Acoustic communication of passerine birds of Anaikatty hills with special emphasis on Common Iora *Aegithina tiphia*

Thesis submitted to the Bharathiar University in partial fulfillment of the requirements for the Degree of

DOCTOR OF PHILOSOPHY

in

ZOOLOGY

By

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(Reg. No. 2014R436)

Sálim Ali Centre for Ornithology and Natural History (SACON)

Coimbatore - 641 108, India

October 2019

CERTIFICATE

This is to certify that the thesis entitled **"Acoustic communication of passerine birds of Anaikatty hills with special emphasis on Common Iora *Aegithina tiphia*"** submitted to the Bharathiar University, in partial fulfillment of the requirements for the award of the Degree of Doctor of Philosophy in Zoology is a record of original research work done by **Ms. C. Divyapriya** during the period of November 2014 - October 2019 of her research in the Department of Zoology at Sálim Ali Centre for Ornithology and Natural History (SACON), under my supervision and guidance and the thesis has not formed the basis for the award of any Degree /Diploma /Associateship /Fellowship or other similar title to any candidate of any University.

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INTRODUCTION

True knowledge is not attained by thinking. It is what you are; it is what you become.

- Sri Aurobindo.

CHAPTER I

INTRODUCTION

1.1 BACKGROUND

Bird acoustic communication is intended for species identification between groups (interspecific communication) and for individual identity within a group (intraspecific communication (Simmons, 2002). Bird vocal signals comprise a mixture of tones (harmonic sounds) such as chirps, clicks, less harmonic mumbles, wheezy chats, rattles and buzzy noises. Male birds use complex songs for territorial establishment and maintenance (Catchpole & Slater, 2008; Bhatt et al., 2000; Marler, 2004); and mate attraction (Marler, 2004). Songs have various other functions, for; (i) distracting potential predators (Ritchison, 1991); (ii) informing the mates about the threat (Kermott, & Johnson, 1991); and (iii) coordinating nest exchanges between mates (Smith, 1988).

Bird song is produced in 'syrinx' (Gaunt, 1983; Gaunt et al., 1973) during exertion/ exhalation of air. The intercostal muscles of the thorax and the abdominal muscles around the large abdominal sacs compress the air sacs (Brackenbury, 1982) thereby vibrating tympaniform membrane (TM; Miskimen, 1951; Gottileb & Vandenbergh, 1968; Stein, 1968). Passerines have intrinsic muscle along with the TM for creating mechanical force during air exhalation that formulates the temporal characteristics of the song (Brackenberry, 1980; Brackenberry, 1982). Brackenberry (1980) observed the less tidal volume of air (35 ml) during the resting phase and increased level (approximately 500 ml) during vocal utterance in Cockerels. This explains the sharing of oxygen consumption during a song performance. In singing males, the muscular activity exerts energy and thereby increases the metabolic requirement (Oberweger & Goller, 2001). In non-passerines, the high-intensity vocal signals like crowing and distress calls (Gaunt et al., 1996; Horn et al., 1995) and begging calls (McCarty, 1996; Bachmann & Chappell, 1998; Jurisevic et al., 1999) show increase in metabolic cost during vocal performance but are modulated within a limited frequency range (Beckers et al., 2003).

Passerines with advanced syrinx component produce varied vocal signals ranging from monotonic 'syllables' with uniform frequency range (Beeman, 1998) to frequency modulated (FM) syllables within a short span of time. Vocal signals of birds are generally categorized as songs and calls. Songs and calls are not always distinguishable easily. A single element or single articulation is called as '*call'*, which are necessarily preceded and followed by a silent gap (Borowiec & Lontkowski, 2000; Kumar, 2003). Calls are produced by birds of both sexes all through the year (Catchpole & Slater, 2008). On the other hand, a series of syllables that forms strophes or phrases are termed as '*songs'* (Catchpole & Slater, 2008; Geoff, 1996; Bhatt et al., 2000). Songs are complex and longer, generally pronounced during the breeding season by a male (Catchpole, 1982; Marler, 2004). The field of bird acoustics involves many technical terminologies, though some of them are subjective, they are extensively used in literature. The definitions of these terminologies used throughout this thesis are presented here.

Syrinx: The vocal cord of birds for sound production.

Element: The fundamental unit of vocalisation that is represented as a single expression on the spectrogram, which is necessarily preceded and followed by a gap.

Syllable: Combination of two or more elements.

Call: Short and simple vocal signal produced by both male and female throughout the year for contact, or an alarm signal, etc.

Song: Combination of many syllables produced by male birds during the breeding season.

Birds recognize the species-specific calls through their spectral and temporal features, as they are sensitive to minute (1%) frequency changes. They can find 3dB change of loudness in an auditory signal (Dooling, 1982). The temporal sensitivity threshold shows that birds are good in detecting the gap in between the signals ranging from 2-3 milliseconds (Klump & Maier, 1989) with duration discrimination ability (Maier & Klump, 1990).

Upon receiving a signal, the auditory system of a bird first detects the species-specific signals (in swamp sparrow by Marler (1985)) from the background noises in a habitat, then process it for specific and relevant behavioural context. The signal undergoes a series of cognitive processes such as stream segregation, attention, discrimination, recognition, categorization, temporal pattern detection, memory and decision processes (Knudsen & Gentner, 2010). With much complexity in their vocalisations, the signal serves for a variety of functional implications.

Vocal sensory modality is constrained by the background noise, as it decreases the receiver's ability to detect and discriminate a signal from another (Brumm & Slabbekoorn, 2005; Wiley & Richards, 1982). Birds typically use long-range signal ranging between 50-200m (Marler & Mitani, 1988). The receiver bird faces challenges such as a decrease in the intensity (attenuation) and degradation of signal (reverberation). Attenuation is caused by interference between direct and reflected waves. Attenuation affects the receiver bird's detection ability, while reverberation disturbs both detection and recognition capabilities (Wiley & Richards, 1982). Morton (1975) and Chappius (1971) showed greater attenuation of higher frequency signals in forests than in open landscape. Vocal signals of 1-2 kHz are attenuated less than much lower or higher frequencies (Marten & Marler, 1977; Marten et al., 1977). Temperature, wind gradients and background noise are the other crucial factors influencing the effective signal transmission. During the midday of sunny days, temperature and wind gradients arise above the ground towards the vegetation and cause air turbulence. On the other hand, sound transmission near the ground is favourable during night times (Wiley & Richards, 1982). Diurnal bird species vocalise majorly in early hours of the day (dawn) and in the dusk, whereas nocturnal animals call throughout the night (Henwood & Fabrick, 1979). Atmospheric conditions are favourable at sunrise than at sunset for long-range signal transmission.

The background noise from a non-biological source such as wind, rain and running water and biotic noise by other vocalising animals adds up to the ambient noise schema of an environment (Brumm & Slabbekoorn, 2005). A calling bird must propagate the signal against the abiotic noise (Catchpole & Slater, 2008); the vocalisation of other colonial birds (Aubin & Jouventin, 2002) and aggregation of frogs (Gerhardt & Huber 2002), in order

to reach the receiver bird. The overlap of other biotic or abiotic noise of similar frequency causes a masking effect on the birds' vocal signal. The masking impairs the information transfer and ultimately limits the mate choice (Gerhardt & Klump, 1988) and restricts the territorial responses (Páez et al., 1993). The birds avoid the masking of nearby birds through strategies (Popp & Ficken, 1987; Popp et al., 1985). Brumm and Todt (2003) showed that songbird perches at a favourable position in accord with the perceived position of the receiver that enhances the signal propagation. Birds have vocal partitioning or 'acoustic niche' (Brumm, 2006; Planque & Slabbekoorn, 2008; Luther, 2009; Hart et al., 2015). Red-winged blackbirds *Agelaius phoeniceus* use "silent window" during slight background noise for vocal communication (Brenowitz, 1982). Blue monkeys *Cercopithecus mitis* and Pygmy marmosets *Cebuella pygmaea* avoid the masking by making calls with dominant frequencies that get coincided with the characteristic low-amplitude region in the noise spectra (Brown & Waser, 1984; Torre & Snowdon, 2002). Narins et al. (2004) explained that concave-eared torrent frogs *Amolops tormotus* and Black-faced Warbler *Abroscopus albogularis* produce prominent ultrasonic harmonics that perhaps project the signal to stand out against lower frequency noisy streams. The animals perform short-term adaptation through adjusting the vocal characteristics by; (i) increasing the amplitude upon rising in the noise level (Lombard effect; Lombard, 1911) in Nightingales, *Luscinia megarhynchos* (Brumm (2004)); (ii) increasing the call syllable duration (in common marmosets *Callithrix jacchus*) as a response to playback (Brumm et al., 2004); (iii) increasing the redundancy – increase in call syllable numbers in Japanese Quail *Coturnix japonica* (Potash, 1972); in King Penguins *Aptenodytes patagonicus* by Lengagne *et al*., (1999); (iv) regulating the vocal frequency in frogs (Bee et al., 2000) and birds (Hultsch & Todt, 1996; Manabe, 1997); (v) adjusting the signal timing (Cody & Brown (1969)). They showed that Wrentits and Bewick's wrens showcased asynchronous pattern in song output during morning hours.

Forest habitat encompasses several bird species that have unique species-specific calls and songs. The compilation of all vocal signals of a species (vocal repertoire) is difficult to estimate (Krebs & Kroodsma, 1980; Kroodsma, 1982). Zebra finches *Taeniopygia guttata* have only a single type of song which is 'simple' and 'discrete' (Catchpole & Slater, 2008). Ovenbird *Seiurus aurocapillus* (Falls, 1978), White-crowned Sparrow

Zonotrichia leucophrys nuttalli (Baptista, 1975), Splendid Sunbird *Nectarinia coccinigaster* (Grimes, 1974) had a single type of song and their repertoire size are one. Chaffinches *Fringilla coelebs* have 1-6 (Slater, 1981), Great tit *Parus major* have 2-8 (Krebs et al., 1978), Song Sparrow *Melospiza melodia* has 7-11 (Beecher et al., 2000) and Cardinal *Richmondena cardinalis* has 8-12 (Lemon, 1974) song repertoires. Nightingale *Luscinia megarhynchos* (Kipper et al., 2004) and Song thrushes *Turdus sp*. (Ince & Slater, 1985) have a complex repertoire and tend to switch from one song to another during their vocal broadcasting. With 160-231 and 138-219 song repertoire sizes respectively, these birds produce 'continuous' vocal performance.

With this understanding of the wide background information on the vocal communication of animals, especially birds, the present work is attempted to understand the vocalisations of bird species of the Anaikatty hills with the following objectives:

1.2 OBJECTIVES

The specific objectives of the study include;

1. To study the extent of ornithophony in the soundscape of Anaikatty hills,
2. To analyse the song repertoires of three groups of closely related coexisting species, and
3. To analyse the song repertoire of a select species, Common Iora *Aegithina tiphia*, their call characteristics and contextual implications.

1.3 OUTLINE OF THE THESIS

The thesis is structured into seven chapters; of which three are technical chapters, each addressing the objectives of the study. Chapter I provides a general introduction about the acoustic communication of birds encompassing a broad overview and conceptual background of the study. Chapter II covers the exhaustive review of literature of the objectives, as a prelude to the technical chapters. The study area and methodology are covered in chapter III. The pattern of bird vocalisation in the soundscape of the study area was investigated in chapter IV, the first technical chapter. This chapter brings out the

dominant vocalising birds of the area. The second technical chapter, chapter V focusses on the vocal characteristics of the ecologically related three co-existing bird species groups – sunbirds, bulbuls and prinias. This chapter is an attempt to study the spectral uniqueness of their syllables. The study gets further narrow down to a single species' Common Iora *Aegithina tiphia,* in the final technical chapter, chapter VI. Their vocal repertoire and associated behaviour were studied and results were presented. Chapter VII summarizes the inferences of the present study on the vocalisations of birds. References is presented at the end of the thesis.

Chapter - II

REVIEW OF LITERATURE

Somewhere, always, the sun is rising, and somewhere, always, the birds are singing.

- Donald E. Kroodsma.

CHAPTER II

REVIEW OF LITERATURE

2.1 ACOUSTIC COMMUNICATION

Communication is the exchange of message (information) from a sender with a contextual meaning (Truax, 1984) to an intended receiver. The signal can mutually benefit the sender and receiver (Smith, 1986) or only benefit the sender (Dawkins & Krebs, 1978; Wiley & Richards, 1982; Wiley, 1983; Krebs & Dawkins, 1984). The vocal signal may only influence the behaviour of the receiver (Wiley & Richards, 1982; Wiley, 1983; McGregor, 1991). In birds, vocal communication is the preferred mode of signal transfer as it is best suited for long-range (50-200 m) signal propagation (Marler & Mitani, 1988).

2.1.1 'Syrinx' – vocal box in birds

Syrinx and associated muscles influence the spectral and temporal characteristics of birds vocal signals. During the expiration process, vocal signals are produced by compression of the air stream through bronchus and the syrinx (Gaunt, 1983; Gaunt et al., 1973; Brackenbury, 1980) by vibrating tympaniform membrane (TM) (Miskimen, 1951; Gottileb & Vandenbergh, 1968; Stein, 1968). Syrinx and associated respiratory muscles are the reasons for amplitude and frequency modulation in birds' vocalisations (Greenewalt, 1968; Fletcher, 1988; Stein, 1968). Syrinx; (i) produces rapid sequences of notes (or trills) in Budgerigars *Melopsittacus undulatus* (Suthers, 2001), Canaries *Serinus canaria* (Hartley & Suthers, 1989), and Northern cardinals *Cardinalis cardinalis* (Suthers & Goller, 1996); (ii) determines the temporal characteristics of a song (Brackenbury, 1980; Brackenbury, 1982); (iii) produces monotonic 'syllables' with uniform frequency range (Beeman, 1998) to frequency modulated (FM) syllables within a short span of time. Bird vocalisation includes either 'whistles' (smaller amplitude of vibration) or 'complex notes' (larger amplitude of vibration) and/or combination of the both (Greenewalt, 1968).

2.1.2 Repertoire size in birds

Song repertoires vary among bird species (Kroodsma, 1982). European blackbirds *Turdus merula* have seven types of calls (Snow, 1958). Similarly, the tropical bird species Red-vented Bulbul *Pycnonotus cafer* and Oriental Magpie Robin *Copsychus saularis* have seven repertoire size (Kumar & Bhatt, 2000; 2001). Adult Pied Flycatchers *Ficedula hypoleuca* and Collared Flycatchers *F. albicollis* (von Haartman & Löhrl, 1950); Great Tits *Parus major* (Gompertz, 1961); and Black-capped Chickadees *Poecile atricapillus* (Hailman & Ficken, 1996; Ficken et al., 1978) have twelve call types each. The long-tailed Manakin *Chiroxiphia linearis* males produce thirteen call types in Costa Rica (Trainer & McDonald, 1993). The Collared Jay *Cyanolyca viridicyana merida* have large call repertoire than any other New World jays (Hardy, 1967). Birds produce targeted vocalisations towards male conspecifics or female.

2.1.3 Species-specific vocal signals

Birds also have species-specific calls that differentiate from vocal signals of other co-existing bird species. Birds use the invariant song subsets for species recognition (Emlen, 1972; Becker, 1982). The distinct song features also serve as species-recognition signals (Marler, 1960; Emlen, 1972). Birds' recognize the complexity of songs, i.e. the phrase composition, syntax and frequency variation, and interphase interval (Emlen, 1972); and variation in intensity (Coles et al., 1980). Field Sparrow *Spizella pusilla* differentiate the songs of other two birds Chipping Sparrow *S. passerine* and Prairie Warbler *Dendroica discolor* present in the same habitat (Goldman, 1973; Morrison-Parker, 1977).

The duration and the repetition of sound produced in Bush Cricket *Homorocoryphus nitidus* by rubbing their forewings are unique for its species (Bailey, 1976). The cricket species' have this species-targeted vocal signal for a functional implication of creating a response in females (Elsner & Popov, 1978). The loudness and frequency add more information for the recipient female, as the attenuation increases with distance. The intensity or the loudness of a signal shows the distance of the speaker from the receiver individual and frequency shows the direction of the incident sound (Lewis & Gower, 1980).

2.1.4 Long-distance signal transmission – biological constraints

Among the visual, chemical, tactile and vocal mode of communication, vocal communication is the widely used way among avian communities, (i) as the sound travel for longer-distance; (ii) can be easily distinguished between species; (iii) travel in all direction (omnidirectional); and (iv) can be produced both during day and night (Slabbekoorn, 2004b). Littlejohn (2001) explained that the cause of long-distance communication is primarily for advertising the sender's presence to the receiver.

Vocal signal transmission in a habitat is affected by attenuation and degradation (Wiley & Richards, 1982; Forrest, 1994). The physical obstacles like trees, branches and leaves absorb the signals or reflects it into different directions (Aylor, 1971; Marten & Marler, 1977; Marten, 1980) causing loss of sound energy, also termed as 'excess attenuation'. Along with the external environmental factors, song loudness, ambient noise also impacts the signal transmission in birds (Slabbekoorn, 2004a). Omnidirectional sound suffers from the effect of spherical spreading and attenuates at 6dB for every doubling of distance (Witking, 1977; Larsen & Dabelsteen, 1990). Sage Grouse males produce directional whistles that get spread to sideways during their display (Dantzker et al., 1999).

The volume of the song might be influenced by body size, wherein larger birds have louder utterances. Animals with greater mass are efficient in producing low-frequency signals (Ryan & Kime, 2003). This relationship is proved in favour in several studies among various taxa, such as in frog species (Ryan & Rand, 2001); in bird species (by Morton, 1977; Wallschager, 1980; Bowman, 1983; Ryan & Brenowitz, 1985; Wiley, 1991); and mammal species (Fitch & Hauser, 2003). At the same time in birds and mammals, this relationship is not always consistent wherein the correlation is not strong as expected. Martin (1972) showed that generally, large-sized toads have larger syrinx that can produce lower dominant frequencies, which is in contrary to the body size and frequency relationship. However, this shows that the vocal communication of animals is dynamic in nature. Moreover, in frogs, the frequency-modulated calls can be produced by altering the syrinx tension during signal synthesis (Ryan & Kime, 2003).

2.1.5 Non-biological constraints

The signal loss by degradation (attenuation) and reflection and/or absorption on vegetation (reverberation) are crucial for signal transmission of birds (Wiley & Richards, 1978). The receiver either would not be able to detect or recognize the signal due to signal-to-noise ratio due to the alteration in the temporal and spectral feature of the vocalisations (Wiley & Richards, 1978; Wiley, 1991; Michelsen & Larsen, 1983). The environmental constraints can be reduced or mitigated by 12 "rules" (Endler, 1992), adapted from earlier studies (Wiley & Richards (1982); Capranica & Moffat (1983); Brenowitz (1986); Okanoya & Dooling (1988); and Ryan (1988)). This includes; (i) usage of lower frequencies lesser than 2 kHz to reduce reverberation, attenuation and scattering effects; (ii) production of signal ranging 0.5 – 1 kHz by animals near the ground; (iii) synthesis of species-specific frequency bandwidth to decrease overlapping of other species signals; (iv) usage of increased amplitude signals to increase the signal-to-noise ratio for enhanced transmission distance and detection by receiver; (v) usage of redundant signals during the presence of background noise for increasing detection probability; (vi) preferring 'acoustic space' that avoid non-biological sound; (vii) broadcast the signal from a taller perch to minimize ground attenuation and absorption of vegetation. Birds use all the above guidelines during their signal production. 'Active space' is defined as the signal travel distance for achieving the intended function (Lemon et al., 1981).

Experiments validate that the lower frequency signals attenuate lesser than higher frequency signals (Morton, 1975; Marten & Marler, 1977; Marten et al., 1977; Waser & Brown, 1986). The high-frequency signals are highly susceptible for absorption by the objects on the way and signal loss by atmospheric turbulence. The low-frequency signal produced by birds closer to the ground level also experience more attenuation due to the interference of direct and reflected waves arise from the ground (Wiley & Richards, 1978).

2.1.6 Optimisation of active acoustic space

Birds increase the possibility of signal transmission by avoiding or reducing the influence of the above-mentioned factors. Birds' increase the perch height to avoid the ground effect (Marten & Marler, 1977; Waser & Waser, 1977; Brenowitz et al., 1984; Mathevon et al., 1996). Males prefer calling in tall perches in trees or during the flight

(Mathevon et al., 1996). Birds produce high-pitched songs that project above the background noise; in the Large-billed Leaf Warbler *Phylloscopus magnirostris* (Dubois & Martens, 1984; Martens & Geduldig, 1990); in White-throated Dippers *Cinclus cinclus* against running stream water (Brumm & Slabbekoorn, 2005); and in Rufous-faced Warbler *Abroscopus albogularis* (Nairns et al., 2004). Ryan and Brenowitz (1985) showed that the evolution of low-frequency bird calls is an adaptation for high-frequency insect noise as background in tropical forests.

The environmental and weather conditions vastly vary over the diurnal hours. Along with that, the calling bird faces the biotic sound of other species and abiotic noise of environment that vary across the day. Hence, birds prefer a particular period that is devoid of above-mentioned constraints. Early morning (dawn) and evening (dusk) hours are best suited for sound transmission in all habitats including deserts to tropical forests (Waser & Waser, 1977; Henwood & Fabrick, 1979).

2.1.7 Dawn chorus

The birds are active in the morning as their testosterone level are high (Staicer et al., 1996) and the energy procured by the previous day food is conserved. The environmental factors like sunrise time, moon brightness, cloud cover, rainfall, and temperature also influence the time of dawn chorus (Allen, 1913; Davis, 1958; Thomas et al., 2002; Miller, 2006). Dawn chorus is beneficial for the signaler as it functions as mate guarding signal (Mace, 1987a; Møller, 1991). Male Great Tit *Parus major* peaks the dawn singing during the fertile period of the female (Mace, 1987b). However, not all species perform dawn chorus (Hanski & Laurila, 1993). Males perform dawn singing targeting rival males ((interspecific communication); Kroodsma et al., 1989; Nelson & Croner, 1991) or targeting females nearby their perch (Mace, 1987b; Björklund et al., 1989; Kroodsma et al., 1989; Cuthill & Macdonald, 1990).

Dawn singing are also made to inform the absence of predator around (Johnson & Kermott, 1989); for extra-pair mate attraction (Mace, 1987a; Smith, 1988; Heg et al., 1993; Sheldon, 1993); for avoiding cuckolders (Mace, 1987a; Møller, 1991); and for territory maintenance (Armstrong, 1973; Hanski, 1992). Dawn singing is efficient for incident

signal, as signaler can transmit the signal and avoid intruder and predation risk. It is better mode to broadcast in poor light conditions (Pärt, 1991; Davis, 1992).

2.1.8 Co-existing birds' cacophony

Vocalisations of each species are distinctive in nature. The sympatric species use "acoustic niche" to avoid overlap of signals. This is advantageous to locate and respond for the conspecific receiver in a heterospecific dominated environment. Frogs maintain different sites for calling that increases the chance of response from conspecific mates (Duellman, 1967; Hödl, 1977). The co-existing species encounter one another vocally and diversify their ecological niches (Chesson, 2000; Losos, 2010). Trill rate and song duration are the main spectral features of the Darwin finches' song traits that minimize the masking by other bird signals (Grant & Grant, 2010). Goodwin and Podos (2013) showed that Black-capped Chickadees *Poecile atricapillus* produces real-time frequency modulations to avoid overlapping tones of neighbours. Though the above discussed biotic noise and abiotic noise influences the vocalisation in birds, the major selective drive is limited by morphological factors (Ryan & Brenowitz, 1985). The functional implication of the calls and songs are the prime factor for evolution and diversity of songs (Byers & Kroodsma, 2009).

