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ORIGINAL ARTICLE

Towards a regional call library: Classifying calls of a species-rich bat assemblage in a Bornean karst rainforest

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ABSTRACT

Acoustic monitoring with ultrasonic detectors has emerged, in recent years, as an essential tool to quantify the activity of echolocating, insectivorous bats and identify critical commuting and foraging habitats. Comprehensive reference call libraries are critical for the identification of species from their calls. This is especially important in species diverse areas like Gunung Mulu National Park (Sarawak). This study aims to (1) develop a call library for all known echolocating bat species found in Gunung Mulu National Park, (2) determine if calls of different species can be automatically classified using discriminant function analysis, and (3) examine intraspecific variation in relation to sex and geographical location, for calls in species of the families Rhinolophidae and Hipposideridae. Between 2012 and 2017, insectivorous bats were trapped within and outside the park. Echolocation calls were recorded from a total of 508 individuals, representing 31 species from 8 families. Results from discriminant function analysis indicated that the majority of cave roosting bats, which included *Chaerephon plicatus, Miniopterus australis, Myotis horsfieldii* and 13 species from the families Rhinolophidae, Hipposideridae, and Emballonuridae, could be readily distinguished from their calls, when manually separated into groups according to call structure. However, classification success was much lower for the remaining 15 species that consisted mainly of forest roosting bats from the family Vespertilionidae. This reference call library is expected to contribute to a regional online open-access database. It can be used to survey and monitor selected species in Gunung Mulu National Park as well as highlighting the importance of threatened habitats outside the boundary for these species.

INTRODUCTION

Habitat loss and fragmentation have been identified as the major factors contributing to the decline of bat populations in the tropical forests of Southeast Asia, where peak diversity of threatened bat species is known to occur (Kingston 2013, Meyer et al. 2016, Voigt & Kingston 2016, Frick et al. 2020). In karst landscapes, cave roosting bats are particularly vulnerable to the disturbance caused by limestone quarrying (Clements et al. 2006), uncontrolled mass tourism (Vermeulen & Whitten 1999, Furey & Racey 2016a), swiftlet nest collecting (Hall et al. 2002, Suyanto & Struebig 2007), guano mining (Wiles & Brooke 2010), and hunting (Hall et al. 2002, Wiles & Brooke 2010, Mildenstein et al. 2016). Ongoing conversion of forests to agriculture, in particular large-scale monoculture plantations surrounding karst outcrops that support high densities of cave roosting bats (Clements et al. 2006, Furey & Racey 2016a, Liew et al. 2016), has led to the loss of valuable foraging habitats (Struebig et al. 2009, Furey et al. 2010, Kingston 2013) and reported decline in populations (Hall et al. 2002, Shazali et al. 2017). Therefore, there is an urgent need to improve the efficiency of surveys to document the diversity, distribution, and habitat requirements of bats in both pristine and disturbed areas of the region (Kingston 2010, 2013).

Borneo has a high diversity of bat fauna, with 99 species currently documented (Phillipps & Phillipps 2016, Shazali et al. 2018). Since the late 1980's researchers have conducted numerous surveys to document bat diversity in the Malaysian states of Sabah and Sarawak, with most studies focusing on species inventories, particularly in protected areas (Struebig et al. 2010, Kumaran et al. 2011, Shazali et al. 2018). However, there is still a lack of information on this important group of mammals from many localities (Kumaran et al. 2011, Khan et al. 2019, Yoh et al. 2020).

The majority of studies on insectivorous bats in Borneo have used harp traps and mist-nets to capture, identify, and assess the condition of individual bats (e.g. Struebig et al. 2010, Naharuddin et al. 2015, Shazali et al. 2016, Khan et al. 2019, Yoh et al. 2020). However, capture often causes stress and interferes with the animal's natural behaviour and

therefore, it has limited use for determining activity patterns and the types of habitats used by various bat species for foraging (Hayes et al. 2009). Bats that normally fly in the understory, such as species in the families Rhinolophidae, Hipposideridae, and Vespertilionidae subfamilies Kerivoulinae and Murininae are easily captured in harp traps that are usually set, at ground level, across narrow forest trails or streams (Francis 1989, Kingston et al. 2003a, Struebig et al. 2010). Mist nets are more suitable for use in open or edge space but the species that normally fly in these habitats can often detect and avoid mist nets through long-range echolocation (Francis 1989, Kingston et al. 2003a, Struebig et al. 2010). Therefore, high-flying insectivores are seldom captured and are usually missing from inventories (Francis 1989, Neuweiler 1989, Kingston 2013). However, because these species have less manoeuvrability in flight (Norberg & Rayner 1987), they are occasionally captured in situations where they cannot turn to avoid nets, such as near roosts or when they descend to fly low over rivers to drink or forage (Kingston 2013).

