month (Bayne et al., 2017; La & Nudds, 2016).

The bioacoustics approach, employing static recorders, is similar to the point-count bird method, but data is more accurate and extensive. Various studies have compared point-count data with automated acoustic recording in a wide range of habitats such as rainforest (Leach et al., 2016), temperate woodlands (Furnas & Callas, 2015; Holmes et al., 2014), tropical savanna (Alquezar & Machado, 2015) and temperate meadows (Tegeler et al., 2012). On the other hand, for the traditional point count method, it has been shown that an experienced observer is required from which the bird species in the survey area can be identified reliably by sight and sound (Bibby et al., 2000; Sedláček et al., 2015) and the method does not require specialized equipment. Nonetheless, the advantage of using a bioacoustics approach in the ecological study is that it does not require a large amount of workforce and resources.

From the recordings obtained, the research aspects can range from basic on-site biological information such as species richness, abundance, presence or absence, and detection probabilities (Shonfield & Bayne, 2017), to autecology such as species behaviour (Pérez-Granados & Schuchmann, 2021b) and activity patterns (Kotila et al., 2023; Pérez-Granados & Schuchmann, 2021a) as well as ecological interactions (Fraser et al., 2016) within a soundscape. Factors causing bird species to fluctuate in a population can be obtained through assessing the relationship between birds species monitored from the sound recorder and local habitat conditions; areas that have higher species richness are often associated with good ecosystem health and dispersal ability that can function more efficiently (Ducatez et al., 2015). This study focused on assessing the mangrove soundscape particularly acoustic patterns displayed by the bird community within mangroves of different planting ages so as to understand the ecological interactions and responses of such community to mangrove habitat gradients.

Globally, birds from the families of Nectariniidae, Trochilidae and Meliphagidae have been known as pollinators (Cronk & Ojeda, 2008). Morphologically, most of them have relatively longer bill, slender and smaller body allowing them to feed on nectars while picking up and transferring pollens during which pollination occurs (Amar-Singh, 2020, but see Amar-Singh 2010). Malaysia has a total of 20 species within Nectariniidae, half of which are sunbirds and half are spiderhunters (Puan et al., 2020). Many sunbirds that are sexually dimorphic with males being more colourful (Puan et al., 2018), and their vocalisations are often comprising similar yet distinct high-pitched calls (Cheke et al., 2001; Wells, 2007). Owing to its diversity and the sympatric nature for some species, the distributions and behaviour of sunbirds pose intricate ecological questions pertaining to interspecific niche partitioning (Noske, 1993; Wee et al., 2014).

Due to specific habitat preference, some form of niche segregation, at least by vegetation in mangroves, has been described for these birds especially in the case of mangrove specialists (Noske, 1995; Wells, 2007). In the mangroves in Malaysia, the Copper-throated Sunbird (*Leptocoma calcostetha*) is a mangrove specialist with a narrow foraging niche in back mangroves and tidal rivers (Wells, 2007) as compared with Brown-throated Sunbird (*Anthreptes malacensis*) a syntopic and rather widespread confamilial mangrove-adapted species (Noske, 1993; Wee et al., 2014) in Southeast Asia. In fact, the latter is one of the commonest sunbirds found in the foliage of edge habitats ranging from back mangroves, coastal and inland wooded areas to the adjacent habitats (Wells, 2007). Other sunbirds such as Olive-backed Sunbird (*Cinnyris jugularis*) are more habitat generalists that are widespread in various habitats including urban areas and mangroves.

1.2 Problem Statement

Forest restoration is an essential practice in both species and habitat conservation in the tropics. Due to different vegetation structure, forest age and size, reforested areas may contain only a subset to the original species. Species composition, e.g., birds may change following the age of the reforested area (Junior et al., 2016). Forest age is one of the crucial factors as it directly influences biodiversity (Gao et al., 2015). In response to the urgent need for enhancing the protection of natural areas and biodiversity conservation, the concept of restoration reserves was proposed by Brancalion et al. (2013) as a new category of protected areas that aims at not only preserving existing habitats but also actively restoring degraded ecosystems. Among the protected ecosystems, mangroves, with their unique ecological attributes and specialized flora and fauna, face significant threats and have experienced widespread loss globally, particularly in Southeast Asia (Field, 1999). The relatively less complex floristic composition of mangroves renders them vulnerable to disturbances that further degrade habitat quality (Mohd-Azlan et al., 2012). On the other hand, forest size might contribute an important role in maintaining ecological balance and providing essential ecosystem services. Therefore, replanting should not only focus on the number of plants successfully planted, but the size and habitat structure of the forest should also be taken into account in increasing the biodiversity including birds and other wildlife species.