2.1.9 Contextual significance of vocal signals

Communication helps in maintaining social relationships among individuals in general (Catchpole & Slater, 2008; Rutovskaya, 2011). Primates and birds have a unique set of calls (repertoire) with the species-specific contextual message (Gottfried et al., 1985; Fischer & Hammerschmidt, 2001; Fragaszyet al., 2004).

The major function of the song is for female attraction and successful breeding and was first explained by Gilbert White of Selborne (1789). Male sings vigorously at rival mates during the breeding period to show aggression (Armstrong, 1973). Sethi and Bhatt (2008) demonstrated that Indian Chat *Cercomela fusca* has eight distinct calls including territorial call, begging call, feeding call, alarm call, threat call, contact call and distress

call. The tropical species Pied Bush Chat *Saxicola caprata* had five types of calls for territorial, begging, alarm, contact and distress functions (Sethi et al. 2012). Kumar (2004) had shown that Red-vented Bulbul *Pycnonotus cafer* also had similar seven types of calls.

Chapter - III

STUDY AREA AND METHODOLOGY

The woods would be very silent if no birds sang there except those that sang best.

- Henry Van Dyke

CHAPTER III

STUDY AREA AND METHODOLOGY

This study was performed in the dry deciduous, moist dry deciduous forest and scrub forests in and around Sálim Ali Centre for Ornithology & Natural History (SACON) campus, Anaikatty hills (Figure 3.1). The study area is situated in Nilgiri Biosphere Reserve (NBR), Western Ghats, which is one among the 45 biodiversity hotspots of the world (Noss et al., 2015).

3.1 ANAIKATTY HILLS

3.1.1 Topography

The study area Anaikatty hills (11°5'26" and 11°5'49" N; 76°46'41" and 76°47'33" E) lies within Nilgiri Biosphere Reserve (NBR) (Mukherjee & Bhupathy, 2007). This Anaikatty reserve forest area is bounded by Sathyamangalam forest in the north, Nilgiris in the south, Erode in east and Palghat forest division in the west (Eswaran, 2006; Pramod & Eswaran, 2006). The total area of Anaikatty reserve forest comprises 4447.74 ha (south division – 2292.08 ha and north division – 2155.66 ha) (Nirmala & L. Vijayan, 2002).

3.1.2 Soil and climatic condition

Anaikatty hills' soil composition includes minerals such as Mica, Quarzite, Talc, Garnetite, Feldspar, Amethyst, Calcite, Hematite, etc., (Mukherjee, 2007). The metamorphic rocks of this region belong to the Archean age (Balasubramanian, 2017). The soil types include hard-gravel majorly and red soil in the hilly region. The plains are rich in red loamy and sandy soil, brown soil and black clayey soil (Soundarapandian, 1992). The region experiences temperature varying from 17 to 36 ˚ C (Mukherjee & Bhupathy 2007).

The study site is at the leeward side of the Western Ghats and receives an average annual rainfall of about 700 mm (Kumar & Umapathy, 1999), which is mainly contributed by the north-east monsoon (September to November). The other seasons; namely southwest monsoon (June to August), followed by Northeast monsoon, and then

winter between December to February and summer months between March and May (Pramod & Eswaran, 2006; Eswaran & Pramod, 2016). This region experiences temperature varying from 17 to 36 ˚ C (Mukherjee & Bhupathy, 2007).

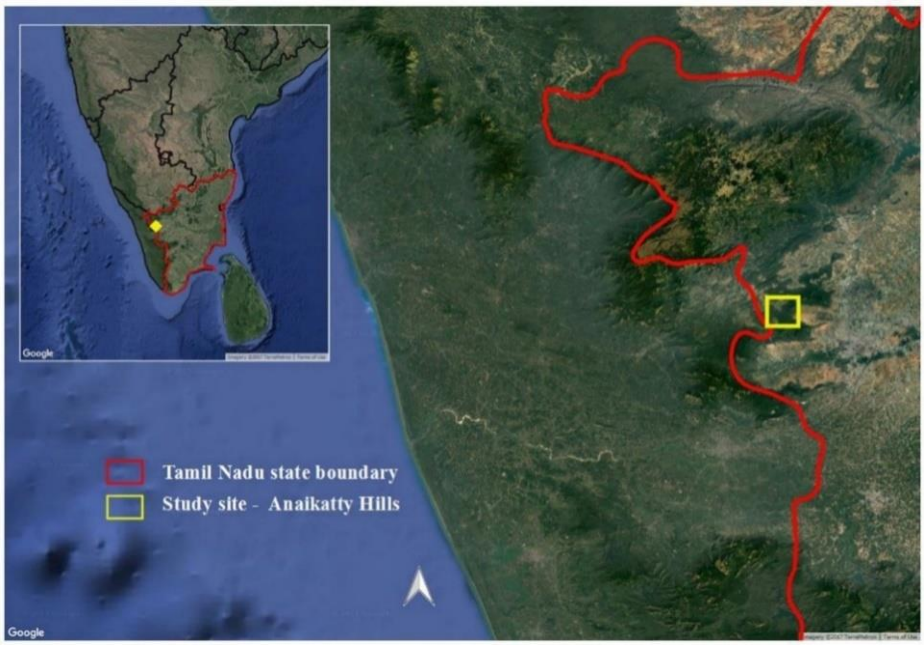

Figure 3.1 Study site location with Tamil Nadu boundary in the inset

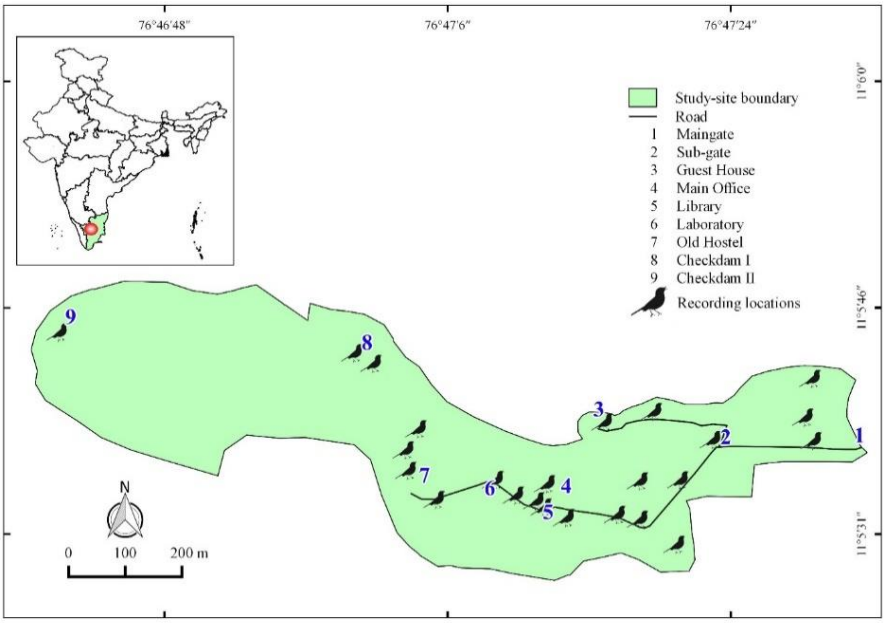

Figure 3.2 The 24 recording locations in SACON campus and adjacent area with India map in the inset.

3.1.3 Flora and fauna

The study area is in the south-eastern slopes of Nilgiri Biosphere Reserve, falls in the eastern region of the Western Ghats (Balasubramanian et al., 2017). The forest type is categorized as 'southern dry mixed deciduous forests' (Champion & Seth, 1968). This region has mixed dry deciduous forests (47%) and tropical thorn forest (scrub jungle) (47%). The deciduous forests have short trees with girth size about < 50 cm and grow up to 10 m height. The scrub forest has open, thorny vegetation with shorter trees reaching maximum height 6 to 9 m. The study site is dominated by trees such as *Chloroxylon swietenia*, *Acacia leucophloea, Ziziphus mauritiana, Albizia amara, Terminalia arjuna*, *Albizia lebbeck, Cassia fistula, Polyalthia longifolia, Millingtonia hortensis, Pongamia pinnata, Bauhinia racemosa, Santalum album, Ficus sp., Acacia leucophlea* and *Acacia polyacantha.* (Subramanyam & Nayar, 1974; Balasubramanian et al., 2017). The following shrubs are commonly seen here *Chromolaena odorata, Clausena indica, Elaeodendron glaucum, Flacourtia indica, Lantana camara*. The seasonal ground plants like *Ageratum conyzoides, Leucas aspera, Malvastrum coromandelicum* and *Phyllanthus amarus.*

The study area has 402 flowering plants species comprising 84 families and 210 genera. The *Prosopis juliflora* is dominant in the North-Eastern side of SACON campus. The major grass species of this region are *Aristida setacea, Allopteris cimicina, Dactyloctenium aegyptium and Heteropogon contortus*. Ornamental species such as *Millingtonia hortensis*, *Spathodea campanulata*, *Tabebuia rosea*, *Tecoma stans* and *Polyalthia longifolia* are seen here. The medicinal value-rich plant species such as *Gymnema sylvestre*, *Morinda coreia*, *Azadirachta indica*, *Ocimum americanum* and *Ocimum tenuiflorum* are found in this region. The region has exotic weeds such as *Prosopis juliflora*, *Lantana camara* and *Chromolaena odorata* (Balasubramanian et al., 2017). Ms. Aruna (2012) investigated the avian frugivory species and fruiting phenology in the tropical mixed dry deciduous forest of Anaikatty hills and Attapadi hills, in the Western Ghats along with Scrub forest of Eastern Ghats for her doctoral thesis. During her field study (2007 – 2012), she found avian frugivores to use 32 tree species belonging to 16 families. Tree species of Moraceae family (of 6 plant sp.) were most favoured by birds. Many birds visited

Ficus benghalensis tree. The most common frugivore observed during here study was Red-vented Bulbul, followed by Red-whiskered Bulbul *Pycnonotus jocosus*.

Insects' species belonging to 14 orders and 77 families were documented from SACON campus. They are abundant during monsoon or wet season (July to December). Butterfly migration falls during mid-October to November and butterflies are abundant in November here. Totally 107 species of butterfly species were observed in this region. The insect diversity and their community ecology of this region were studied by Eswaran between 2003 and 2005 for his doctoral research (Eswaran, 2006). Hymenopterans were more abundant on ground and foliage microhabitats, whereas hemipterans were more abundant in shrub microhabitat. The most common butterfly family is Nymphalidae (Eswaran, 2006). The common butterfly species includes Common Rose *Pachliopta aristolochiae*, Crimson Rose *Pachliopta hector*, Blue Tiger *Tirumala limniace*, Lesser Grass Blue *Zizinia otis*, etc. About 44 species of odonates of eight families were documented here. The region contains seasonal streams and stagnant pools that supports the diversity of dragonfly and damselfly community. The common odonates are *Vestalis gracilis, Anaximma culifrons, Trithemis aurora, Tetrathemis platyptera,* etc. (Balasubramanian et al., 2017).

Eight species of amphibians are so far documented from this region. One toad species i.e., Common Indian Toad *Duttaphyrinus melanostictus;* three species of nocturnal and burrowing frogs *viz.,* Red Narrow-mouthed Frog *Microhyla rubra*, Indian Burrowing Frog *Sphaerotheca breviceps,* Marbled Balloon Frog *Uperodon systoma;* one species of tree frog – Common Tree Frog *Polypedates maculatus* and three species of water associated frogs were reported from here (Balasubramanian et al., 2017). Debanik Mukherjee studied the resource utilization patterns of reptiles in Anaikatty hills for his doctoral research between June 2002 and December 2005. He had documented 58 reptile species in the study area (Mukherjee, 2007), including one freshwater turtle, 24 lizards and 33 snakes. Two new species such as Anaikatti Day Gecko *Cnemaspis anaikattiensis* (Mukherjee et al., 2005) and Yellow Collared Wolf Snake *Lycodon flavicollaris* (Mukherjee & Bhupathy, 2007) were discovered during his study. The venomous snakes such as Spectacled Cobra, Common Indian Krait, Russell's Viper and Saw-scaled Viper;

14 mild venomous and non-venomous snakes are recorded so far. Other reptile species such as one Uropeltid snake, Chameleon, agamid lizard, two species of skinks, geckos and one species of turtle are documented from the study location.

Kumar & Umapathy (1999) had published initial mammal species of this region. Anaikatty-Veerapandi elephant corridor is one among the six elephant corridors in Coimbatore division, Tamil Nadu. Most commonly observed mammals are Asian Elephant *Elephas maximus*, Wild Gaur *Bos gaurus*, Chital *Axis axis*, Sambar *Rusa unicolor*. Leopard *Panthera pardus*, Wild Dog *Cuon alpinus*, Sloth bear *Melurus ursinus*, Wild Boar *Sus scrofa cristatus*, Indian three-striped Palm Squirrel *Funambulus palmarum*, Black-naped Hare *Lepus nigricollis* (Pramod & Eswaran, 2006) are seen here.

Nirmala (2002) studied the ecology of bird communities of Anaikatty hills for her doctoral thesis, the first systematic study of birds in this region. Ali et al. (2013) listed 145 bird species more recently. The forest-dwelling and woodland birds' species are commonly seen in this area such as 7 species of cuckoos, 7 species of woodpeckers, 9 species of chats and flycatchers, 6 species of doves and pigeons. A total of 177 bird species are compiled, wherein 100 species are resident birds and are observed throughout the year. Twenty-seven migrant species of birds visit every winter and 15 local migrants' visits SACON campus (Balasubramanian et al., 2017).

3.2 STUDY DESIGN

3.2.1 Study plan

The study is devised to understand the basic pattern and process of vocalisation of birds of Anaikatty hills. The SACON campus and the neighbouring places like Nilgiri Biosphere Nature Park (NBNP), Kondanur village were explored for the acoustic community of birds during the reconnaissance survey from June 2014 to November 2014 (Figure 3.1). I used the Sony PCM-M10 portable linear PCM audio recorder (2009), with an Audio-Technica ATR6550 condenser shotgun microphone to record the vocal signals in .WAV format with 44.1 kHz sampling frequency and 24-bit accuracy rate.

3.2.2. Sampling strategy

Based on the understanding of the vocal communication of the above-mentioned locations in and adjacent to SACON campus, 24 locations were decided as sampling points for further intensive investigation (Figure 3.2). Intensive data collection was performed between November 2014 to October 2016. The audio recording data were collected during the breeding season and non-breeding season.

3.3 METHODOLOGY

3.3.1 Field methods

Objective I: The ornithophony of the diurnal birds is the first objective of the study. The diel pattern of the acoustic behaviour of birds was observed and calls were recorded from 6 h to 19 h spanning 13 hours of a day. The daylight period is segmented into 13 one-hour slots (from henceforth mentioned as 'observation window'). Six replicates of 5-minute bird call recordings were collected from each window, of which each 5-minute call recording is considered as 'a sampling unit'. I held the microphone for one minute in each direction to capture the soundscape. The sampling effort was 6 replications * 13 hrs. The recording date, GPS coordinates, list of vocalising and non-vocalising birds, time and location were noted during the recording period. Recordings were not collected during rainy days. The detailed data analyses, results and discussion are presented in chapter 4. The average sampling effort per location was 3.0. The distribution of the sampling periods were done following a randomization process in 24 locations across 13 hours of recording windows. The distribution of sampling period was presented in Table 3.1.

Table 3.1 Distribution of sampling period in 24 locations of study area

13 hrs/ 24 loc	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
6-7 H		■											■			■	■		■					
7-8 H				■		■						■	■				■							
8-9 H			■	■						■			■											
9-10 H								■	■	■			■									■		
10-11 H		■	■						■				■				■			■				
11-12 H	■	■			■								■									■		■
12-13 H		■											■		■			■			■			
13-14 H		■								■				■					■		■			
14-15 H				■									■	■					■			■	■	
15-16 H		■		■					■	■											■			
16-17 H		■					■							■					■			■		
17-18 H		■								■				■							■	■		
18-19 H											■		■				■		■		■			

The sampling effort was distributed across 13 hours in 24 locations to capture the soundscape of the study area.

Objective II: The second objective of the study narrows down to understand the spectral parameters of the vocalisations of the ecologically related three bird groups and understand the underlying similarities and uniqueness (if, any). The study species include: (i) three sunbird species - Purple-rumped Sunbird (PRSB) Leptocoma zeylonica, Purple Sunbird (PLSB) Cinnyris asiaticus and Loten's Sunbird (LTSB) Cinnyris lotenius; (ii) three Bulbul species - Red-vented Bulbul (RVBB) Pycnonotus cafer, Red-whiskered Bulbul (RWBB) Pycnonotus jocosus and White-browed Bulbul (WBBB) Pycnonotus luteolus; and (iii) three Prina species - Ashy Prinia Prinia socialis, Grey-breasted Prinia Prinia hodgsonii and Jungle Prinia Prinia sylvatica.

Study species

I. Sunbirds

Among these selected three sunbirds, PRSB and PLSB are relatively common than LTSB and all are resident species to the study area.

A. Purple-rumped Sunbird (PRSB) *Leptocoma zeylonica*

PRSBs are resident species of Indian subcontinent preferably in lowlands up to 1000 m. They are common in open deciduous woodland, groves, orchards, gardens, and in towns and cities. They are nectarivores and feed also on invertebrates. The songs are high pitched, thin, short metallic upstrokes of frequency ranging up to 4 kHz. The calls are very short, thin, high-pitched, metallic *tzip*! (Rasmussen & Anderton, 2012).

B. Purple Sunbird (PLSB) *Cinnyris asiaticus*

Resident to the Indian subcontinent and widespread in the peninsular region up to 2400 m. Common habitats were dry deciduous forest and woodland, thorn and coastal scrub, riverbed shrubbery, and gardens. Their songs are either strident and loud, short, crackling, rapid rattles, followed by up slurred notes or longer strophes, ringing notes, with the frequency bandwidth of 3 – 6 kHz. The calls are generally short, hard, stony notes, or short, ringing up-slurred notes with frequency 4 – 7 kHz (Rasmussen & Anderton, 2012).

C. Loten's Sunbird (LTSB) *Cinnyris lotenius*

LTSBs are observed in lowlands up to 1600m of the Western Ghats in moist deciduous forest, farmland, and gardens. Their songs are short, musical, starts as a soft, rattling titter, to loud, staccato notes with frequency 2.5 – 6 kHz. Calls are zing, mid-pitched, relaxed upstrokes with 3 – 4 kHz frequency (Rasmussen & Anderton, 2012). They devour on insects, spiders and nectar (del Hoyo et al., 2006b). They nectar-rob the flowers by puncturing the base of calyx.

II. Bulbuls

Among these selected three bulbuls, RVBB are relatively more common, secondly RWBB and then WBBB. All the three bulbuls are resident species to the study area.

A. Red-vented Bulbul (RVBB) *Pycnonotus cafer*

This resident species occupies plains, valleys, foothills lesser than 1600 m. They are common in dry and secondary forests and scrublands, also common in gardens and in cities. This conspicuous species is vocally active all through the day. Majorly a frugivore in nature feeds also on insects and nectars. Their songs are loud and cheerful varies about 1.5 kHz. The calls are very harsh, vigorous and guttural in nature (Rasmussen & Anderton, 2012). They occupy deciduous biotope at the juncture of evergreen and deciduous. RVBBS were often seen in pairs or large congregations for *Ficus* tree fruits or in *Lantana* patches. These species generally were arboreal and rarely descends to the ground. They are swift in alerting on seeing predators' in the vicinity (Ali & Ripley, 2001a). A study by Kumar and Bhatt (2000) showed this species to produce seven types of vocal signals; such as contact signals, roosting signals, two types of the alarm signal, distress signals, twittering and begging calls. Twittering calls are sub-song of unclear function produced by both males and females (del Hoyo et al., 2006c).

B. Red-whiskered Bulbul (RWBB) *Pycnonotus jocosus*

This species is spread across from Punjab (foothills of Himalayas) to Arunachal Pradesh, most parts of Peninsula till Rameswaram. They are commonly seen up to 2000m, in dense woodland and secondary scrub and gardens. They are more inclined towards evergreen areas than RVBBs. RWBBs were a frugivorous bird, also feed on nectar and insects. Their songs are short, cheerful, with frequency modulation ranging from 2 to 3.8 kHz (Rasmussen & Anderton, 2012). They are usually observed in pairs, and along with other bulbuls. These insectivores mostly feed on trees, bushes and on the ground (Ali & Ripley, 2001a).

C. White-browed Bulbul (WBBB) *Pycnonotus luteolus*

WBBBs widely spread across the peninsular region in lowlands up to 1300 m. They are observed in forest edges, scrublands and thorn thickets. Their songs are distinct from the other two bulbuls, with long, loud, ebullient, guttural, rapid chatters, ranging from 1 to 3 kHz. Calls are song fragments with rasping *churr (*Rasmussen & Anderton, 2012).

They feed on fruits and berries of *Zizyphus sp.*, *Lantana*, figs and nectar of *Erythrina sp.*, *Salmalia sp.*, etc. They are observed mostly in pairs, very shy, skulks, and hence, heard quite often than spotted in wild (Ali & Ripley, 2001a). They mimic calls of Red-vented Bulbul, Large Cuckoo-shrike *Coracina macei* and Green Bee-eater *Merops orientalis* (del Hoyo et al., 2006c).

III. Prinias

A. Ashy Prinia (ASPR) *Prinia socialis*

This is endemic species of India, resides in plains up to 1800 m, is a common species in the peninsular region. They habituate in tall grass, scrubland, farm margins, dry forest edges, shrubbery, reedbeds. The songs are loud and ringing three-elemental strophes, with 3 – 7 kHz frequency. Calls were nasal mew and buzzy (Rasmussen & Anderton, 2012). Generally unobtrusive species forages close to ground and moves inside bushes (del Hoyo et al., 2006a).

B. Grey-breasted Prinia (GBPR) *Prinia hodgsonii*

These are resident species distributed in scrub grassland, forest clearing, bushes, gardens, bamboos plains up to 1800m. They are hyperactive, gregarious and confiding. The songs are trilled chips. Their songs and calls may be mixed as irregular and jangly notes, ranging 3 – 8 kHz (Rasmussen & Anderton, 2012). They perch top of bushes or trees to give lively, scratchy repetitive warbles, the note generally rises and intensifies and ends abruptly (del Hoyo et al., 2006a).

C. Jungle Prinia (JNPR) *Prinia sylvatica*

JNPRs are endemic and resident species to peninsular lowlands, seen up to 1500 m in thorn shrub, dry open areas, ravines and in boulder-strewn hillsides. The songs are hard, loud, lengthy, with repetitive warbles, ranging 2-6 kHz. The calls are agitative, rapid, hard, uniform chatter with 2.5-3.5 kHz of frequency (Rasmussen & Anderton, 2012). They feed generally on small invertebrates, such as spiders, grasshoppers, ants, etc., close to ground and climbs up on bushes (del Hoyo et al., 2006a).

Objective III: This section further narrows down to study the vocalisations of single species – Common Iora (COIO) *Aegithina tiphia*. The bird calls were recorded from January 2015 to July 2016. The behaviour of the calling bird such as; feeding, flying, hopping, perching during the vocalisations; perch height from the ground, distance from the recording device/researcher, bird presence in tree or shrub, GPS co-ordinate, and other non-vocalising bird species were also simultaneously recorded.

The COIO syllable types, characterization of the spectral and temporal features of the syllables are studied in the third objective. To understand the partner association during Common Iora song performance, the presence of the partner, their hopping and/or feeding behaviour, visibility of the bird in perch, (Table 6.1) were also collected during the fieldwork along with each call recording.

Study species: Common Iora (Figure 6.1) is a tropical scrub jungle and dry deciduous forest species, generally seen in pairs. The breeding season extends from January to August (Ali & Ripley, 2001b). They forage by gleaning on the barks and tree leaves. While they actively feed, the male and female calls frequently for contacting the partner and show acrobatic poses during feeding. They search for food on the tree and hops actively from one branch to another and across trees. Both the male and female vocalises frequently (Ali & Ripley, 2001b) and produce short syllables that are repeated consecutively (personal observation).