Over the past few decades, acoustic sampling with ultrasonic detectors has been used in numerous studies worldwide to document the occurrence and study the ecology and behaviour of insectivorous bats (Brigham et al. 2004, Britzke et al. 2013). In most temperate areas, many species can be identified from their calls (Fenton & Bell 1981, Waters & Gannon 2004) and extensive call libraries, combined with automatic classifiers, are now available to quantitively and quickly identify species using computer software programs (Adams et al. 2010, Walters et al. 2012, Agranat 2013). As a result, acoustic monitoring programs have been running for several years, particularly in Europe and North America (Walters et al. 2012, Jones et al. 2013, Barlow et al. 2015, Loeb et al. 2015). However, caution is recommended when interpreting results from automatic classification programs as calls may be misclassified (Russo & Voigt 2016, Rydell et al. 2017). Therefore, combining automatic identification with manual validation is considered the best option for a more accurate interpretation of sound files (López-Baucells et al. 2019).

Despite the high diversity of bat species in tropical regions of the world, very few acoustic studies have been conducted in these regions (Walters et al. 2013). One of the biggest obstacles to conducting acoustic monitoring in the tropics is the lack of local and regional call libraries (Furey et al. 2009, Walters et al. 2013, López-Baucells et al. 2019). Although echolocation calls for many species that occur in Southeast Asia have been described (e.g. Kingston et al. 1999, 2000, 2003b, Francis 2008, Furey et al. 2009, Hughes et al. 2010, 2011, Phauk 2013), call recordings are mainly held in the private collections of institutions. Several collections of calls exist for Borneo but few descriptions have been published and recordings are not available in any public database (e.g. Castle et al. 2014, Khan et al. 2020, Mullin et al. 2020, Senawi et al. 2020). Numerous studies have shown that calls, particularly from species in the families Rhinolophidae and Hipposideridae, have substantial geographic variation (Francis 2008, Furey et al. 2009, Hughes et al. 2010, Webala et al. 2019). Published descriptions of species recorded elsewhere in Southeast Asia may therefore have limited application to monitoring the same species in Borneo. Furthermore, to use machine-learning techniques to develop an automatic classifier for species identification a large number of calls must be available and should incorporate intraspecific variation (Hughes et al. 2010, Britzke et al. 2013, López-Baucells et al. 2019, Webala et al. 2019).

In this study, echolocation calls are described for 31 species of insectivorous bats recorded within and outside the boundary of Gunung Mulu National Park (GMNP). The aims of this study were: 1) Build an echolocation call library that can be used to identify insectivorous bats in GMNP; 2) Determine which species of echolocating bats that occur in the park can be reliably identified from their calls, using an automatic classification technique; and 3) Assess intraspecific variation in call structure and frequencies for Rhinolophidae and Hipposideridae, in relation to flight situation, sex and geographical location, which may influence the correct acoustic identification of species.

MATERIALS AND METHODS

Study Sites

The main study area, where bats were sampled to record their echolocation calls, was Gunung Mulu National Park (GMNP) in northern Sarawak, Malaysian Borneo. To compare calls of similar species from a different geographical location, bats were also sampled at Bako National Park (BNP) and Wind Cave Nature Reserve (WCNR) in southwestern Sarawak (Fig. 1A). GMNP (N4.04238° E114.81343°) covers a total area 85,671 hectares and is known for its high mammal diversity (Shazali et al. 2016). The extensive cave systems of the park, caused by its karstic topography, provide numerous roosting opportunities for cave roosting bats (Chapman 1985, Hall 1996). The soils of GMNP are derived from three main rock types: sandstone, limestone and shale; and alluvial clay deposits (Anderson & Chai 1982, Proctor et al. 1983). Altitude starts at 28 metres and extends to 2377 metres above sea level. An estimated 40% of the park is covered in lowland forests of five distinct types: alluvial, mixed dipterocarp, limestone, kerangas, and peat swamp (IUCN 2000). Vegetation at all sampling sites within the park was lowland riverine forest, bounded on one side by limestone scree forest. In contrast, vegetation at locations outside the park consisted of young secondary forest and community gardens.

Between 2012 and 2017, a total of 98 sites within and outside the boundary of GMNP were sampled, over 62 nights, with four-bank harp traps (Francis 1989) and mist nets. The number of harp traps per night varied between one and ten. Inside the park, 80 sites were sampled with harp traps for 57 nights. Traps were set across narrow forest trails, at suitably sized gaps between vegetation along river banks, and at a narrow cave passage in Lagang Cave to capture bats during emergence (Fig. 1). In 2014 and 2015, either one to two combined mist nets (12 m wide and 2.5 m high) or one high pole mist net (12 m wide and 7.5 m high) were used to sample at six sites along a riverbank, across rivers and in open spaces, during 12 nights. Outside the park boundary, two sites were sampled with harp traps for two nights in 2013 and ten sites over three nights in 2014 (Fig.