In Asia, mangrove forests continue to be destroyed to make way for more industrial, aquaculture, agricultural, and urban development (Field & Dartnall, 1987; Saenger et al., 1983). In Malaysia, the detrimental effects of logging for construction purposes have necessitated rehabilitation efforts in certain areas (Kenzo et al., 2007). The decrease in mangrove forests will lead to local species extinction and natural disasters, such as the loss of barrier for a strong wave during a tsunami. In some countries, a government's initiative in rehabilitating mangroves forests not only contributed to the conservation of biodiversity but have also provided locals to earn a living. For instance, in Kenya, which has planted more than 100,000 mangrove seedlings in Gazi Bay since 2016 (Schueman, 2021). However, in some situations, the involvement of non-government organisations (NGOs) has also been shown to be important, especially in the cooperation between local and rural communities. Assessing the success of mangrove rehabilitation can be effectively conducted through the examination of bird diversity, as birds exhibit rapid responses to habitat disturbances, especially breeding birds (Weston et al., 2015). Birds serve as an ideal model group for studying ecosystem recovery, given their important ecological roles such as seed dispersal, pollination, predation, scavenging, and their classification as ecosystem engineers (Whelan et al., 2008). Such an approach has been applied in mangrove rehabilitation efforts in the Florida Everglades. For instance, the successful recovery of historical nesting patterns of White Ibis (*Eudocimus albus*) and Wood Stork (*Mycteria Americana*) was used as an indicator of rehabilitation success as these two species occupy quite different niches in the mangrove habitat (Frederick et al., 2009).

To date, most studies that examine bird species composition only focused on survey methods e.g., mist-netting and point count sampling, while the potential of automated recording methods has been relatively underexplored. Point-count sampling, commonly used in bird surveys, provides limited data compared to automated acoustic recordings. A research has been done in a variety of habitats such as rainforest to distinguish between point-count data and automated acoustic recording (Leach et al., 2016). Previous research done by Shonfield and Bayne (2017) showed that in total, 82 species were observed using an acoustic method while traditional point counts, 63 species were observed in the Aberdare National Park, Kenya. These findings highlight the potential of automated sound recording devices indirectly capturing species presence through vocalisations, addressing the limitations of human physical abilities and the time-consuming nature of exhaustive observational surveys. Furthermore, the capture and detection rate of bird species using standard traditional methods, e.g., point count and mist-netting could be affected by many factors (Blake, 1992; Karr, 1981; Krementz et al., 1997). These factors include the risk of double counting, observer bias, and direct disturbance due to the presence of the observer (Fuller & Langslow, 1984). In the case of mist-netting, some species of higher vegetation strata may not be captured and/or during the presence of surveyors (Remsen & Good, 1996), and surveys are often restricted to dawn or daylight (Francis et al., 2009b; Krementz et al., 1997).

Priyadarshani et al. (2018) developed automated sound recording devices to overcome these challenges and enable efficient and accurate recording of species. Additionally, Abrahams (2019) supported that a potential weakness in human counting methods can be overcome by using a bioacoustic method, which can estimate species diversity efficiently and effectively; the result is promising with respect to species diversity when used for an equal length of survey time. Therefore, adopting bioacoustic methods in bird surveys presents an opportunity to enhance the accuracy and efficiency of species diversity estimation while reducing the constraints associated with traditional survey methods.

Despite the ecological significance of mangrove birds, many species, particularly specialists are relatively less studied. This is mainly due to sighting difficulties and obstacles in assessing mangroves at night, particularly during changes in high and low tides. Therefore, it is crucial to comprehensively assess the diversity of mangrove birds to understand their ecological roles and evaluate the effects of rehabilitation initiatives in mangrove areas. This knowledge is essential for improved management and conservation practices aimed at safeguarding the ecological integrity of mangrove ecosystem.

Within mangroves, some form of interspecific interactions is expected between these nectarivores either via spectral or temporal segregations which could have linked to their roles in pollinating mangroves. For instance, seasonal availability of mangroves flowers such as those of *Bruguiera* spp. (Wee et al., 2014) has been described to influence the distributions of these sunbirds, particularly for the Copper-throated Sunbird which may forage elsewhere when mangroves are not flowering for a few months. Hence, their roles in mangrove pollination and niche differentiation in relation to mangrove distributions deserve further investigation especially when mangroves are a threatened ecosystem (Bryan-Brown et al., 2020). Due to difficult terrain as well as attempt to minimise human disturbance, we employed passive acoustic method to examine the vocalisations and vocal activity patterns of three sunbird species with emphasis on their segregation by time and frequency in mangroves in the west coast of Peninsular Malaysia.

1.3 Objectives

The general objective of this study was to assess the mangrove bird community using the bioacoustic method as indicators of mangrove health in Selangor, Peninsular Malaysia specially in four mangroves of different planting ages, namely Telok Gong Forest Reserve (10 years of age), Kapar Tambahan Forest Reserve (19 years of age), Banjar Utara Forest Reserve (25 years of age) and Kuala Selangor Nature Park (an old-growth mangrove forest). The specific objectives of this study were as follows:

1. To assess diel activity patterns of birds in these four mangrove forests,
2. To examine the relationship between mangrove habitat variables and bird species richness, and
3. To assess acoustic niche partitioning among bird species within these mangroves with reference to nectarivores.