Common Iora species were identified and recorded at four distinct and separate roosting-cum-nesting locations. The song perches and non-song perches of Common Ioras were marked to delineate their territories. Based on the spot mapping technique (Emlen, 1977), the territories of Common Iora pairs were identified as approx. 400-500 m apart. As the intention was not to compare between the locations of any specific pairs, opportunistic sampling of bird calls was done depending on the availability of bird calls in the locations. Continuous 5-minute recording from four different locations was considered as a ‘sampling unit’. It were attempted to record the samples distributed throughout the day

between 0600 HRS to 1900 HRS. From these recordings, the vocal signals of the Common Iora were extracted.

3.3.2 Vocalisation data

Totally 390 minutes of bird call data were collected between January 2015 to October 2016 and used to address the first objective. For the second objective, totally 18 call recordings accounting for 68 min; 48 sec, recorded between January 2015 and May 2016 were analysed for sunbird syllables. Sixteen Bulbul calls recorded between March 2015 and July 2016, yielded 72 min; 9 sec of vocal recordings. The opportunistic Prinia calls recorded from January 2015 to July 2016 generated 101 min; 21-sec calls from 22 vocal recordings. For the third objective, the data collected from March 2015 to October 2016 covering the breeding and non-breeding seasons were used. From these call data, 48 recordings comprising 240 minutes of song recordings, 142 vocalisation events of Common Iora were extracted for further analysis.

3.3.3 Spectrogram visualisation

For the three objectives, Raven Pro 1.4 (Bioacoustics Research Program, 2011), a bioacoustics interactive software was used to view spectrogram and perform temporal and spectral analyses. The spectrogram parameters measured for each objective was mentioned under the specific objectives above. The spectrogram settings in RAVEN Pro 1.4 were as follows: Hann 512, 3dB filter Bandwidth 124 Hz, 50 % overlap, grid spacing 86.1 Hz. The frequency values of bird vocalisations were measured by visual inspection method

(Irwin 1990; Nowicki & Nelson 1990; Baker & Boylan 1995; Cardoso & Atwell 2011; Singh & Price 2015). Audacity 2.0.6. software was used to amplify or noise reduction when necessary.

Objective 1: The audio data were visually inspected on the spectrogram.

Objective 2: The spectral features such as low frequency, high frequency, delta (difference of high and low frequencies) and center frequency (with equal energy on either side of the measurement) were measured by visual inspection method.

Objective 3: The frequency-time analysis measures the spectral features on individual notes or on the entire call from the song sequence. The following parameters were measured: start time, end time, time duration (delta time), low frequency, high frequency and delta frequency (frequency range).

This information can be viewed by scrolling across the spectrographic display (Beeman, 1991; 1996). The detailed statistical analyses, results and the discussion for each objective were presented in Chapters 4, 5 and 6 respectively.

Chapter - IV

BIRDS VOCALISATION PATTERNS IN THE SOUNDSCAPE OF ANAIKATTY HILLS

The trees' rustling voices told it to the winds,

Flowers spoke in ardent hues an unknown joy,

The birds' carolling became a canticle...

- Sri Aurobindo.

CHAPTER IV

BIRDS VOCALISATION PATTERNS IN THE SOUNDSCAPE OF ANAIKATTY HILLS

4.1 INTRODUCTION

The biological sound produced by vocalising birds and animals, and stridulating insects' forms the "biophony" and the non-biological sounds such as wind, rain, running stream were described as "geophony" in any natural habitat (Hildebrand, 2009). Both biological and non-biological sound constitute the soundscape of that area (Pijanowski et al., 2011; Gage & Axel, 2014) and methods to quantify their pattern form the basis of soundscape studies (Pijanowski et al., 2011). Schafer (1977) describes that natural processes of an area are reflected in their acoustical characteristics. The term such as "biophony" and "geophony" was first coined by Krause in 1987.

The man-made sounds produced from automobile, machinery (technophony or anthrophony) are dominated in an urban setup and are rarely detected in forest habitat (Krause, 1987; Pijanowski et al., 2011; Gage & Axel, 2014). Vocalisation of birds (ornithophony) of a terrestrial habitat varies due to the variations in the dominant vocalisers, the number of species involved in the vocal activity and the time specificity of the birds. It is well known that many species of birds are more vocally active during dawn and dusk hours as they are active in search of food and/or attracting a female partner (Slabbekoorn, 2004b; Brumm, 2006; Catchpole & Slater, 2008; Ey & Fischer, 2009). Leaving aside the functionality, the bird vocalisations or ornithophony is observed as one of the dominant aspects of the soundscape of any natural ecosystem, especially in forests.

The vocal communication of the birds was well studied, experimented and the results give insights about the characteristics of avian vocal signals (Aylor, 1971; Morton, 1975; Wiley & Richards, 1978; Brenowitz, 1982). The environmental factors such as humidity, temperature, atmospheric turbulence, or vegetation cover influence the signal transfer through masking, absorption, attenuation, reverberation or signal scattering effect

(Wiley & Richards, 1978). Birds prefer a suitable environmental condition for the effective long-distance signal transfer (Morton, 1975; Kroodsma, 1977; Brenowitz, 1982). As the vocal communication consumes significant energy and time (Prestwich, 1994; Oberweger & Goller, 2001), animals adapt their vocal signals spectrally, by altering their syllable structure and usage; or temporally, by opting for a better daytime hour for signal transfer (Ficken et al., 1974; Morton 1975; Nelson & Marler, 1990; Boncoraglio & Saino, 2007; Planque & Slabbekoorn, 2008; Ey & Fischer, 2009; Velásquez et al., 2018). Birds must reduce the interference and masking effect of other animal signals such as insects (Stanley et al., 2016), and abiotic noise like wind and water (Klump, 1996). Hence, birds have vocal partitioning or 'acoustic niche' (Krause, 1987; Brumm, 2006; Planque & Slabbekoorn, 2008; Luther, 2009; Hart et al., 2015), wherein they adjust their signals to exploit the vacant niches in the auditory spectrum.

As dawn and dusk hours have the favourable environmental condition (Morton, 1975; Slagsvold, 1996; Hutchinson, 2002) and enhance long distant signal transfer (Henwood & Fabrick, 1979; Brown & Handford, 2003), birds prefer those hours for consistent signal transfer. The 'acoustic transmission hypothesis' claims a proof for this (Farina 2013). It argues that birds sing during the quieter time of the day when the signals are not degraded by any environmental factors such as air turbulence, temperature and other biophonies. Brown and Handford (2003) studies show that signal transmission quality was higher at dawn than midday for the song of the White-throated Sparrow *Zonotrichia albicollis* and Swamp Sparrow *Melospiza georgiana*. However, there was no significant overall transmission between dawn and midday songs. Moreover, the experiments on the propagation of the Blackcap *Sylvia atricapilla* showed no favourable environmental conditions for dawn acoustic propagation (Dabelsteen & Mathevon, 2002). The other arguments that favour dawn communication is that the poor light at dawn hours are unsuitable for foraging (Kacelnik, 1979); surplus energy from the overnight reserve (Hutchinson, 2002); and circadian cycles of testosterone (Farina, 2013).

To appreciate the patterns and process of biophonies of the soundscape, spectral frequency (Hz) analysis is a valid method (Irwin, 1990; Nowicki & Nelson, 1990;

Cardoso, 2010; Cardoso & Atwell, 2011). Overlapping of sound frequencies of geophony (such as wind, rain) or technophony (automobiles) may mask the biophony signals (Qi et al., 2008; Mullet, 2017). Most of the technophony and a few biophonic sounds (birds) occur in the lower frequency range 1 – 2 kHz. Passerines species' frequency ranges between 2 and 6 kHz (Pijanowski et al., 2011), whereas insects occupy higher range > 6kHz, and all the geophony are of low frequency ranging 1 – 11 kHz (Napoletano, 2004; Qi et al., 2008; Joo et al., 2011; Kasten et al., 2012; Gage & Axel, 2014).

Apart from the above mentioned environmental constraints on the signal transfer, the physiological limitation, i.e. the body mass influences the frequency of the signal (Wallschager, 1980; Bowman, 1983). Large-bodied birds may produce a signal as low as 1kHz. Morton (1970, 1975) observed a "frequency window" (1585-2500 Hz) in low-forest that attenuates less rapidly. Bowman (1983) studies demonstrated higher body-sized Darwin finches producing lower frequency songs than lesser body-sized Darwin finches. The interspecific interactions, body size and environmental factors influence the vocal signals and their propagation.

Biophony of the soundscape can be comprehended by examining the temporal framework across the daytime from dawn to dusk (Joo, 2008; Joo et al., 2011). It also provides valuable insights on species diversity (Napoletano, 2004; Sueur et al., 2008) and ecosystem (Qi et al., 2008). This study is a first step to understand the biophony in the soundscape of Anaikatty hills through a community acoustics' approach on the ornithophony across daylight hours.

4.2 DATA ANALYSES

Each 5-min recording was analysed by dividing it into 150 '2-sec' parts (henceforth mentioned as 'observation unit(s)'). I manually investigated each 2-sec unit for capturing the dominant vocalising bird species by navigating on the spectrogram. It was a challenging and time-consuming task. However, it helped to understand the soundscape in a much finer resolution. About 90 % of the species were identified and the remaining was documented as unidentified species. One second would be too short, whereas the

3-sec part would miss out the short vocal signals, hence, 2-sec units were preferred. The term 'vocal unit' is used to refer to any biophony (animal vocalisations) present in it. The calls/audio signals of; (i) individual birds, (ii) unidentified birds, (iii) birds which were identified to their genus category, (iv) gap during the absence of any vocal signal of bird, (v) wind, (vi) vehicle noise, (vii) sound of other animals like Spotted Deer, Indian Palm Squirrel, Goat, and (viii) other indistinct sounds were also noted in each observation units. The loud and vocally dominant species in each observation unit was visually classified and considered for further analysis. The vocalisations identified to group level was also considered as separate taxa for broad level classifications. However, they are not included as separate species while accounting for the total number of species vocalised.

The thirteen daytime hours were classified into the morning (6 to 9 h), mid-day (9 to 12 h), afternoon (12 to 16 h) and evening (16 to 19 h) hours. To study the variation on the number of bird species and vocal units across 13 observation windows, ANOVA test (Fisher, 1925) with random effect was performed. Kruskal-Wallis test (Kruskal & Wallis, 1952) was performed to show statistical proof for significant variation between morning and evening hours against mid-day and afternoon hours. All the statistical tests were performed using SPSS v.16.0 (SPSS Inc., 2007).

Hierarchical cluster analysis using Euclidean similarity index with paired group unweighted pair group method with arithmetic mean (UPGMA) algorithm was performed to compare between the passerines and non-passerines' call characteristics (low and high frequencies) with body mass. The characteristic contrasts between birds producing harmonics and non-harmonic producing passerines were analysed using 2-dimensional non-metric multi-dimensional scaling (NMDS) method. All harmonic speakers have fundamental frequencies. The harmonic speakers were grouped separately against non-harmonic speakers. The low and high frequencies with body mass (in gm.); and high frequency with the body mass of 39 passerines were separately analysed using NMDS.

4.3 RESULTS

4.3.1 Soundscape analysis

The six replications in 13 hours of sampling effort yielded 78 recordings with a total duration of 390 minutes. Bird calls were sampled from multiple locations (24) of the same landscape evenly spread along with the 13 different observation windows. This gives 900 observation units per window adding to 11,700 units in total. Among the total 11,700 observation units, birds occupied 8,629 (74%); of the remaining 26 % of the sample, 12.53 % was contributed by biophony of other creatures such as insects and 5.50 % by geophony (wind, indistinct noise). Undetectable or indistinct sounds were only 7.56 % and the remaining negligible 0.41 % occupied by anthropogenic noise. Among 8629 vocal units, passerines occupied 7269 (84.24 %), and non-passerines only 1360 (15.76 %) vocal units. The dominant vocalising bird species in each observation unit was manually recorded. A total of 62 bird species' calls were recorded during the study period (Tables 4.1 & 4.2). Thirty-nine passerine species (62.90 %; Table 4.1) and 23 (37.09 %) non-passerine species (Table 4.2; Figure 4.1) were recorded as the vocalisers in the soundscape of the study area (Figure 4.2). The checklist of bird species was prepared following Praveen et al. (2019). Passerines dominated all through the 13 day-hours and non-passerines were more vocalising from 18 to 19 h. Especially, the first three hours had 19, 22 and 20 passerine species (Figure 4.2). ANOVA (Fisher, 1925) showed that the bird species and vocal units significantly varied across the 13 observation windows, i.e. $F_{12,65} = 4.220$, $p < 0.01$ and $F_{12,65} = 2.251$, $p = 0.019$, respectively. ANOVA (Fisher, 1925) showed that vocalisation number of bird species vocalised were significantly varied across 13 hours (random effect in ANOVA).

4.3.2 Bird vocalisations across diurnal hours

The number of species recorded vocalising were high in the initial three hours of the day (Figure 4.2) and vocal units' composition across diurnal hours are presented in Figure 4.3. In the first hour of observation i.e., 6 – 7 h, 95% of the time was occupied by bird calls (858 out of 900 observation units). 10 – 11 h window received the next maxima with 763 bird vocal units and in the evening, just before the sunset i.e., 17 – 18 h, had the next

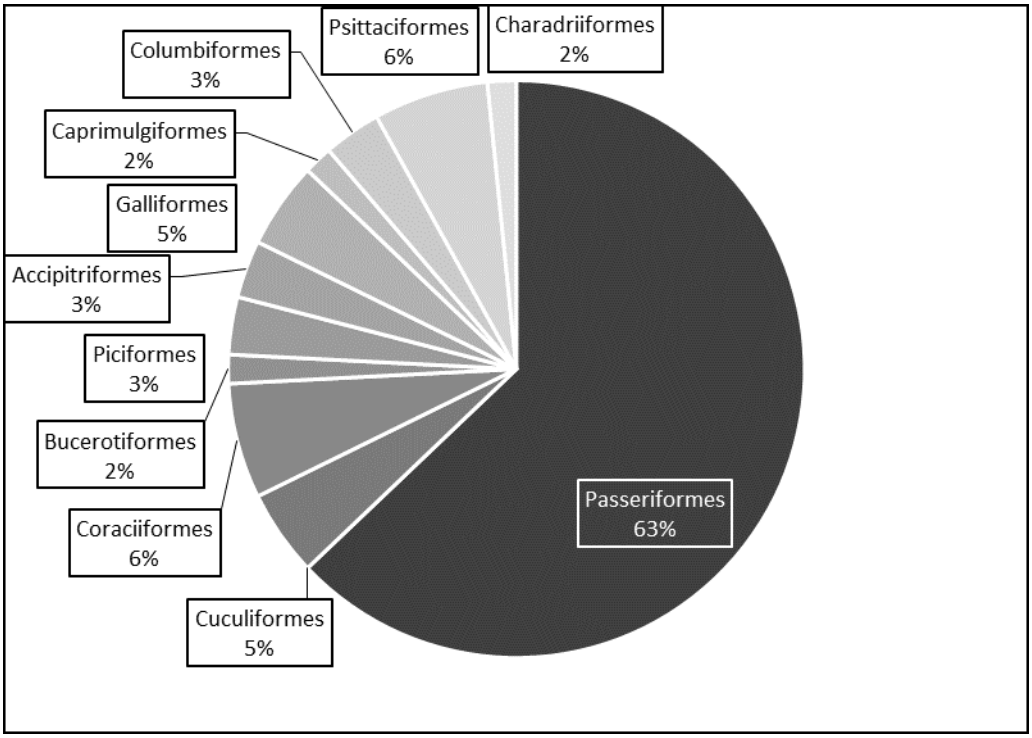

Figure 4.1 Vocalising bird species composition. Passerines occupied 63 % of the soundscape of the study area and non-passerines 37 % with 23 species vocalising during the study period.

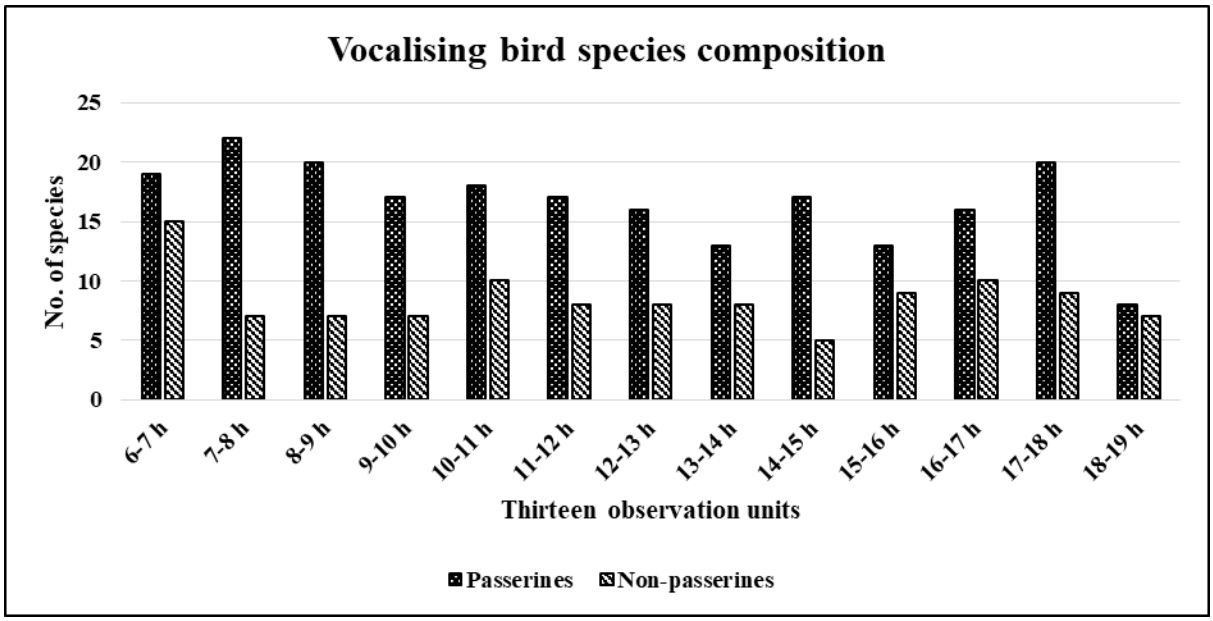

Figure 4.2 Bird species composition of vocalising passerines and non-passerines in all 13 observation windows. Passerines were more vocalizing between 6 h to 18 h.

peak with 647 vocal units. (Figure 4.4). Kruskal-Wallis test showed no significant difference across the bird species between mid-day--afternoon hours against morning-evening hours, $\chi 2 = 3.47$, $df = 1$, $p = 0.063$ (N = 13). There was no significant variation in vocal units among the tested groups $\chi 2 = 0.73$, $df = 1$, $p = 0.39$ (N = 13). In any one hour observational window, a minimum of 16 species was recorded to be vocally active.

Non-passerines were higher in 6 – 7 h and declined as the day progresses, there was a peak of their vocalisations in the dusk hour 18 – 19 h (Figure 4.2 and 4.3). It is to be noted that non-passerines vocal contribution increased from 15 h onwards (Figure 4.2 and 4.3). Indian Pitta was the only passerine species with more vocal units uttered during 18 – 19 h. The 15 species that contributed to dusk calls were either producers of low-frequency calls and/or harmonics. Totally, 10 species (Yellow-billed Babbler (YBBR), Jungle Crow (JNCR), Common Tailorbird (CMTB), Indian Peafowl (INPF), Indian Robin (INRB), White-browed Bulbul (WBBB), Spotted Dove (SPDV), Red-vented Bulbul (RVBB), Grey Junglefowl (GYJF) and Common Hawk Cuckoo (CHCK)) were observed to be vocalising both in dawn and dusk time. The low-frequency values of the 62 species are given in Tables 4.1 and 4.2.

4.3.3 Dominance in vocalisation

Eight species dominated the ornithophony with 63.65% of vocal units' contribution (Figure 4.5) and their statistical analysis is provided in Table 4.3. Of these dominant species, five of them such as Common Tailorbird, Red-vented Bulbul, Yellow-billed Babbler, Indian Robin and White-browed Bulbul were vocalised in all 13-hour observation window (Figure 4.6), whereas Purple-rumped Sunbird (PRSB), Grey-breasted Prinia (GBPR) and Common Iora (COIO) were absent in 18 – 19 h window. Common Tailorbird was recorded as the most vocal bird in the studied landscape during the study period (Figure 4.5 and 4.6). Common Tailorbird dominated the soundscape of the study area with 1619 vocal units, i.e., 18.76 % vocal signal contribution and was present in 74 out of 78 recordings. White-browed Bulbul's vocal signals were present in 66 recordings, occupies just 3.97% of total bird soundscape (Table 4.3). Indian Paradise-flycatcher was found vocalising in only one recording, however, as their song rate is higher, occupied in many observation units. The Common Rosefinch, Blue-bearded Bee-eater, Rose-ringed Parakeet, Indian Golden Oriole, Ashy Drongo, Plum-headed Parakeet, Tawny-bellied Babbler, Greater Racket-tailed Drongo and Barn Swallow were observed in only one of the recordings.

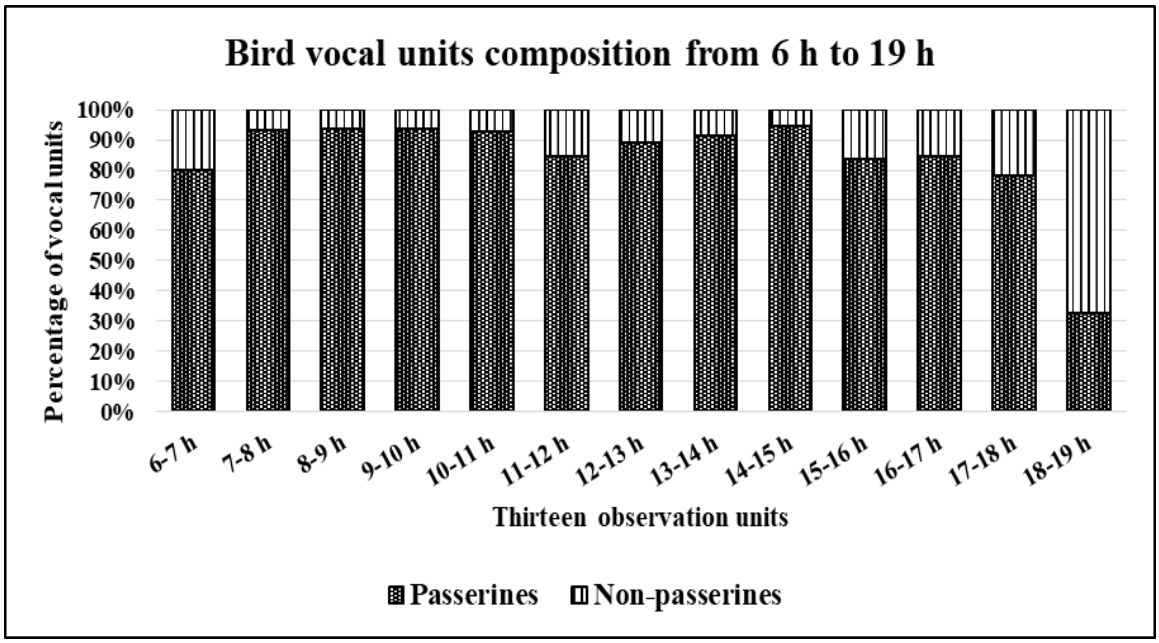

Figure 4.3 Vocal units of birds across 13 observation windows. Passerines are more in the morning from 7 – 8 h onwards. Non-passerines are more between 18 – 19 h.

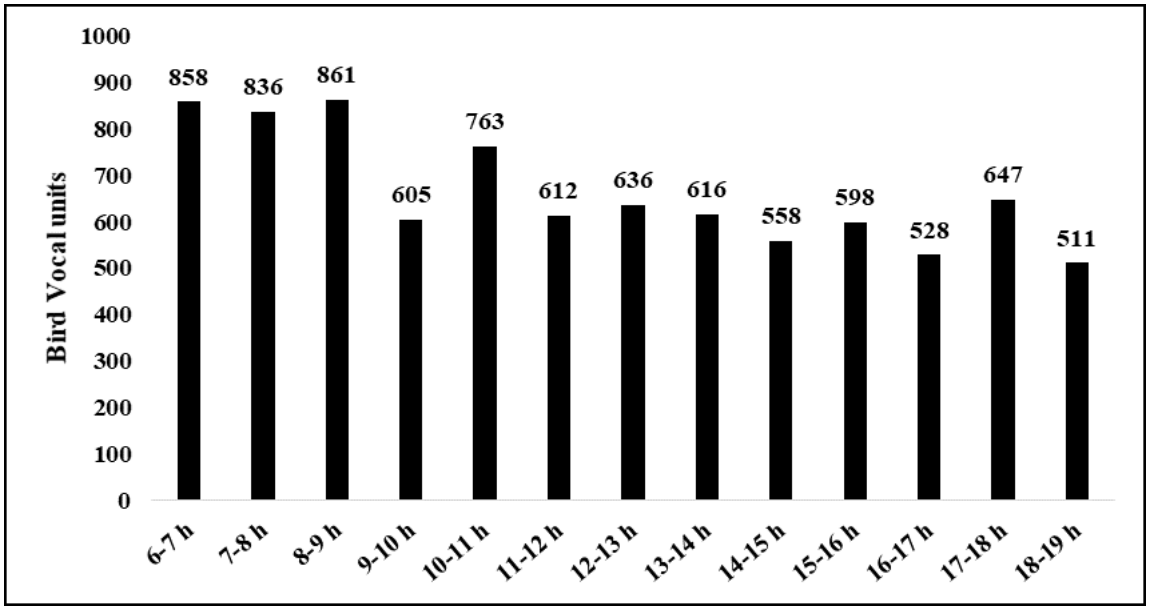

Figure 4.4 Distribution of bird vocal units in the study area shows that the early hours have more vocal units with the second peak at 10 – 11 h and a third maxima at 17 – 18 h.

Table 4.1 List of passerine species of Anaikatty hills recorded during the study. Birds with harmonics are marked with an asterisk (*). The sample size of the low and high frequencies was ten, except [#] - sample size 5; [^] - sample size 4. The body mass in grams (Dunning 2008); [†] - body mass values of both males and females are provided, male values are taken; [~]- mean body mass (sex unknown); [$] - body mass max. value (sex unknown).

S.No.	Bird Species /Family	Bird code	Scientific name	Low-frequency (in Hz) (Mean ± S.D.)	High-frequency (in Hz) (Mean ± S.D.)	Body mass (mean)
	Pittidae					
1	Indian Pitta	INPT	*Pitta brachyura*	1662.5 ± 289.5	4662.9 ±3353.1	55.5
	Oriolidae					
2	Black-hooded Oriole	BHOR	*Oriolus xanthornus*	1465.97 ± 798.58	2229.97 ± 564.44	56.3
3	Eurasian Golden Oriole	IGOR	*Oriolus oriolus*	1099.7 ± 408.8	7825.8 ± 6266.1	79
	Aegithinidae					
4	Common Iora	COIO	*Aegithina tiphia*	1589.54 ± 301.49	3432.68 ± 682.08	12
	Dicruridae					
5	Ashy Drongo*	ASDR	*Dicrurus leucophaeus*	1661.9 ± 329.3	10420.0 ± 3202.1	37.6
6	Greater Racket-tailed Drongo [~]	GRTD	*Dicrurus paradiseus*	1673.6 ± 118.9	2741.6 ± 53.9	79.5
	Laniidae					

S.No.	Bird Species /Family	Bird code	Scientific name	Low-frequency (in Hz) (Mean ± S.D.)	High-frequency (in Hz) (Mean ± S.D.)	Body mass (mean)
7	Brown Shrike*	BRSH	*Lanius cristatus*	2166.9 ± 504.1	10701.9 ±1479.1	33.5
	Corvidae					
8	Rufous Treepie*~	RUTP	*Dendrocitta vagabunda*	815.2 ± 272.5	18059.0 ± 1996.3	100
9	House Crow *†	HSCR	*Corvus splendens*	1205.1 ± 955.5	3136.6 ± 1317.2	317
10	Large-billed Crow *†	JNCR	*Corvus macrorhynchos*	1193.6 ± 690.6	2298.2 ± 658.7	582
	Monarchidae					
11	Indian Paradise-flycatcher*~	APFC	*Terpsiphone paradisi*	1231.56 ± 262.78	13764.35 ± 1550.62	18.5
	Dicaeidae					
12	Thick-billed Flowerpecker	TBFP	*Dicaeum agile*	2562.6 ± 602.4	14147.4 ± 592.3	9
13	Pale-billed Flowerpecker	PBFP	*Dicaeum erythrorhynchos*	3721.5 ± 549.8	11403.5 ± 567.2	6.3
	Nectariniidae					
14	Purple-rumped Sunbird $	PRSB	*Leptocoma zeylonica*	3581.8 ± 461.5	6273.3 ± 1006.4	11
15	Purple Sunbird	PLSB	*Cinnyris asiaticus*	4145.5 ± 1099.1	7016 ± 734.1	8.1
16	Loten's Sunbird $	LTSB	*Cinnyris lotenius*	4145.5 ± 662.3	6643.9 ±1530.6	15
	Chloropseidae					

S.No.	Bird Species /Family	Bird code	Scientific name	Low-frequency (in Hz) (Mean ± S.D.)	High-frequency (in Hz) (Mean ± S.D.)	Body mass (mean)
17	Jerdon's Leafbird*	JRLB	*Chloropsis jerdoni*	1844.6 ± 460.3	7736.8 ± 5421.0	33*
	Fringillidae					
18	Common Rosefinch [#†]	CORF	*Carpodacus erythrinus*	2060.1 ± 146.1	6003.3 ± 166.8	25
	Paridae					
19	Cinereous Tit ˜	SGTT	*Parus cinereus*	2835.5 ± 350.4	8553.6 ± 427.4	15
	Cisticolidae					
20	Grey-breasted Prinia	GBPR	*Prinia hodgsonii*	3002.7 ± 329.6	7107.9 ± 325.6	6.4
21	Jungle Prinia˜	JNPR	*Prinia sylvatica*	2705.6 ± 244.5	6545.5 ± 600.1	16.1
22	Ashy Prinia	ASPR	*Prinia socialis*	2821.5 ± 530.2	6394.2 ± 611.4	8
23	Common Tailorbird ˜	CMTB	*Orthotomus sutorius*	2604.27 ± 1153.85	5840.91 ± 833.58	7.5
	Acrocephalidae					
24	Blyth's Reed Warbler ˜	BRWR	*Acrocephalus dumetorum*	2663.7 ± 505.34	7379.51 ± 335.14	11.2

S.No.	Bird Species /Family	Bird code	Scientific name	Low-frequency (in Hz) (Mean ± S.D.)	High-frequency (in Hz) (Mean ± S.D.)	Body mass (mean)
	Hirundinidae					
25	Red-rumped Swallow*	RRSW	*Cecropis daurica*	2719.4 ± 196.9	7807.4 ± 1334.1	22.2
26	Barn Swallow*†	BASW	*Hirundo rustica*	2587.8 ± 597.3	8021.2 ± 2566.4	16.2
	Pycnonotidae					
27	Red-whiskered Bulbul ˜	RWBB	*Pycnonotus jocosus*	1703.8 ± 509.9	3667.3 ± 488.7	27.4
28	Red-vented Bulbul †	RVBB	*Pycnonotus cafer*	1562.8 ± 194.1	3062.5 ± 393.1	45.8
29	White-browed Bulbul ˜	WBBB	*Pycnonotus luteolus*	1256.8 ± 227.8	3707.7 ± 504.8	34.7
	Phylloscopidae					
30	Greenish Leaf Warbler ˜	GLWR	*Phylloscopus trochiloides*	3438.2 ± 716.6	7505.9 ± 1717.6	7.1
	Timaliidae					
31	Indian Scimitar Babbler*^	SCBR	*Pomatorhinus horsfieldii*	622.7 ± 116.9	1300.2 ± 248.2	43
32	Tawny-bellied Babbler ˜	TBBR	*Dumetia hyperythra*	3475.0 ± 554.3	6443.7 ± 193.6	12.9

S.No.	Bird Species /Family	Bird code	Scientific name	Low-frequency (in Hz) (Mean ± S.D.)	High-frequency (in Hz) (Mean ± S.D.)	Body mass (mean)
	Leiothrichidae					
33	Yellow-billed Babbler*	YBBR	*Turdoides affinis*	3702.7 ± 518.8	9946.6 ± 2710.5	22
	Sturnidae					
34	Common Myna*†	COMY	*Acridotheres tristis*	1399.8 ± 393.8	10244.5 ±3148.6	120
35	Jungle Myna* ~	JNMY	*Acridotheres fuscus*	1368.7 ± 204.5	9803.4 ± 3469.0	82.8
	Muscicapidae					
36	Indian Robin	INRB	*Saxicoloides fulicatus*	5034.9 ± 1375.7	7261.5 ± 642.1	16.6
37	Oriental Magpie Robin*	OMPR	*Copsychus saularis*	2399.4 ± 320.9	6770.0 ± 2349.3	36
38	Tickell's Blue flycatcher ~	TBFC	*Cyornis tickelliae*	3095.0 ± 206.8	7318.3 ± 1788.8	14.6
39	Pied Bushchat	PDBC	*Saxicola caprata*	2037.4 ± 349.7	5089.6 ± 849.5	15.2

Table 4.2 List of non-passerine species of Anaikatty hills recorded during the study. Birds with harmonics are marked with an asterisk (*). The sample size for low and frequencies of the species are ten, except ^ - the sample size is 8. The body mass in grams (Dunning 2008); † - body mass values of both males and females are provided, male values are taken; ˜- mean body mass (sex unknown).

S.No.	Bird Species /Family	Scientific Name	Scientific Name	Low-frequency (in Hz) (Mean ± S.D.)	High-frequency (in Hz) (Mean ± S.D.)	Body mass (in gm)
	Phasianidae					
1	Indian Peafowl*†	INPF	*Pavo cristatus*	551.36 ± 84.9	10284.2 ± 891.5	4766
2	Grey Francolin*†	GRFN	*Francolinus pondicerianus*	1908.2 ± 106.1	6700.1 ± 1873.2	274
3	Grey Junglefowl*†	GYJF	*Gallus sonneratii*	763.5 ± 647.6	8009.7 ± 4212.4	790
	Columbidae					
4	Spotted Dove	SPDV	*Streptopelia chinensis*	569.0 ± 44.2	837.9 ± 39.6	159
5	Laughing Dove	LGDV	*Streptopelia senegalensis*	640.8 ± 26.4	886.1 ± 22.9	101
	Caprimulgidae					
6	Jerdon's Nightjar ˜	JRNJ	*Caprimulgus atripennis*	574.9 ± 41.2	1476.0 ± 30.8	61

S.No.	Bird Species /Family	Scientific Name	Scientific Name	Low-frequency (in Hz) (Mean ± S.D.)	High-frequency (in Hz) (Mean ± S.D.)	Body mass (in gm)
	Cuculidae					
7	Greater Coucal †	SOCC	*Centropus sinensis*	398.0 ± 102.5	870.5 ± 233.4	247
8	Asian Koel*˜	ASKL	*Eudynamys scolopaceus*	982.3 ± 75.49	10473.3 ± 4694.39	167
9	Common Hawk Cuckoo ˜	CHCK	*Hierococcyx varius*	1510.81 ± 357.50	2225.95 ± 280.65	103
	Charadriidae					
10	Red-wattled Lapwing*	RWLP	*Vanellus indicus*	1490.9 ± 431.3	8282.1 ± 4678.9	181
	Accipitridae					
11	Crested Serpent Eagle*˜	CRSE	*Spilornis cheela*	1806.7 ± 91.9	6317.6 + 1242.54	900
12	Shikra*†	SHIK	*Accipiter badius*	1472.9 ± 453.0	13709.4 ± 1980.1	122
	Upupidae					
13	Common Hoopoe ˜	COHP	*Upupa epops*	795.0 ± 410.2	1621.1 ± 1052.1	61.4
	Megalaimidae					
14	White-cheeked Barbet ˜	WCBR	*Psilopogon viridis*	940.8 ± 61.7	1307.6 ± 40.2	80.5
15	Coppersmith Barbet ˜	CSBR	*Psilopogon haemacephalus*	633.8 ± 25.1	898.1 ± 25.4	46.7

S.No.	Bird Species /Family	Scientific Name	Scientific Name	Low-frequency (in Hz) (Mean ± S.D.)	High-frequency (in Hz) (Mean ± S.D.)	Body mass (in gm)
	Meropidae					
16	Blue-bearded Bee-eater †	BBBE	*Nyctyornis athertoni*	586.17 ± 80.15	3740.23 ± 695.06	93
17	Green Bee-eater	LGBE	*Merops orientalis*	2781.7 ± 219.5	4373.6 ± 241.5	14.8
18	Chestnut-headed Bee-eater	CHBE	*Merops leschenaulti*	2538.88 ± 113.84	3590.01 ± 215.33	27.2
	Alcedinidae					
19	White-throated Kingfisher*	WTKF	*Halcyon smyrnensis*	2436.2 ± 105.3	7272.7 ± 2739.7	91.4
	Psittaculidae					
20	Plum-headed Parakeet*^~	PHPK	*Psittacula cyanocephala*	1828.0 ± 468.1	6735.8 ± 1347.2	66
21	Malabar Parakeet*~	MBPK	*Psittacula columboides*	2571.6 ± 165.1	4199.9 ± 277.9	85.5
22	Rose-ringed Parakeet*†	RRPK	*Psittacula krameri*	2047.4 ± 798.9	8566.3 ± 1257.9	126
23	Vernal Hanging Parrot*	VHPR	*Loriculus vernalis*	6261.7 ± 571.0	7948.1 ± 179.5	35.7

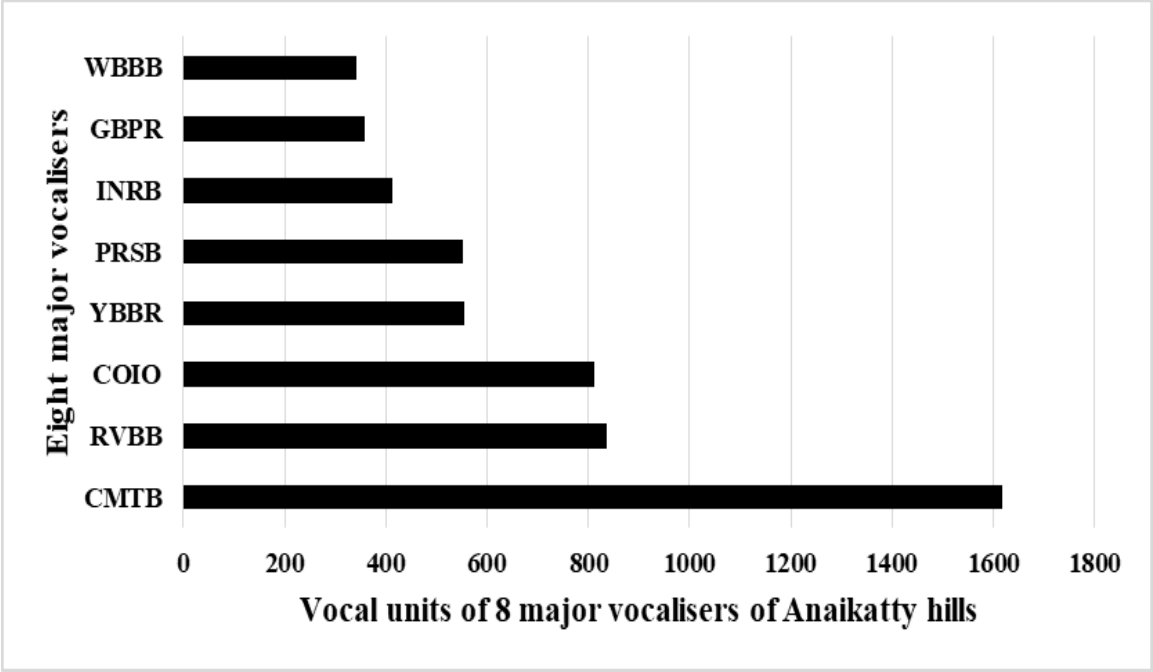

Figure 4.5 Vocal units of the eight most vocalising passerines. Resident passerine species such as Common Tailorbird (CMTB), Red-vented Bulbul (RVBB), Common Iora (COIO), Yellow-billed Babbler (YBBR), Purple-rumped Sunbird (PRSB), Indian Robin (INRB), Grey-breasted Prinia (GBPR) and White-browed Bulbul (WBBB) were the common vocalisers and together occupies 63.65 % of total birds' vocal participation of Anaikatty.

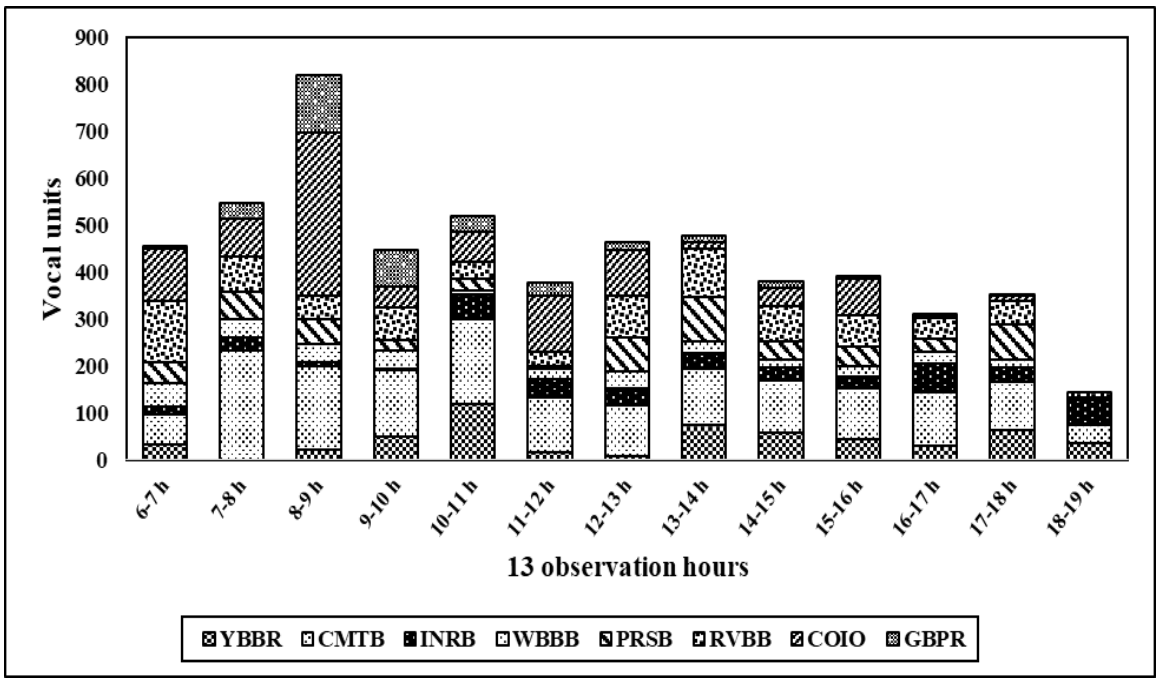

Figure 4.6 Vocal units' composition of eight dominant speakers across 13 hours.

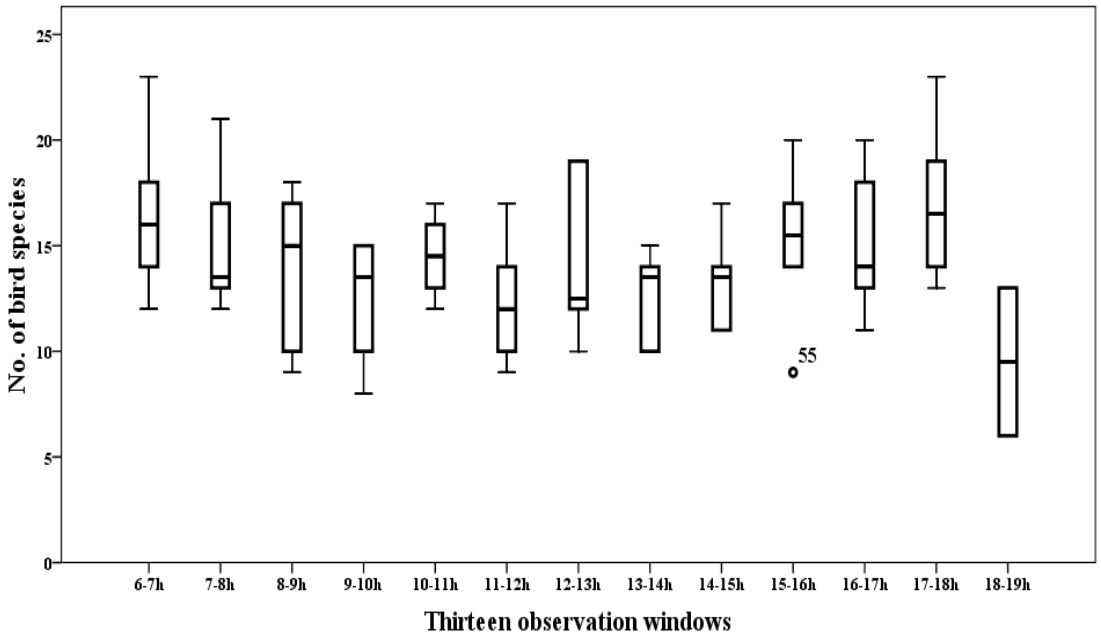

Figure 4.7 Vocalising bird species per sampling unit of 13 observation windows

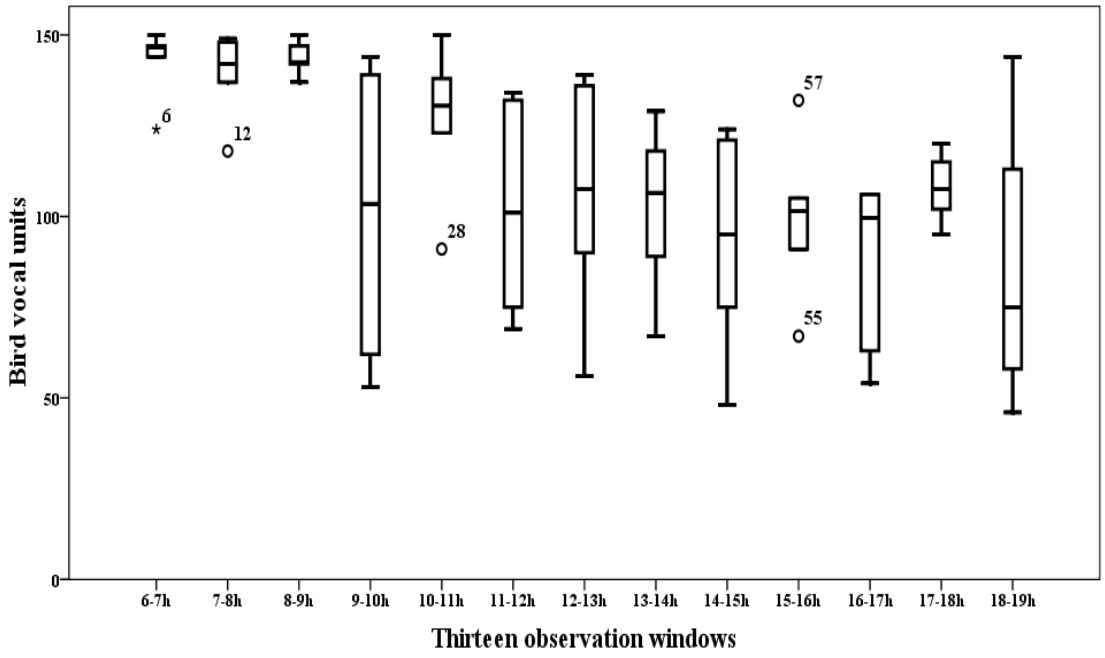

Figure 4.8 Bird vocal units per sampling units of 13 observation windows

Fifteen non-passerines were recorded vocalising during the dawn hour 6 – 7 h, after that non-passerine composition declined in the subsequent hours (Figure 4.2). Indian Peafowl, Grey Francolin, Grey Jungle Fowl, Red-wattled Lapwing, Jerdon's Nightjar, Common Hawk Cuckoo were the dominant non-passerines during 18 – 19 h window and were at low ebb or almost nil during other hours. Indian Peafowl is the only non-passerine to be vocally active in all 13 observation windows, secondly, Grey Francolin was present in 7 out of 13 observation windows and Grey Junglefowl calls were recorded in 6 observation windows. Indian Pitta being a winter visitor and lower song rate species had lesser vocal units in the present study. Figure 4.7 shows the number of bird species' spread in each observation window. Six to 8 h window has more bird species, whereas, 18-19 h had least. Figure 4.8 depicts the vocal units' data spread. Vocal units at 9-10 h, 12-13 h and 18-19 h were relatively variable than other observation hours.