The conceptual framework of the thesis is shown in Figure 1.1:

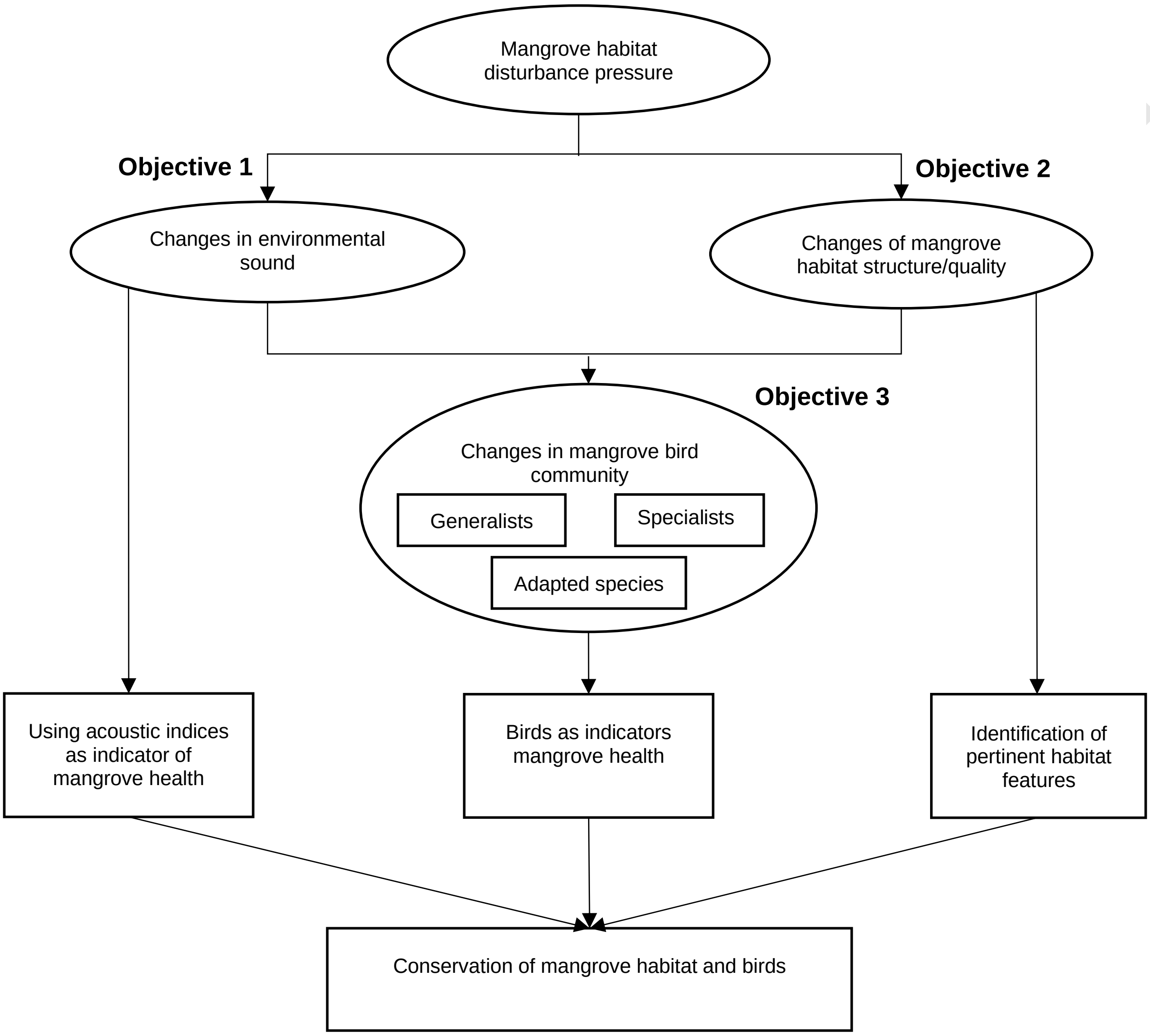

Figure 1.1 : Conceptual framework of the thesis.

The intricate relationship between mangrove habitat disturbance and its impact on the mangrove bird community is a key focus of the conceptual framework. As mangrove habitats are facing various disturbances, two primary components affected. Firstly, changes in environmental sound resulted from such disturbances, creating a ripple effect that significantly affects the mangrove bird community. These changes in ambient sound levels can disrupt the intricate balance of communications and interactions among the avian inhabitants of the mangrove ecosystem. In order to assess such a response of the avian community, the acoustic indices were used as indicators of forest health.

Secondly, the changes within the mangrove habitat due to disturbances play an important role in shaping the dynamics of the mangrove bird community. Shifts in the physical composition of the habitat directly influence the availability of resources and suitable nesting sites for the avian species, thereby leading to distinct changes in the composition and behaviour of the mangrove bird community. Therefore, by identifying the pertinent habitat features, this study was able to investigate the relationship between habitat structure and mangrove bird community as reflected via their acoustic patterns. It is expected that acoustic niche partitioning may occur within the mangrove bird community. Thus, by recognizing the interactions among habitat disturbances, environmental sound, habitat structure, and the mangrove bird community, the whole conceptual framework depicted the importance of the recognizing the ecological changes and interactions at different levels, i.e. community, functional groups, and species in response to changes in the mangrove habitat which is expected to contribute significantly towards the conservation of mangrove habitat and birds.

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