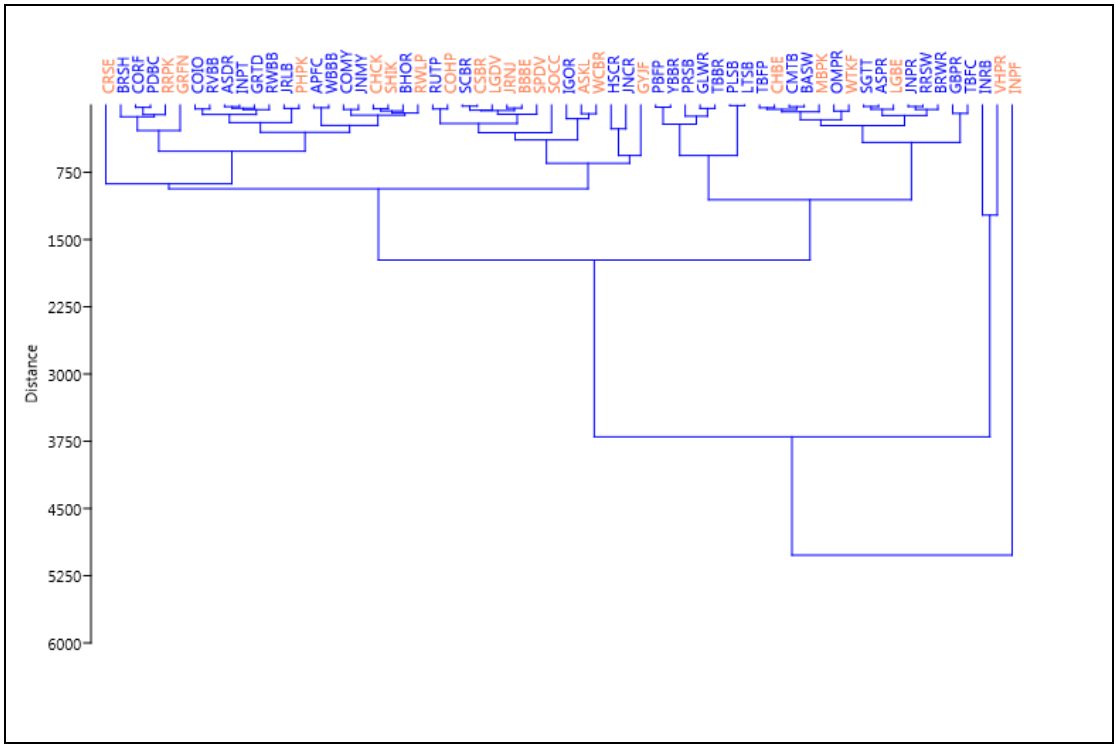

Figure 4.9 The Euclidean similarity index with paired group (UPGMA) algorithm in cluster analysis shows the relationship between low frequency (Hz) and body mass (mean in g) of 39 species of passerines (blue) and 23 species of non-passerines (orange).

4.3.4 Allometry between call frequency and body mass

The 39 passerine species' low and high-frequency values were separately correlated with their body mass using Pearson's correlation method. The low frequency showed a negative correlation with their body mass r^2 = -0.24, p = 0.05, however, there was no significant correlation between high frequency and body mass (in gm.). Hierarchical cluster analysis using Euclidean similarity index with unweighted pair group method with arithmetic mean (UPGMA) algorithm was performed to compare between the passerines and non-passerines' call characteristics (low and high frequencies) against their body mass. Thirty-seven species formed the first cluster, 22 species formed the second cluster (Figure 4.9). The ecologically closely related bird groups are placed together. RVBB and RWBB were in the same sub-cluster with the distinct vocalising species WBBB in the following sub-cluster. PLSB and LTSB were combinedly formed a sub-cluster and the PRSB in another sub-cluster. JNPR, ASPR and GBPR were placed in separate sub-clusters, but within the same larger cluster. In the case of high-frequency cluster analysis, many of the non-passerines hold a separate cluster or a separate sub-cluster (Figure 4.10).

The characteristic contrasts between birds producing harmonics and non-harmonic producers were analysed using 2-dimensional non-metric multi-dimensional scaling (NMDS) method. The call characteristics and body mass of passerines and non-passerines were presented in Table 4.1 and 4.2. The high frequency against body mass (in gm) showed a distinct separation with harmonic speakers (blue), being distantly placed from each other and the non-harmonic speakers (in brown) being placed closely with stress value 0. The closeness of data points shows the similarities between each data point (Figure 4.11). There were relatively closer similarities between Common Myna (COMY) and Jungle Myna (JNMY). Whereas, Jungle Crow (JNCR) and House Crow (HSCR) were placed at a far distance, shows differences among their call characteristics.

There is a distinct separation of harmonic and non-harmonic speakers on analysing low, high frequencies against their body mass (Figure 4.12). JNCR and HSCR were placed in non-harmonic speakers' cluster. All the three sunbirds Purple-rumped Sunbird (PRSB), Purple Sunbird (PLSB) and Loten's Sunbird (LTSB) were closely packed and similarly, the other

co-existing bird groups – bulbuls and prinias. Pale-billed Flowerpecker (PBFP) forms as outlier away from the cluster. One-way Analysis of similarities test (ANOSIM) test showed a significant variation among the tested groups with permutation N = 9999, R = 0.7242, p = 0.0001. R values being close to value 1, describes differences between the two groups. The classical clustering, NMDS and ANOSIM tests were performed in PAST software ver 3.0.

Table 4.3 Descriptive statistics of the eight most vocalising passerines of the study area.

Bird Species	Mean ± S.D.	CV	Min	Max	The presence among 78 recordings	Total vocal units
Common Tailorbird	20.76 ± 15.43	74.32	1	61	74	1619
Red-vented Bulbul	10.73 ± 10.36	96.53	1	45	69	837
Common Iora	10.42 ± 16.47	158.06	1	63	52	813
Yellow-billed Babbler	7.13 ± 10.47	146.83	1	58	54	556
Purple-rumped Sunbird	7.09 ± 11.61	163.72	1	68	52	553
Indian Robin	5.31 ± 7.99	150.55	1	36	55	414
Grey-breasted Prinia	4.59 ± 9.60	209.14	1	41	29	358
White-browed Bulbul	4.40 ± 4.19	95.38	1	18	66	343

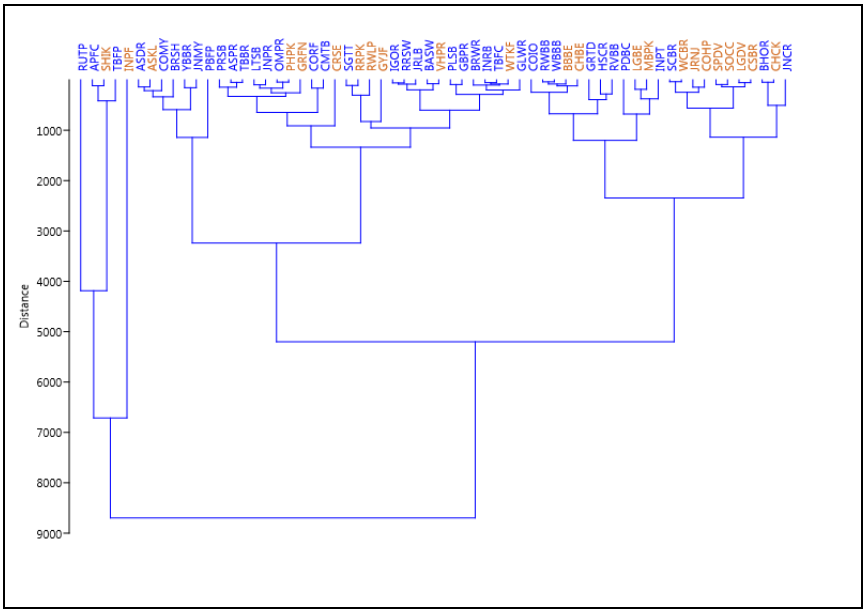

Figure 4.10 The Euclidean similarity index with paired group (UPGMA) algorithm in cluster analysis shows the relationship between high frequency (Hz) and body mass (mean in g) of 39 species of passerines (blue) and 23 species of non-passerines (brown).

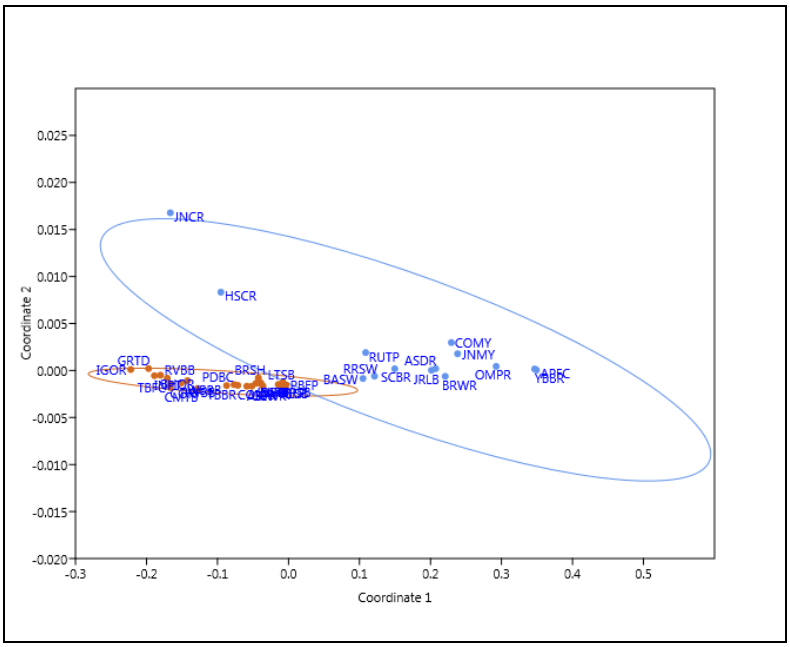

Figure 4.11 NMDS plot showing a distinct separation of high-frequency values of harmonic (blue dots) and non-harmonic (brown dots) speakers of passerines against their respective body mass with stress value 0. The close-by placement of data points shows the similarities between those data points. Common names of the studied birds were presented in Table 4.1.

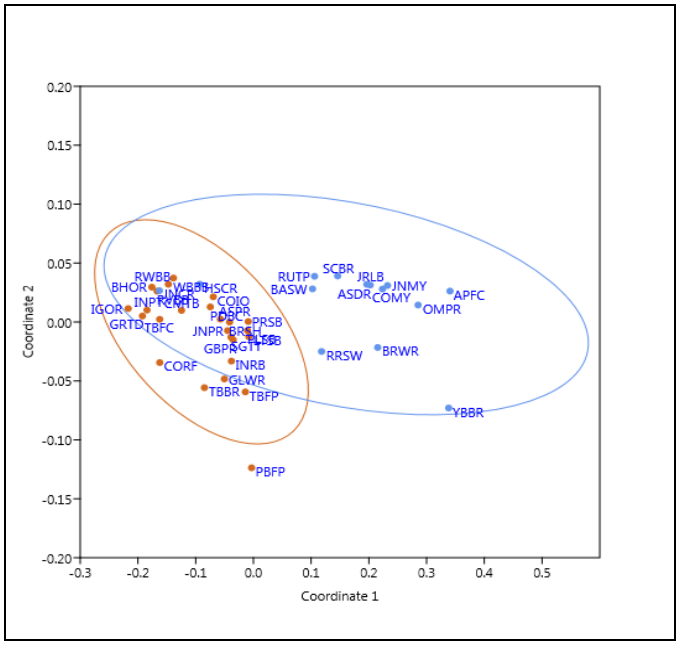

Figure 4.12 Separate clustering of harmonic producing passerines (blue dots) and non-harmonic producers (brown dots) against their respective body mass. There is an overlap of Jungle Crow (JNCR) and House Crow (HSCR) in the non-harmonic group. The stress value is 0.003.

4.4 DISCUSSION

4.4.1 Soundscape analysis

The study area, a scrub jungle in a dry deciduous landscape, has more of sound than silence in day hours. The sound of birds dominated 74 % of the time in the study area, especially in the initial three hours. We have recorded other biophony and other indistinct, undetectable sound source from the study area. The indistinct sound in the study area could be relatively short-bursts of wind or sound produced by any other vocalising animal. Earlier studies showed that the forest environment has lesser decibel (Aylor, 1971; Marten & Marler, 1977; Marten et al., 1977) as background sound than in urban area (Brumm & Slabbekoorn, 2005; Brumm, 2006). The terrestrial habitats are prone to low-frequency noise caused by air turbulence, rain, running water (Brumm & Slabbekoorn, 2005) and other biotic noises (Slabbekoorn, 2004a). The omnipresent cicadas and their concert produce a constant spectrum of background noise (Slabbekoorn, 2004a). Therein the biophony generally ranges between 2 – 11 kHz (Napoletano, 2004; Qi et al., 2008; Joo et al., 2011; Kasten et al., 2012; Gage & Axel, 2014). Mullet et al. (2016) clarify that the high-frequency vocalising passerines can be effectively distinguished from low-frequency producers through a spectrogram analysis. To avoid the biological or non-biological sound frequency overlap, birds utilize different acoustic niches to broadcast the information (Krause, 1987; Qi et al., 2008; Luther, 2009).

This acoustic diversity study assessed the ornithophony distribution across day hours. Biophony of the Anaikatty soundscape has 86.60 % of biophony. Gage & Axel's (2014) soundscape power analysis study of Cheboygan County soundscape showed that the biological sounds attributed to 80 % of total ecoacoustics. The frequency-dependent acoustic analysis corroborates that ornithophony occupies the 2-8 kHz of spectral bandwidth (Napoletano, 2004; Qi et al., 2008; Gage & Axel, 2014). Thus, acoustic diversity study across the day hours will assess the ornithophony distribution and assess the soundscape framework of a habitat.

4.4.2 Bird vocalisations across diurnal hours

A number of species showed acoustic activity in dawn and dusk hours; however, the vocal units weren't significantly different across 13 hours. The soundscape of the study area had higher bird vocalisations in early 3 hours (6 – 9 h). The temperature, wind, humidity is more advantageous with least atmospheric turbulence and less background noise during dawn, that enhances the signal transmission (Morton, 1975; Kroodsma, 1977; Krebs & Davies, 1981; Slagsvold, 1996; Hutchinson, 2002; Luther, 2009; Hart et al., 2015). Early hour bird vocalisations were observed in Arizona and in Kutai Nature Reserve, Borneo, (Henwood & Fabrick 1979); deciduous forest in Denmark (Dabelsteen & Mathevon, 2002); open grassland and closed forest habitat in Ontario (Brown & Handford, 2003); and upland pasture at New York (Brenowitz, 1982). Moreover, the dawn (and dusk) chorus gives the advantage to use the energy reserve unused since the previous night (McNamara et al., 1987; Hutchinson, 2002). Dawn chorus also has reproductive benefits such as attracting a mate and deter other potent males to get access to the partner (Slagsvold, 1996; Catchpole & Slater, 2008), to defend territory and nest site from conspecific males (Slagsvold, 1996).

Low frequency and /or harmonic producing birds' vocalisations dominated the dusk hour 18 – 19 h (Table 4.2). Low-frequency vocalisations of birds and amphibians dominated during the night at Cheboygan County, Michigan (Gage & Axel, 2014). Harmonics increases the difficulty in locating the calling bird (Blindfolded birdwatching, 2010), thus avoid predatory attacks. As the visual cues are undependable during sunset hour (Kacelnik, 1979), low frequency gives an advantage for long-distance signal propagation (Aylor, 1971; Morton, 1975; Marten & Marler, 1977; Marten et al., 1977; Wiley & Richards, 1982; Wiley, 1991). Song activity at dusk increases the pair-bonding behaviour in American Robins (Slagsvold, 1996), and in blackbird (Cuthill & Macdonald, 1990). A peak in the dawn and dusk vocal activity suggest that these hours are important for a male to guard the mate and nest site (Sturkie, 1976; Mace, 1986; 1987; Cuthill & Macdonald, 1990). Soundscape peaked at dawn chorus (6 – 7 h), then drops shortly after sunrise, till evening and once again raised during dusk hours and reached second maxima at 20 h in Cheboygan County, Michigan (Gage & Axel, 2014).

4.4.3 Dominance in vocalisation

The Common Tailorbird was the most dominant vocaliser of the landscape as their calls were louder and have higher song rate, i.e., the number of call syllables produced in a minute. All the eight dominant species vocalises continuously. The passerines are louder and are continuous vocaliser (Garamszegi & Møller, 2004; Catchpole & Slater, 2008; Cardoso, 2010). Seven of the dominant species are forage generalists and were vocally active all through the day yielding a higher vocal unit. The early hours had uniform vocal units' contribution per observation window. Increased variability of vocal units during 9 – 10 h, 12 – 13 h, 14 – 15 h & 18 – 19 h could be attributed to a relatively variable number of vocalisers (Fig. 7). This might also show the need for more sampling efforts.

The 16 – 17 h observation window had more non-passerines (11 species) yielding fewer vocal units whereas, passerines were predominant in the study area with more vocal units. More vocal units and complexity exhibits the versatility of passerines birds (Garamszegi & Møller, 2004; Boncaraglio & Saino, 2007; Catchpole & Slater, 2008; Cardoso, 2010), as they are louder (Calder, 1990; Cardoso & Mota, 2009; Cardoso, 2010) and are continuous vocalisers (Hartley & Suthers, 1989; Irwin, 1990; Podos, 1997; Forstmeier et al., 2002). This makes passerines to occupy a larger portion of the soundscape of Anaikatty hills in general.

Song rate analysis is beyond the scope of this present study; however, any trained ears could relatively understand the song rate of bird calls. The study which aimed at understanding the vocal activity pattern of diurnal birds illustrates that the soundscape of Anaikatty is largely occupied by birds in all those hours.

The eight most dominant vocalising species include high-frequency speakers such as Purple-rumped Sunbird and Indian Robin; mid-range frequency speakers like Grey-breasted Prinia, Common Tailorbird; low-frequency speakers like Common Iora, Red-vented Bulbul and White-browed Bulbul; and wide-range speakers including Yellow-billed Babbler and Common Iora. This shows that the mixture of low, mid-range and high-frequency speakers dominates the Anaikatty soundscape. An in-depth understanding of the spectral /frequency analysis of these species is necessary to

understand their spectral uniqueness and similarities. Especially, the ecologically related bulbuls, prinias and sunbirds' co-existing groups' spectral are further considered for analysis and the results are presented in the next technical chapter (Chapter 5).

4.4.4 Allometry between call frequency and body mass

The relationship between low frequency and body mass shows that the distinct vocalising bulbul species WBBB forming a separate sub-cluster. Each prinia species has unique syllable and were placed in separate sub-clusters. Higher body mass birds had lower frequency vocal signals. Fitch (2006) showed a similar pattern in a non-human primate, where large-bodied individuals have a lower frequency. Wallschläger in 1980 described this phenomenon for the first time in birds. The anatomical and physiological factors like tracheal length and the produced resonances are related to the body size and mass of the signalling bird (Wallschläger, 1980; Ryan & Brenowitz, 1985; Wiley, 1991; Baptista, 1996; Lambrechts, 1996; Appleby & Redpath, 1997; Laiolo & Rolando, 2002; Patel et al., 2010).

Our present study showed no negative relationship between high frequency and body mass. The vocal communication studies in *Geospiza difficilis* (Bowman, 1979) and *Piranga rubra* (Shy, 1983) documented large-sized individuals to produce higher frequency songs. Handford and Lougheed (1991) showed the larger Rufous-collared Sparrow *Zonotrichia capensis*birds making lower-frequency songs. This emphasizes that there may be no relation between syrinx size and body size always. This invariably supports that they body size, i.e., the syrinx (sound-producing organ) may not always influence the song frequencies. Song learning in birds holds credit for the above contradictory phenomenon.

Chapter - V

VOCALISATION OF SELECT CO-EXISTING BIRD GROUPS IN ANAIKATTY HILLS

The wren and the nightingale sound nothing alike but think how dull the world would be without the songs of both birds.

- Kirby Larson

CHAPTER V

VOCALISATION OF SELECT CO-EXISTING BIRD GROUPS IN ANAIKATTY HILLS

5.1 INTRODUCTION

Vocal communication of birds involves endless diversity of sounds through modulations of frequency and time (Nowicki & Marler, 1988). Birds have species-specific songs that are unique with functional implications. Song types and song deliverance vary across species (Hartshorne, 1973; Kroodsma, 1973; Ince & Slater 1985). Birds pick up invariant or distinct components of a song as the species-specific cues for recognition (Marler, 1960; Emlen, 1972; Becker, 1982). Females use songs for species recognition and in evaluating males' quality (Morton, 1996). A bird is sensitive to frequency changes at a 1% level. Birds require about 3dB difference in loudness to detect any change in intensity (Dooling, 1982). The temporal sensitivity threshold shows that birds can detect; (i) the duration increase from a few milliseconds to 200-300 milliseconds (Dooling, 1980) in nature; (ii) gap detection within 2-3 milliseconds; and have duration discrimination ability. The auditory mechanism in birds detect the relevant signal against other background sounds in a habitat and signal processing feature ascertains their relevant behavioural context (Knudsen & Gentner, 2010). Birds have the innate or acquired ability in recognizing the conspecific vocal signals (in swamp sparrows *Melospiza melodia* by Marler (1985). Female birds can ascribe the song output to a specific male individual (Morton, 1996).

The closely related species' when occupying a habitat sympatrically, exploit the resources differently (Hartley, 1953; MacArthur, 1958), such as food resource in titmice, wherein each species of English titmice was separated by their feeding behaviour. This eventually favours the niche hypothesis wherein no two species are identical, here no two co-existing, ecologically closely related species have similar food-seeking behaviour (Hartley, 1953). Kroodsma (1973) observed habitat separation in coexisting Bewick's Wrens *Thryomanes bewickii* and House Wrens *Troglodytes aedon* in Oregon. Treecreeper *Certhia sp*. had successfully defended the territory from their conspecifics and other co-existing

Short-toed Treecreeper *Certhia brachydactyla* (Thielcke, 1970). Exploiting the environmental resources differently attributes to the success of co-existence (Grant, 1966). Sometimes, ecologically closely related species have similar niches (Peterson et al., 1999; Kozak & Wiens, 2006; Warren et al.,2008). Closely related species often possess characteristics that make them continue in an environment (Webb et. al., 2002; Warren et. al., 2008).

Songbirds must focus on the finer details of their species-specific songs and avoid other irrelevant acoustic proportions (Dooling, 1982). Acoustic signals facilitate interspecific recognition in birds (Kroodsma, 1973). Sympatric species have similarities either in morphology or vocal signals or both (Bock, 1964; Hall et al., 1966). However, Bock (1964) described morphological variation based on the upper jaw and mandible of three cardinal species of the genus *Pyrrhuloxia* and *Richmondena* of North America. Two sympatric *Thryothorus* wrens respond to each other songs in Mexico (Grant, 1966). Both species being producing two types of songs show little variation in introductory notes of territorial songs but showed similarities in later parts of the songs. This is due to the convergence of recognition marks as described by Cody (1969). Thomas (1943) observed Bewick's Wrens singing the songs of both conspecifics and House Wrens. Kroodsma (1973) demonstrated the convergence of vocal signals between Bewick's and House Wrens. House Wrens copied at least eight song types of Bewick's Wren; wherein some songs are exact copies and others have not great variations than the intraspecific variations among Bewick's Wren population. This portrays that closely related species have similarities in vocal signals when they are sympatrically distributed (Kroodsma, 1973).

The previous chapter shows that bulbuls, sunbirds and prinias are active vocalising bird species in the study area. RVBB, PRSB, GBPR were among the eight most vocalising passerines. RWBB and PLSB were among the top 20 vocalising species. To understand the similarities and uniqueness in spectral features of ecologically closely related species, the vocalisation of three bird groups - three species of sunbirds, bulbuls and prinias are studied in this chapter. The study species include: (i) three sunbird species - Purple-rumped Sunbird *Leptocoma zeylonica*, Purple Sunbird *Cinnyris asiaticus* and Loten's Sunbird *Cinnyris lotenius*; (ii) three Bulbul species - Red-vented Bulbul *Pycnonotus cafer*, Red-whiskered Bulbul *Pycnonotus jocosus* and White-browed Bulbul *Pycnonotus*

luteolus; and (iii) three Prinia species - Ashy Prinia *Prinia socialis*, Grey-breasted Prinia *Prinia hodgsonii* and Jungle Prinia *Prinia sylvatica*

Sunbirds are gregarious. Their vocalisations are mid-frequency ranged between 3 – 6 kHz (Rasmussen & Anderton, 2012). They are diurnal species, primarily feed on nectar and insects and occasionally on fruits. They are generally seen in pairs. They congregate on flowering trees for nectar. Calls are uttered on arriving at a spot, and while moving from one food plant to another; for contacting the groups. They call while moving in their undulating flight path.

Bulbuls are frugivorous species and are vital seed dispersers of open secondary forests of tropical and subtropical Asia (Lever, 1987; Corlett, 1998). Red-vented Bulbuls are native to India, Pakistan, extended to southwest parts of China. Red-whiskered Bulbuls are native to India and southeast regions of China to northern parts of Malaysia. Both species are sedentary in their region (Islam &Williams, 2000). They are commonly found in gardens, cultivated lands, lower altitude regions (Zia et al., 2014). They have a wide range of feeding habits; from small-sized insects such as mosquitoes and mayflies, larva, aphids, ants; to large-sized insects including crickets, grasshoppers, winged termites', cockroaches (Bhatt & Kumar, 2001).

Cisticolid prinias are territorial birds and have songs for advertising function. Male birds' position at an elevated perch, at the top of a bush or shrub for calling. Songs are repetitive structures, slightly harsher with buzzy trills. They are distributed in open and scrubby habitats. Prinias are found in rank vegetation with a mix of shrubs, herbs and grasses. Del Hoyo et.al. (2006a) had reported that as much as eleven species co-exist within a few hundred meters with elusive micro-habitat distinctions between the closely related species. This may account for species-specific call variation of those species.

5.2 DATA ANALYSES

The Principal Coordinate Analysis (PCoA) shows a convincing depiction of data by creating a dissimilarity distance matrix to find the variance between the members of the group. It presents the data visualization in the full-dimensional principal coordinate space

(Gower, 1966). The low-frequency, high-frequency, delta-frequency and center-frequency values of three species of sunbirds, bulbuls and prinias were used here. PCoA allows the data point positioning in a space of reduced dimensionality, at the same time preserving the distance relationship between them. PCoA represents the samples' relationships faithfully (Rao, 1964).

One-way ANOSIM (Clarke, 1993) was performed to interpret the dissimilarities within Sunbird and Bulbul groups. All the above-mentioned statistical tests were performed in the software PAST v.3.23 (Hammer et al., 2001). Kruskal-Wallis one-way analysis of variance was performed to see dissimilarities within the Prinia group using SPSS ver. 16.0 (SPSS Inc., 2007). Appropriate post-hoc tests using SPSS ver. 21.0 (SPSS Inc., 2007) were performed to compare the call characteristics across three bird groups. The low, high, delta and center-frequency values of all syllables of all sunbirds, bulbuls and prinias are considered for the analysis.

5.3 RESULTS

Purple-rumped Sunbird has six syllables - syllable A to F (Figure 5.1), Purple Sunbird has 5 syllables A to E (Figure 5.2), and Loten's Sunbird has 2 syllables, *viz*., A & B (Figure 5.3), which are structurally distinct. Upon further analysis, Red-vented Bulbul has fourteen syllables *viz*., syllable A to N (Figure 5.4), Red-whiskered Bulbul has six syllables A to F (Figure 5.5) and White-browed Bulbul has two syllables A and B (Figure 5.6). Syllables such as RVBB-F, H, RWBB-B, WBBB-B were pronounced once during the data collection days.

Ashy Prinia, Grey-breasted Prinia and Jungle Prinia each had single syllable (Figure 5.7), wherein Grey-breasted Prinia (GBPR) pronounces introductory notes with a varied inter-elemental gap. There are truncated syllables with devoid of one or two terminal elements and are categorized as '*variants'*. These variants were observed as abrupt stoppage of utterance due to sudden vocalisation of another bird species. The introductory note of GBPR and '*variants'* spectral features are omitted for analysis, as they have high variability. Only the distinct syllables are designated and used for analysis.

5.3.1 Call characteristics comparison of three co-existing bird groups

5.3.1.1 Sunbirds

Low-frequency values

Sunbirds' low-frequency values ranges from 2000 to 6624 Hz, range = 4624 (N=796), mean 3725 ± 671.95 (Table 5.1). Cluster analysis shows Loten's Sunbird syllable B, PLSB syllable D and E stands out as a separate branch. The syllables of the three sunbird species are mixed without species-specific unique clustering (Figures 5.1, 5.2 & 5.3). In PCoA, Principal component (PC)1 contributed 69.91 % and PC2 with 7.89 %. The first 3 PCs summarized 82.4 % of the total variation (Table 5.4). These first three PCs forms the best possible Euclidean approximation of the original distances (Gower, 1982). There was a reasonable consensus between the visual representation of low-frequency values and the clusters found by hierarchical analysis (Figures 5.8 & 5.9; Table 5.4).

The mixed arrangement of PRSB and PLSB syllables together in classical clusters showed that they are closely related than with LTSB-B. LTSB-A showed similarities with PRSB. This is in accord with the results of dissimilarities test One-Way ANOSIM. ANOSIM was performed with 9999 permutations. The results show that there is no significant variation between groups (p = 0.3778) R = 0.02071. However, pairwise analysis shows that PLSB-LTSB is less similar to 0.9559 than PRSB-LTSB 0.5022, whereas PRSB-PLSB were relatively similar 0.2428.

High-frequency values

Sunbirds' high-frequency values ranges from 3969.2 to 8621.1 Hz (Figure 5.1, 5.2 & 5.3), range = 4651.9 (N=796), mean 6537 ± 951.35. In PCoA, Principal component (PC)1 contributed 64.94 % and PC2 with 9.38 %. The first 3 PCs summarized 80.42 % of the total variation (Table 5.4). There was a reasonable consensus between the visual representation of high-frequency values and the clusters found by hierarchical analysis (Figures 5.10, 5.11; Table 5.4)

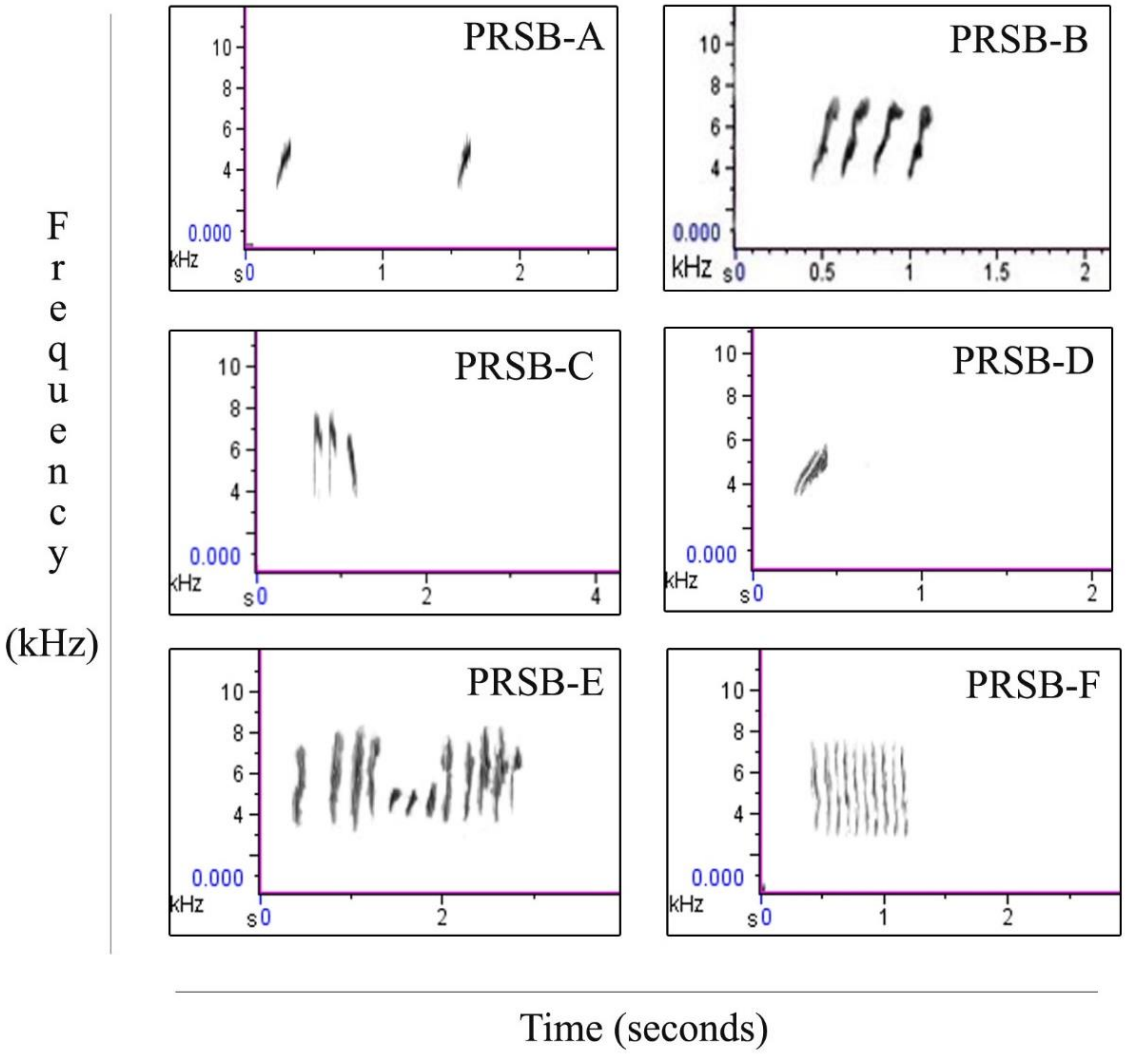

Figure 5.1 Six syllables A to F of Purple-rumped Sunbird *Leptocoma zeylonica* recorded during the study period in Anaikatty hills.

Classical hierarchical clustering with multiple algorithms showed similar results. In the Euclidean similarity matrix, the UPGMA algorithm produced two clusters. As the values are similar, unlike similarities in structure, PRSB-E and PLSB-D were placed in the same cluster, along with PRSB-F. PRSB D and A syllables are grouped together due to their structural similarities. Along with this, PLSB-A and C syllables are grouped as sub-cluster. The first cluster had PLSB-B and LTSB-B placed distantly as separate branches.

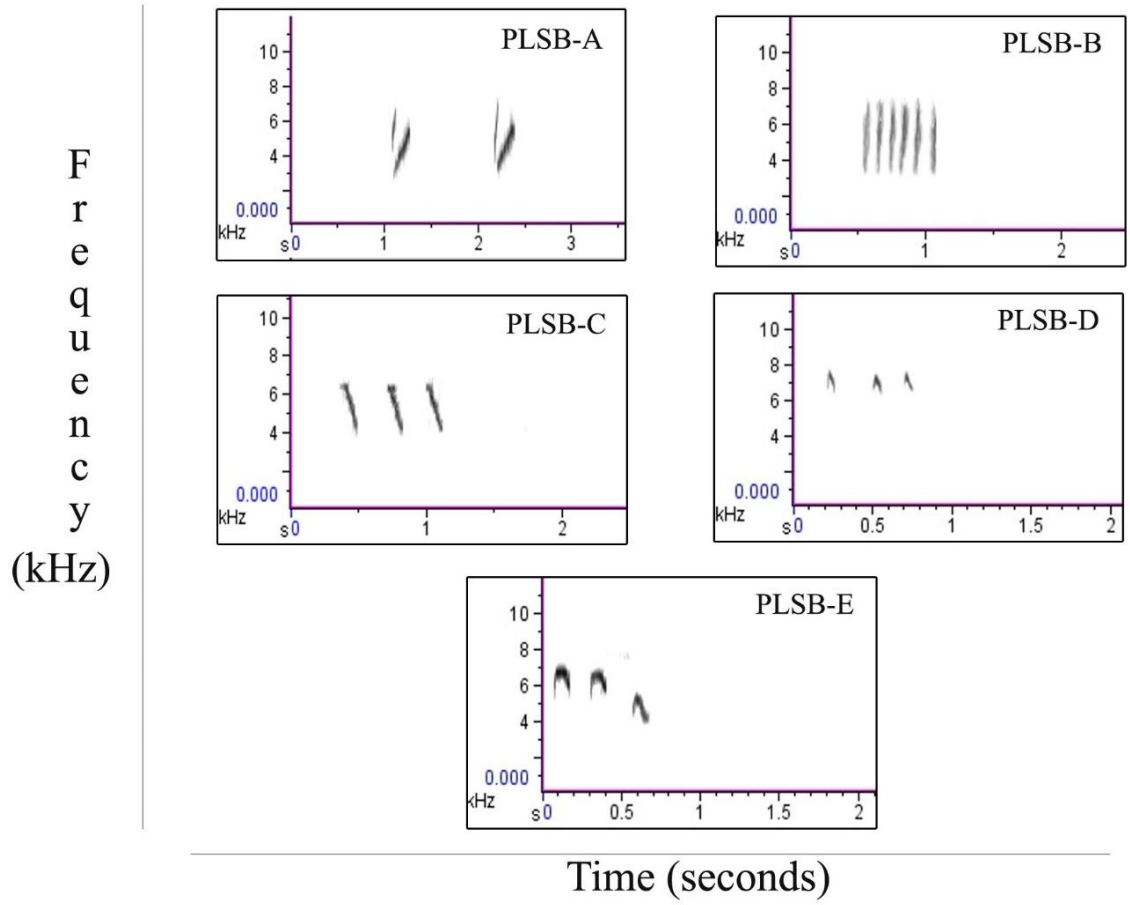

Figure 5.2 Five syllables A to E of Purple Sunbird *Cinnyris asiaticus* recorded during the study period in Anaikatty hills.

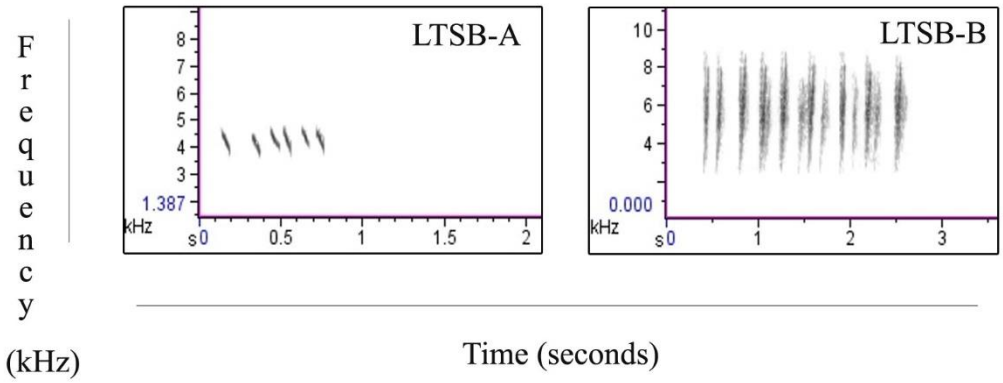

Figure 5.3 Syllable A and B of Loten's Sunbird *Cinnyris lotenius* recorded during the study period in Anaikatty hills.

PLSB syllable B extends as separate branch as their values are higher (7619.50 ± 662.18), moreover, the sample size is less which might also account for such separation. PRSB-C and PLSB-E were placed together as sub-cluster. Similarly, these two syllables' data points overlap in PCoA (Figure 5.11). PLSB syllable D has relatively similar values like B but placed along with PRSB syllable E. Similar looking PRSB A and D were placed together as a sub-cluster. The one-way ANOSIM results show that there is no significant variation between groups (p = 0.3026) R = 0.0429. However, pairwise analysis shows that PRSB and PLSB are less similar 0.712 than other groups PRSB-LTSB and PLSB-LTSB with 0.2505 and 0.0991, respectively.

Delta-frequency values

Sunbirds delta-frequency values ranges from 691.6 to 5802.6 Hz, range = 5111.0 (N=796), mean 2811 ± 978.81. Delta-frequency is the frequency range or difference between high and low frequencies. The similar-looking PRSB-E and PRSB-F get placed nearby in PCoA plot. Principal component 1 (PC1) contributed 62.28 % and PC2 with 11.05 %. The first 3 PCs summarized 78.84 % of the total variation (Table 5.4). There was a reasonable consensus between the visual representation of high-frequency values and the clusters found by hierarchical analysis (Figures 5.12 & 5.13; Table 5.4).

The Unweighted pair-group average (UPGMA) algorithm of Euclidean hierarchical cluster results was concordant with NMDS plots. Single linkage algorithm also gave a similar classification. Four distinct sub-clusters were formed that falls under two clusters. The first cluster had LTSB syllable B in a separate branch. The closely placed PRSB syllables E and F in NMDS forms together as a sub-cluster, with PLSB-B as a separate branch. The second cluster had PRSB-D syllable and PLSB as a sub-cluster that made overlapping points in NMDS plot. LTSB syllable A branched out separately.

The third sub-cluster had PLSB syllables C & E placed together, whereas PRSB A & B were positioned in separate branches. The final cluster has PRSB C & PLSB A syllables. The structurally similar and frequency bandwidth alike syllables like PLSB-B is placed along with PRSB-F and E as a sub-cluster (Figure 5.12).

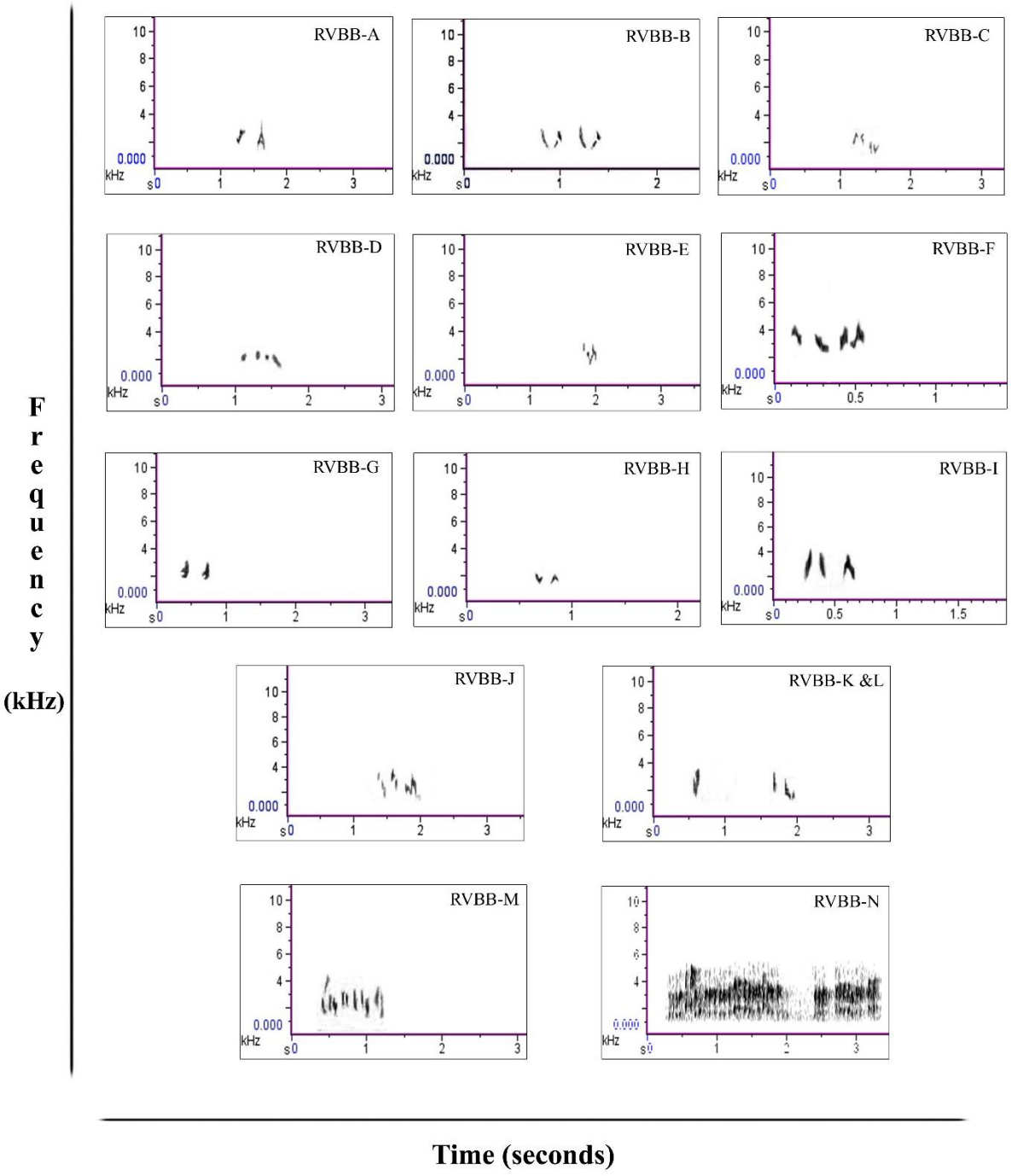

Figure 5.4 Fourteen syllables (A to N) of Red-vented Bulbul *Pycnonotus cafer* of Anaikatty hills recorded during the study period.

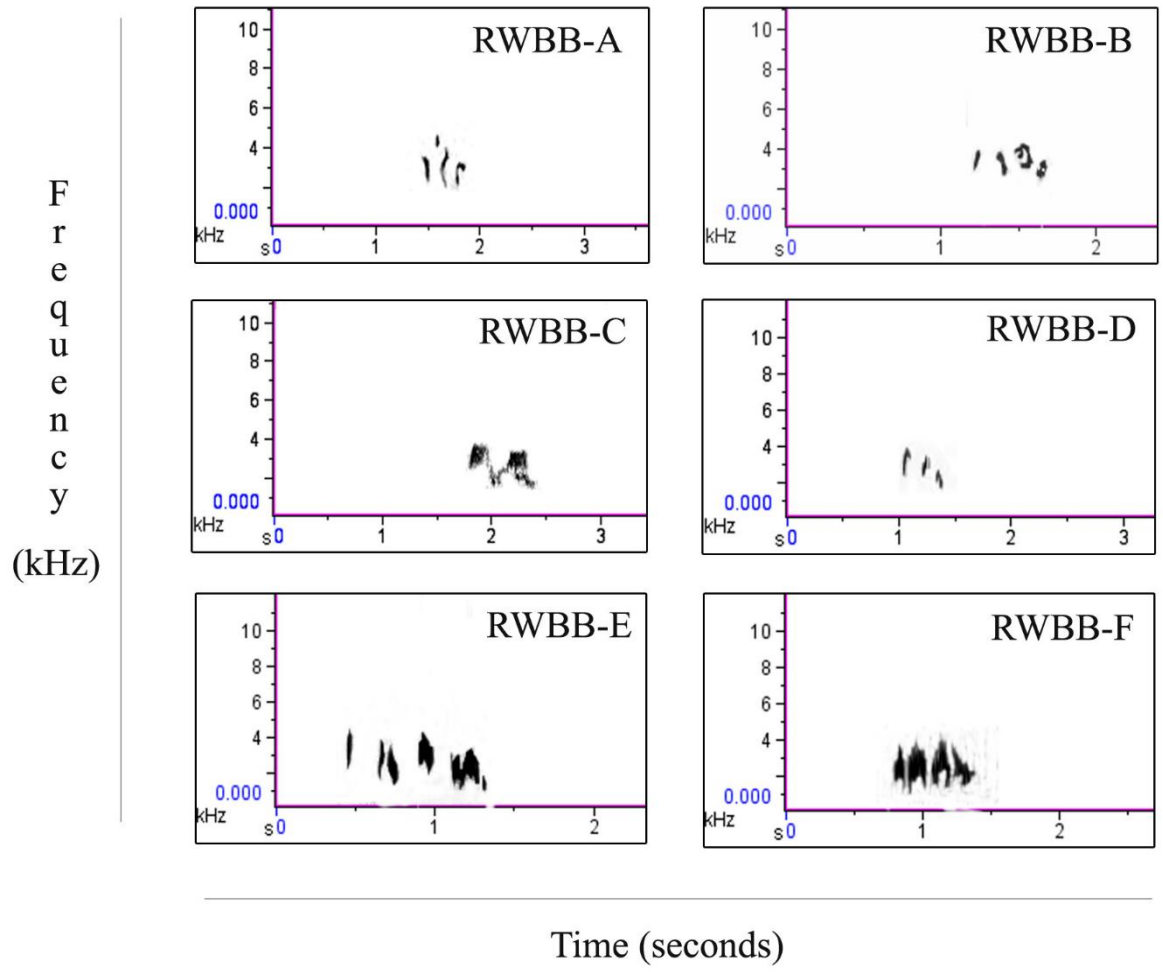

Figure 5.5 Six syllables, A to F of Red-whiskered Bulbul *Pycnonotus jocosus* recorded from Anaikatty hills.

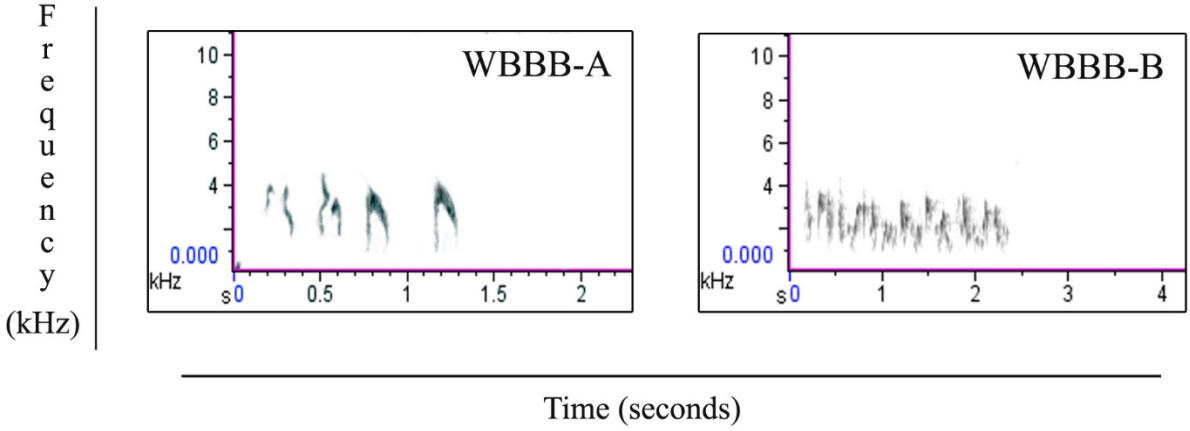

Figure 5.6. Two syllables (A & B) of White-browed Bulbul *Pycnonotus luteolus* recorded during the study period from Anaikatty hills.

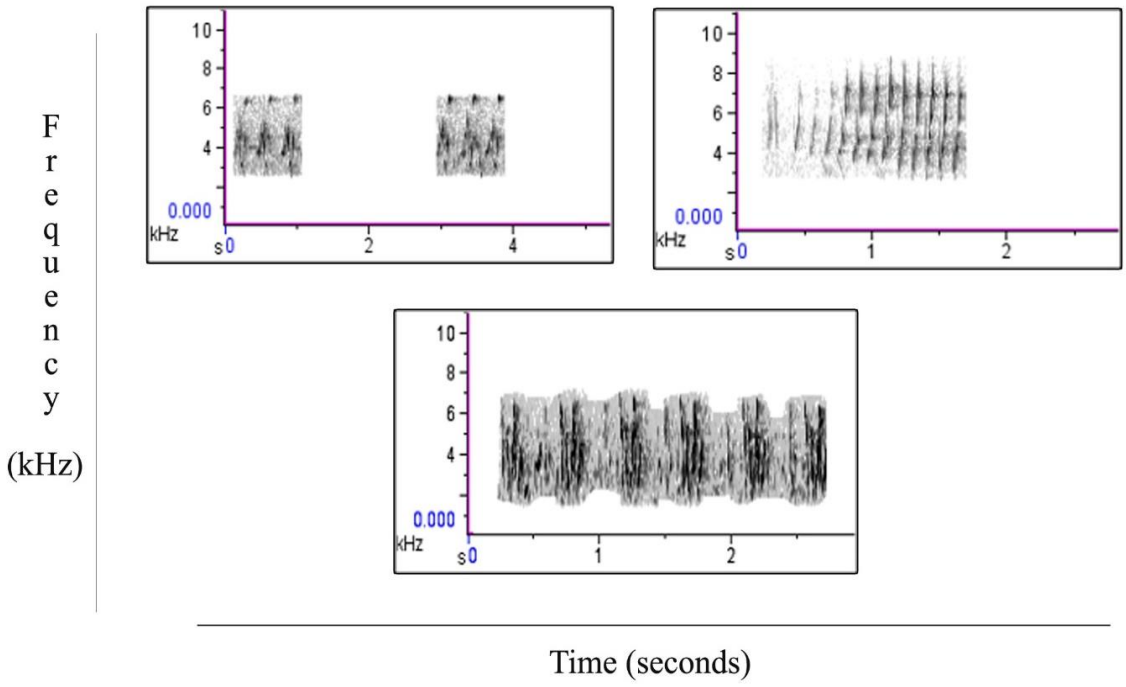

Figure 5.7 Syllable of Ashy Prina (ASPR) *Prinia socialis*, Grey-breasted Prinia (GBPR) *Prinia hodgsonii*, Jungle Prinia (JNPR) *Prinia sylvatica* recorded during the study.

One-way ANOSIM showed no significant variation among the groups (p = 0.5812) with R-value -0.05325. However, the pairwise analysis showed PRSB-PLSB group was less similar to 0.9282, whereas PRSB-LTSB and PLSB-LTSB more similarities, i.e., 0.4671 and 0.2856 respectively.

Center-frequency values

Sunbirds delta-frequency values ranges from 3000.0 to 7312.5 Hz, range = 4312.5 (N=796), mean 5220 ± 683.95. The convex hull of the 2-D NMDS plot showed that PRSB-B and PLSB-D were quite disparate from others and hence, distantly placed. The two-dimensional data reduction map in PCoA with Principal component 1 (PC1) and PC2 showed the distance between the members of the group. PC1 contributed 69.01 % and PC2 with 8.90 %. The first 3 PCs summarized 82.63 % of the total variation (Table 5.4). There was a reasonable consensus between the visual representation of high-frequency values and the clusters found by hierarchical analysis (Figures 5.14 & 5.15; Table 5.4).

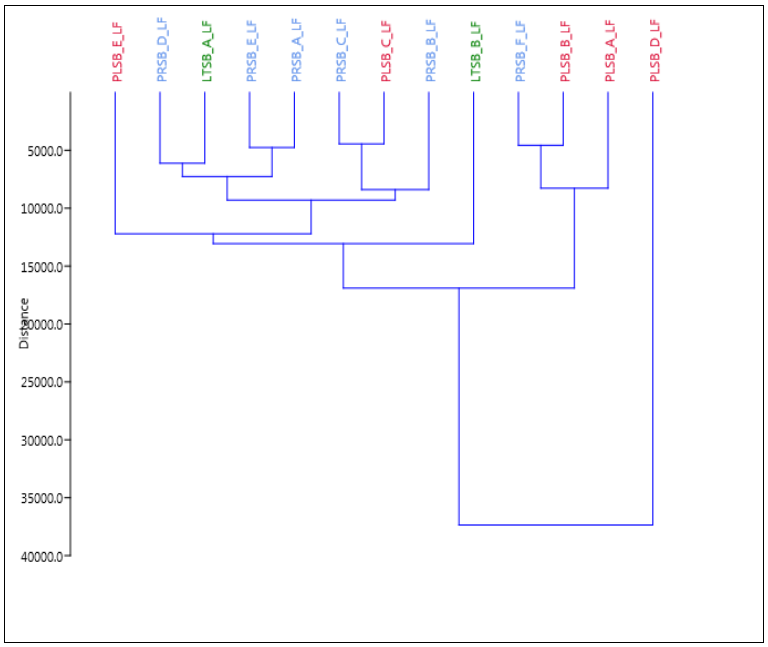

Figure 5.8 Classical hierarchical clustering of the low-frequency values of three sunbird species using Euclidean distance matrix with unweighted pair group method with arithmetic mean (UPGMA) algorithm.

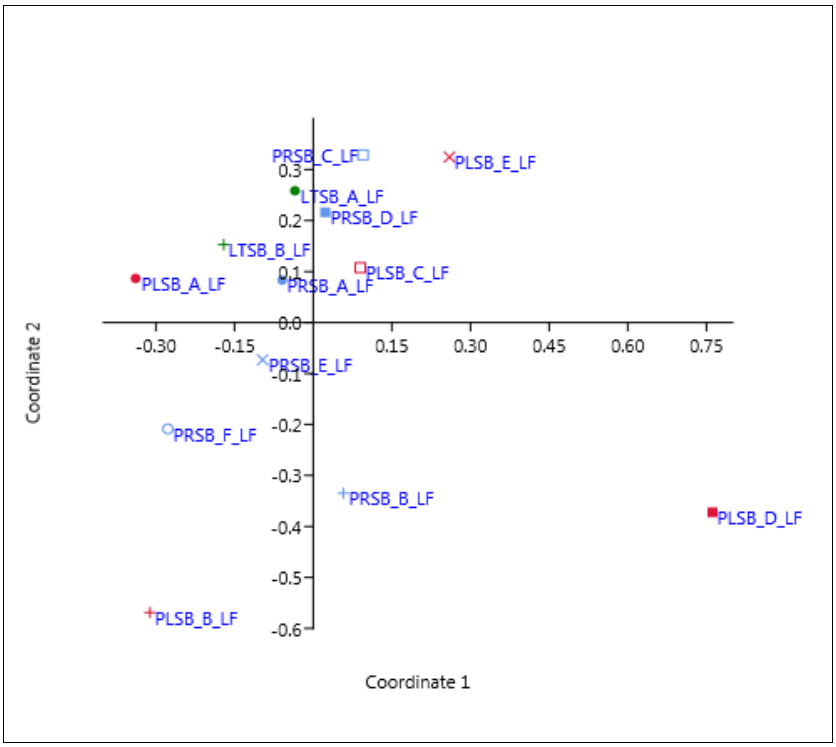

Figure 5.9 Principal Co-ordinate Analysis (PCoA) of the low-frequency values of the three sunbird species of Anaikatty hills

Unweighted pair-group average (UPGMA) and single linkage algorithms of Euclidean hierarchical cluster results were concordant with NMDS plots. Two-dimension NMDS plot gave more appropriate and interpretable results. Like the above parameters, PLSB syllables B, D, LTSB syllables A and B were placed as a separate branch. PRSB-F and PLSB-A were placed together with PRSB-D and PRSB-A as sub-cluster. PRSB-B stands out separately. PRSB-B and E syllables which were branched together in low-frequency were observed as separate branches in two different clusters here. The broader spectral ranged LTSB-B syllable is clustered along with structurally dissimilar PLSB C syllable. PRSB-C and PLSB-E shares a common ancestor. PLSB syllable D extends as a separate branch. One-way ANOSIM showed no significant variation among the groups $p = 0.2708$ and R = 0.06657. Pairwise analysis showed PRSB & PLSB with *p*-value 0.2151, PRSB-LTSB with $p = 0.3622$ and PLSB & LTSB with *p*-value = 0.4257.

5.3.1.2 Bulbuls

Low-frequency values

Bulbuls' low-frequency ranges from 669.9 to 2564 Hz, range = 1894.1 (N=213), mean 1402 ± 312.42. There is a clear separation of RVBB syllables with few being interspersed with RWBB syllables in the hierarchical cluster. The distinct syllables such as RWBB-B, C and RVBB-F were separately placed in NMDS, PCoA and in cluster dendrogram under multiple algorithms. These three syllables were more variable than other syllables and form a separate cluster.

All the data visualization software such as NMDS, PCoA and hierarchical cluster analysis (with multiple algorithms) produced consistent results. Principal component 1 (PC1) contributed 50.64 % and PC2 with 10.38 %. The first 3 PCs summarized 70.48 % of the total variation (Table 5.5). There was a reasonable consensus between the visual representation of low-frequency values and the clusters found by hierarchical analysis (Figures 5.16 & 5.17; Table 5.5).

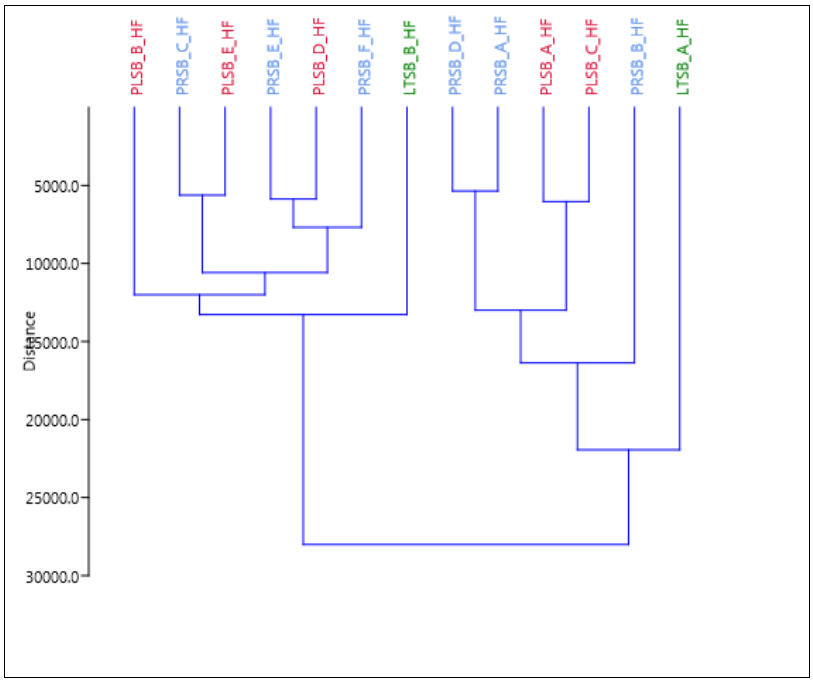

Figure 5.10 Classical hierarchical clustering of the high-frequency of three sunbird species of Anaikatty hills using Euclidean distance matrix with unweighted pair group method with arithmetic mean (UPGMA) algorithm.

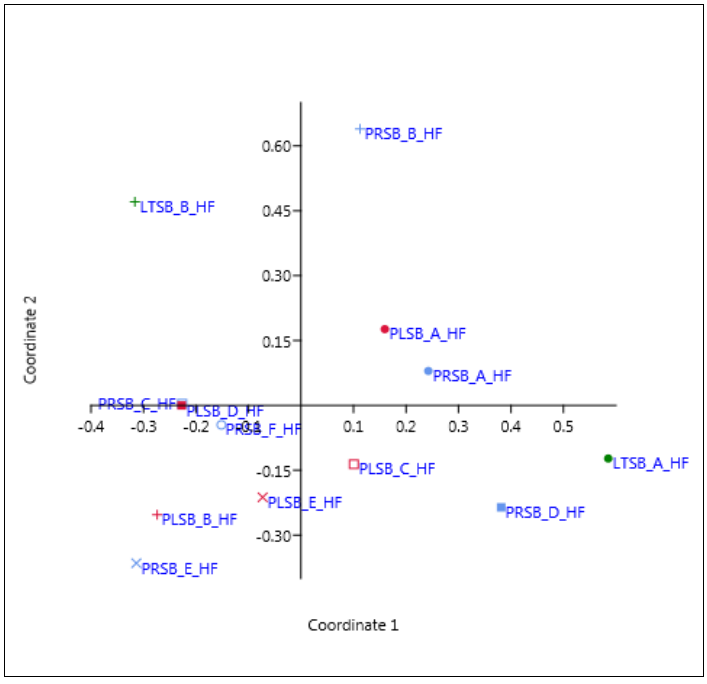

Figure 5.11 Principal Co-ordinate Analysis (PCoA) of the high-frequency values of the three sunbird species of Anaikatty hills.

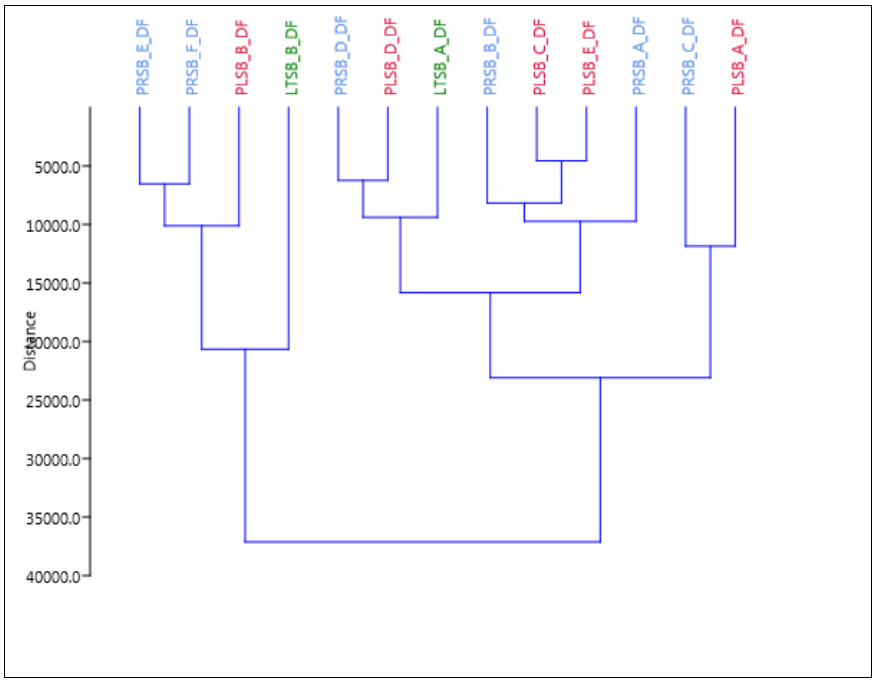

Figure 5.12 Classical hierarchical clustering of delta-frequency of three sunbird species using Euclidean distance matrix with unweighted pair group method with arithmetic mean (UPGMA) algorithm.

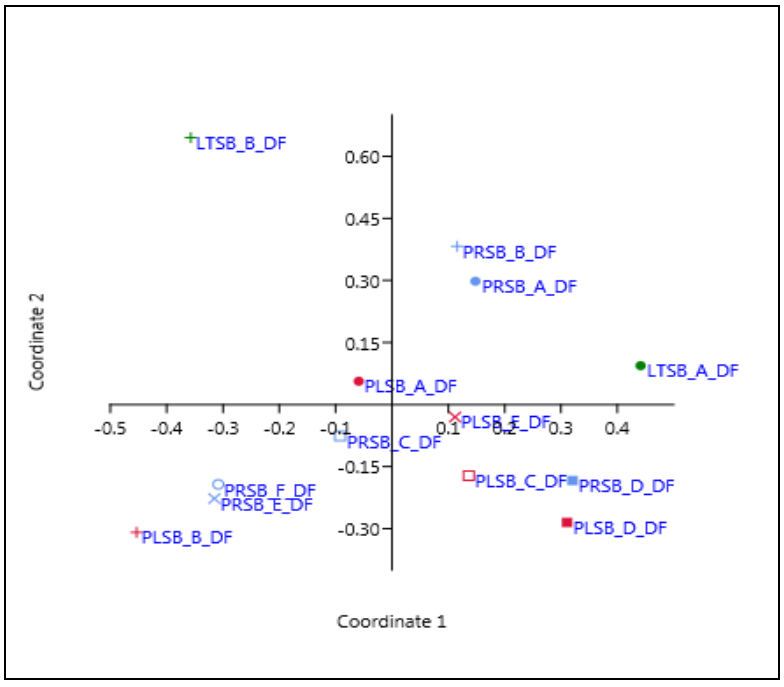

Figure 5.13 Principal Co-ordinate Analysis (PCoA) of delta-frequency values of the three sunbird species of Anaikatty hills.

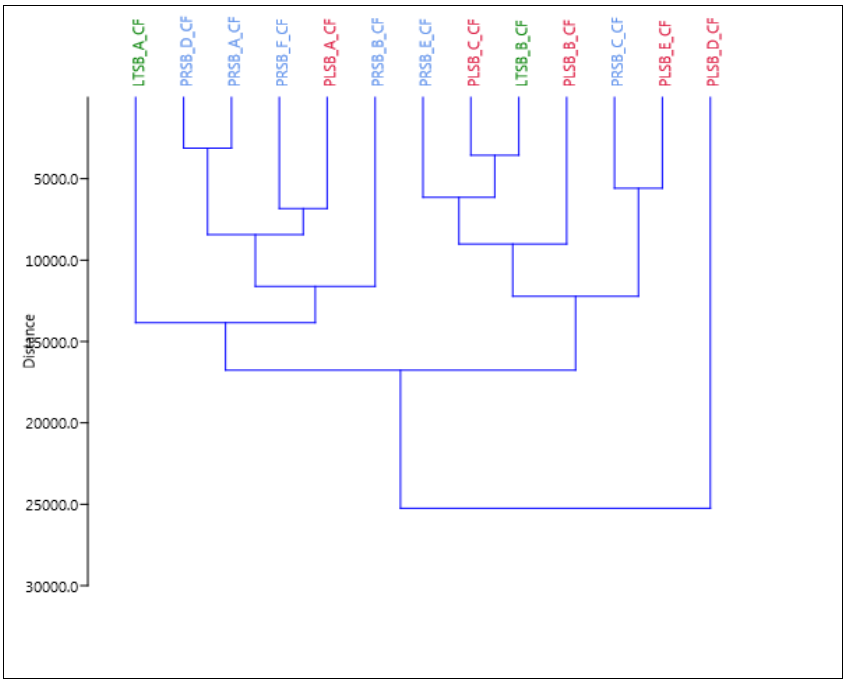

Figure 5.14 Classical hierarchical clustering of the center-frequency values of the three sunbird species of using Euclidean distance matrix with unweighted pair group method with arithmetic mean (UPGMA) algorithm.

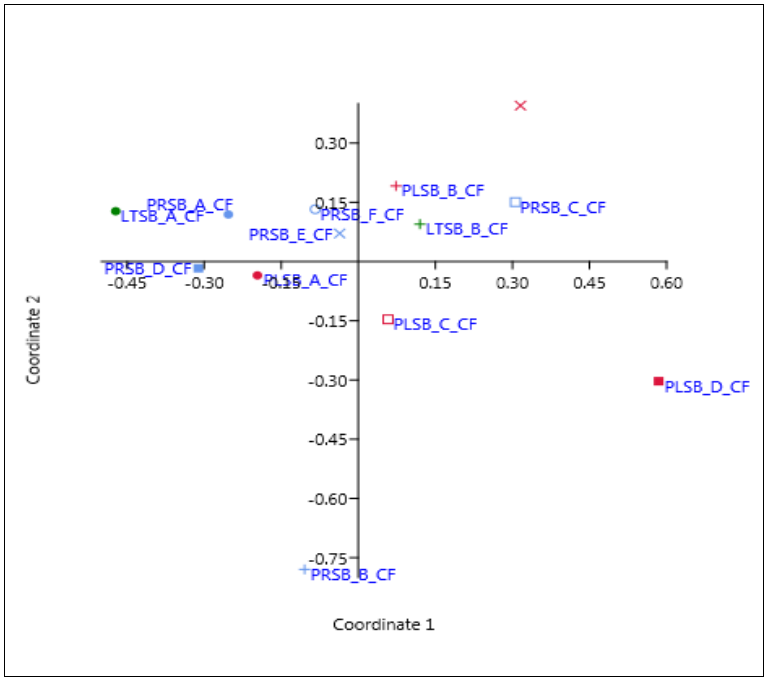

Figure 5.15 Principal Co-ordinate Analysis of the center-frequency values of the three sunbird species of Anaikatty hills.

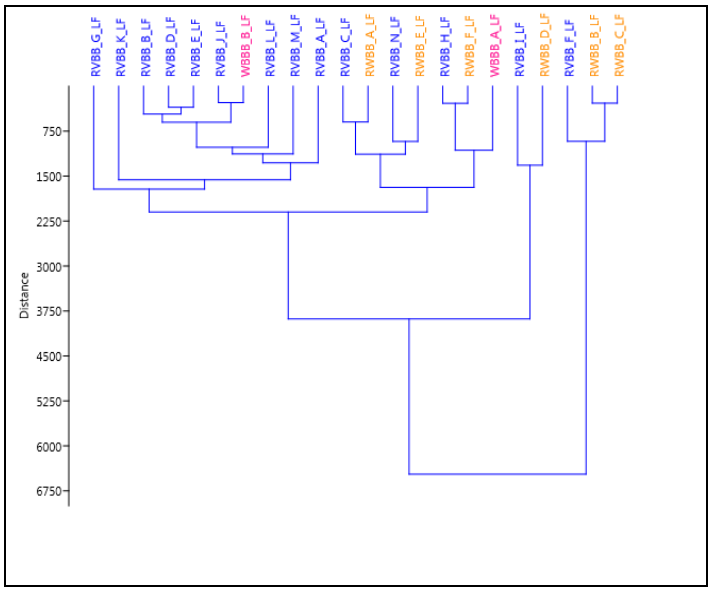

Figure 5.16 Classical hierarchical clustering of the low-frequency values of three bulbul species using Euclidean distance matrix with unweighted pair group method with arithmetic mean (UPGMA) algorithm.

The second most variable syllable group – i.e., RVBB-I and RWBB-D form the second cluster. The structurally resembling syllables form sub-clusters RVBB-N with RWBB-E and RVBB-H with RWBB-F, whereas WBBB-A branches out separately, however, all these five syllables have some similarities and arise from the same ancestor. The rest of the RVBB syllables forms a cluster along with WBBB-B. RVBB-J and similar-looking WBBB-B were placed together, however, WBBB-A remains placed much far away in another cluster. The distinct RVBB-G and RVBB-K were placed in separate branches in the other end of the cluster. ANOSIM showed no significant variation in low-frequency values within three species of bulbuls (p = 0.15 and R = 0.12). However, pairwise results show a significant dissimilarity between RVBB and RWBB, p = 0.05. There is more similarity between RVBB and WBBB (p = 0.5) and RWBB and WBBB (p = 1).

High-frequency values

Bulbuls' high-frequency ranges from 2146.1 to 5636.8 Hz, range = 3490.7 (N=213), mean 3336 ± 638.27. There is a clear separation of RVBB syllables in cluster analysis. High-frequency values gave a little different cluster than low frequencies. Among the two major clusters, the first one has RVBB syllables.

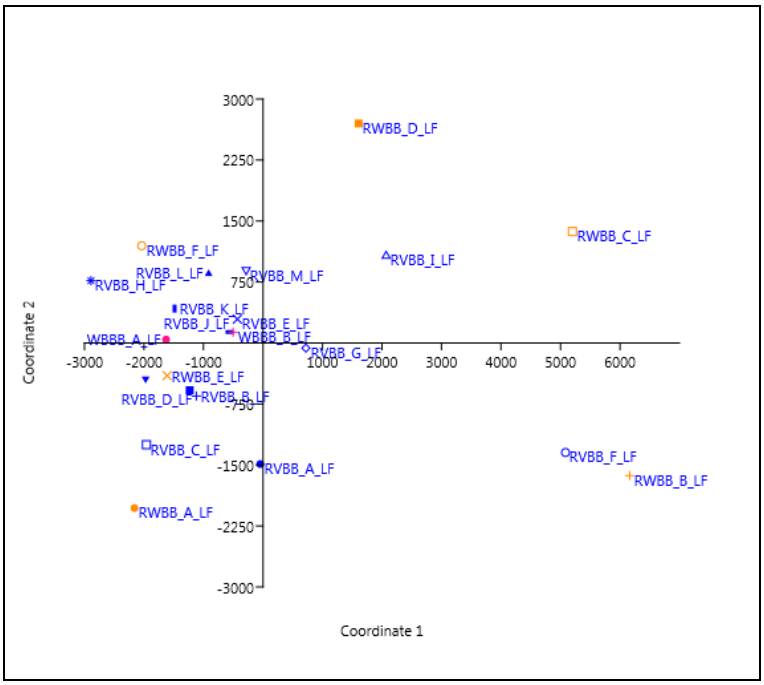

Figure 5.17 Principal Co-ordinate Analysis (PCoA) of the low-frequency values of the three bulbul species of Anaikatty hills.

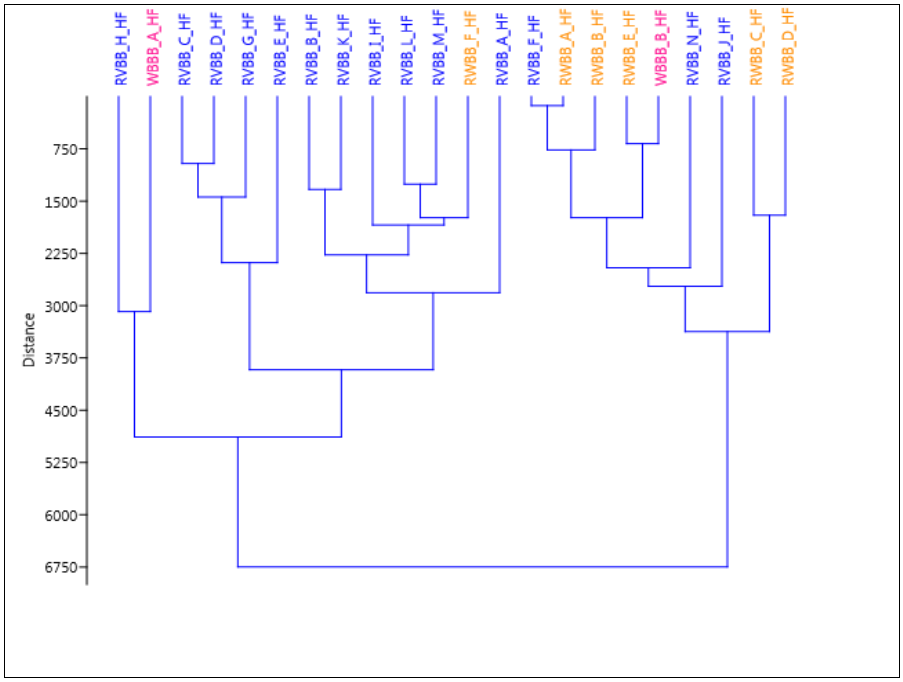

Figure 5.18 Classical hierarchical clustering of the high-frequency of three bulbul species using Euclidean distance matrix with unweighted pair group method with arithmetic mean (UPGMA) algorithm.

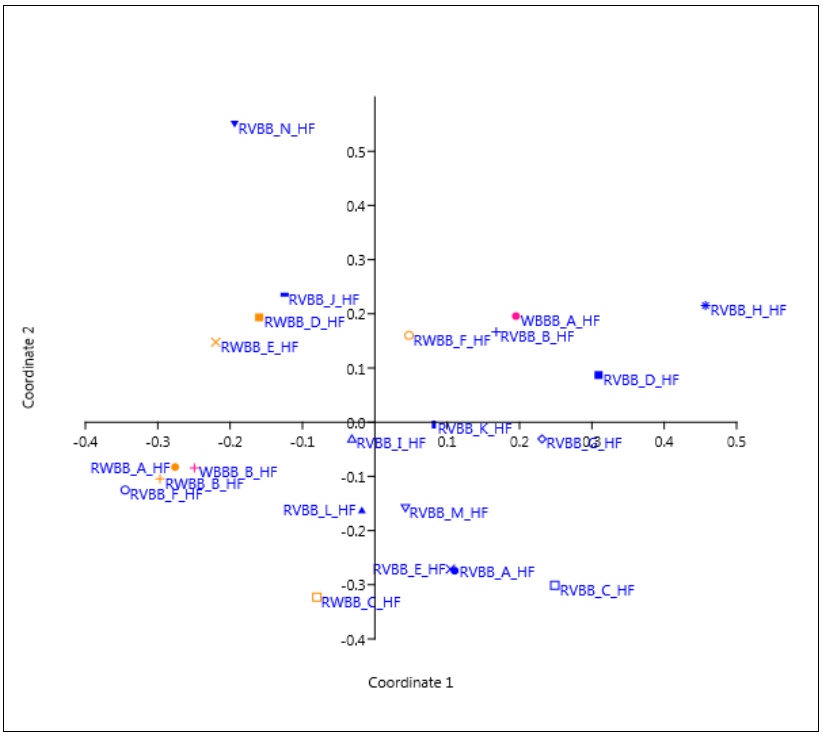

Figure 5.19 Principal Co-ordinate Analysis (PCoA) of the high-frequency of the three bulbul species of Anaikatty hills.

RVBB syllables occupy relatively lower-frequency than RWBB, hence, this separation. RVBB-H and WBBB-A form a separate sub-cluster. NMDS two-dimensional axis with Euclidean similarity index showed stress value 0.1476. The distance in the plot is like the results obtained in multiple algorithms of hierarchical clusters. ANOSIM showed no significant variation in low-frequency values within three species of bulbuls (p = 0.0874 and R = 0.1284) under 999 permutations. However, pairwise results show a significant dissimilarity between RVBB and RWBB, p = 0.04. There is more similarity between RVBB and WBBB (p = 0.309) and RWBB and WBBB (p = 0.394).

The two-dimensional data reduction map in PCoA with Principal component 1 (PC1) and PC2 showed the distance between the members of the group. PC1 contributed 51.741 % and PC2 with 10.509 %. The first 3 PCs summarized 70.5 % of the total variation (Table 5.5). There was a reasonable consensus between the visual representation of high-frequency values and the clusters found by hierarchical analysis (Figures 5.18 & 5.19; Table 5.5).

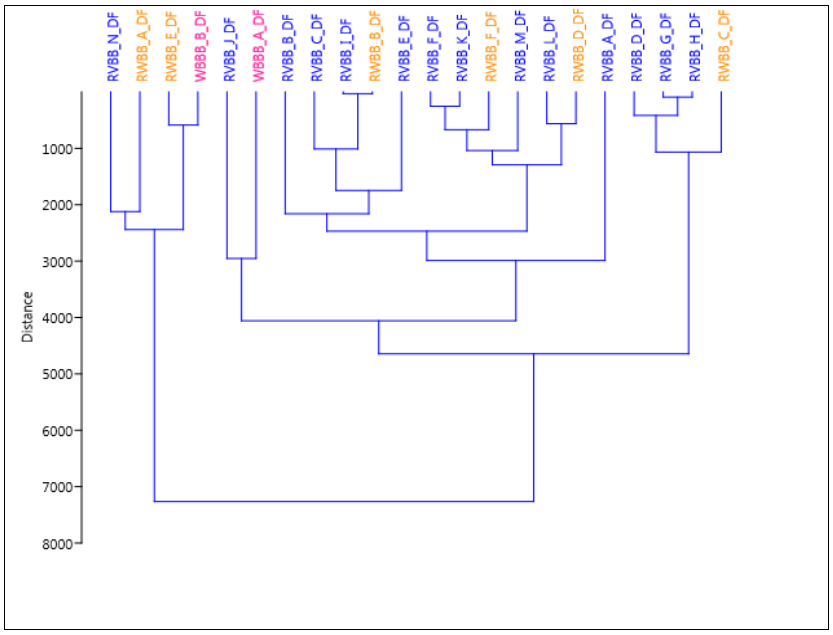

Figure 5.20 Classical hierarchical clustering of delta-frequency of three bulbul species using Euclidean distance matrix with unweighted pair group method with arithmetic mean (UPGMA) algorithm.

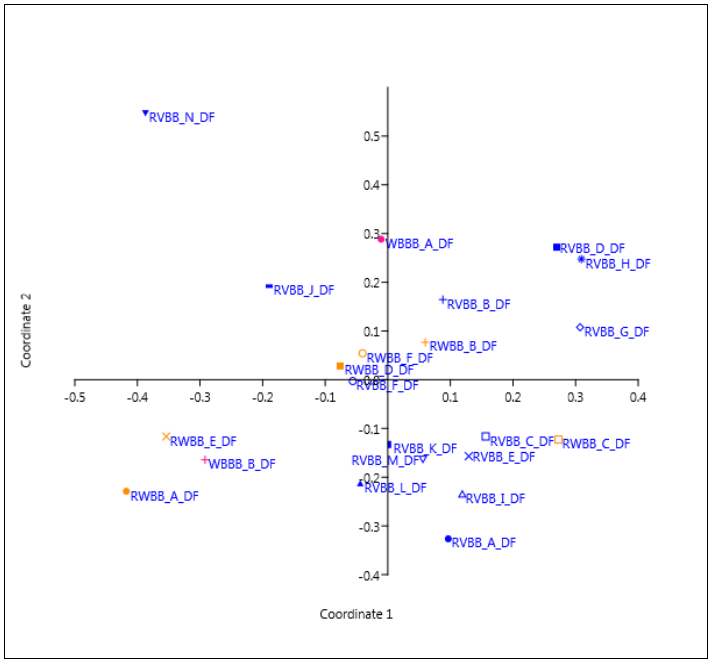

Figure 5.21 Principal Co-ordinate Analysis (PCoA) of delta-frequency of the three bulbul species of Anaikatty hills

Delta-frequency values

Bulbuls' low-frequency ranges from 911.9 to 4559.2 Hz, range = 3647.3 (N=213), mean 1934 ± 695.82. RVBB and RWBB syllables are mixed together and show many similarities at first glance. PCoA reveals much finer detailing of the distance between the members. On comparing the Euclidean distance in UPGMA algorithm and PCoA, results reveal that RVBB-G is closer to RVBB-H and hence clustered together. RVBB-D is much closer to RVBB-H than RVBB-G and placed as a separate branch. The next closer RWBB-C is branched separately which lies in PC1 and PC2 (0.27282 and -0.12269). RVBB-A with much lesser delta-frequency stands out separately in the cluster and in NMDS plot. The syllables that fell near the middle rib of PC1 and PC2 forms the next cluster.

RWBB-B and RVBB-I were placed close together leaving RVBB-E and RVBB-C as separate branches in the next cluster. However, PCoA shows that RVBB-E and RVBB-I were much closer than RWBB-B and similarly in NMDS. The sample size of RWBB-B is one and hence, further discussion is void. The much higher delta-frequency syllables RVBB-N and RWBB-A were placed together as a sub-cluster and were seen distantly placed in PCoA and NMDS. This forms a supercluster along with RWBB-E and WBBB-B. ANOSIM showed no significant variation within three species of bulbuls (p = 0.28 and R = 0.05) under 9999 permutations. Pairwise results shows a similarity between RVBB-RWBB, p = 0.36, between RVBB-WBBB, p = 0.16 and RWBB and WBBB, p = 0.78.

The two-dimensional data reduction map in PCoA with Principal component 1 (PC1) and PC2 showed the distance between the members of the group. PC1 contributed 47.811 % and PC2 with 12.275 %. The first 3 PCs summarized 68.70 % of the total variation (Table 5.5). There was a reasonable consensus between the visual representation of delta-frequency values and the clusters found by hierarchical analysis (Figures 5.20 & 5.21; Table 5.5).

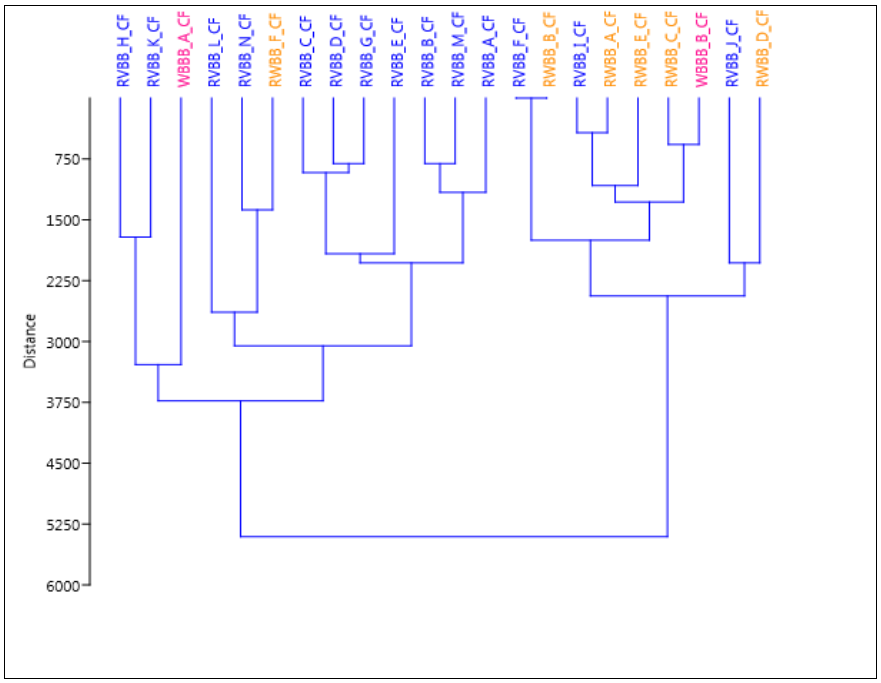

Figure 5.22 Classical hierarchical clustering of the center-frequency of three bulbul species using Euclidean distance matrix with unweighted pair group method with arithmetic mean (UPGMA) algorithm.

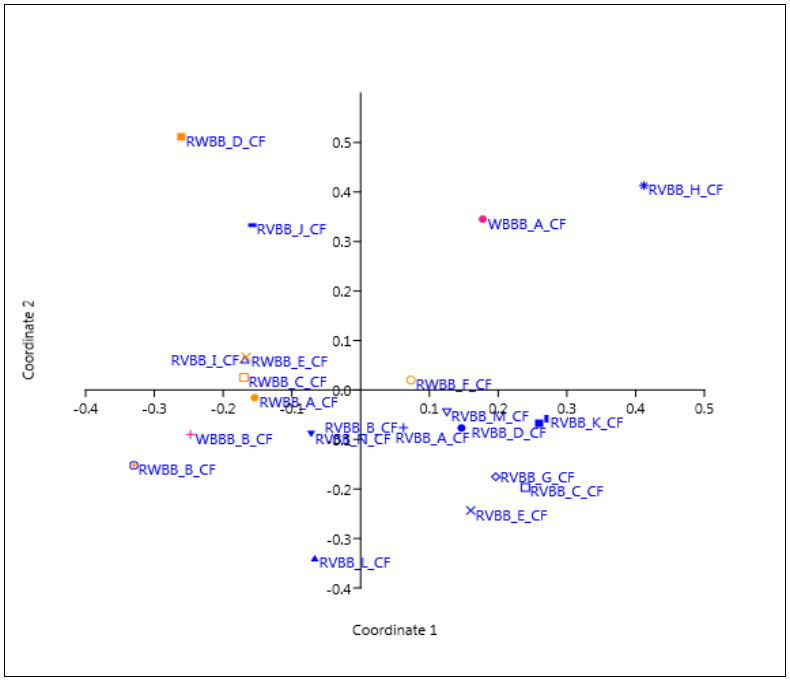

Figure 5.23 Principal Co-ordinate Analysis of the center-frequency of three bulbul species of Anaikatty hills.

Center-frequency values

Bulbuls' low-frequency ranges from 1500 to 3375 Hz, range = 1875 (N=213), mean 2461 ± 425.25. The results of hierarchical cluster analysis and two-dimensional NMDS plot showed variation from left to right, i.e., low center-frequency (C.F.) to high C.F. values. The highest center-frequency syllables such as RVBB-J and RWBB-D were placed at the right end as a sub-cluster. In PCoA, the picture is tilted reverse, that explains RVBB-H, WBBB-A and RVBB-F syllables are more variable than others. As RVBB-F and RVBB-H were observed in singletons, further discussion is negated. The second most variation was observed in PC1 in following syllables RVBB-M, RVBB-B, RVBB-K, RVBB-D, RVBB-A, RVBB-G, RVBB-C and RVBB-E. The third most varying syllables of PC2 were RWBB-D, RVBB-J, RVBB-I, RWBB-E and RWBB-C. The remaining syllables such as RWBB-A, RVBB-N, WBBB-B, RWBB-B, RVBB-F and RVBB-L. There was a clear separation of RVBB and RWBB syllables, except RVBB-N and RWBB-F, were placed together in cluster map and NMDS. However, in PCoA, RVBB-B was placed close to RVBB-N than RVBB-F. RVBB-L syllable placed next in the cluster was farther down at the juncture of PC1 and PC2 in PCoA. Comparing the cluster map and the PCoA graph gives more elaborate distance between the members of the group. RWBB-A, E and C were very closer. RWBB-E and RVBB-I were adjacent in PCoA but not adjacent in cluster, however, placed together in as a subcluster. RVBB-I shares more similarity with RWBB-A as per the cluster analysis results. The three-dimensional NMDS plot showed RVBB-D close to RVBB-G and places RVBB-C little far. But, other points in the three-dimensional plot were not in accord with cluster maps and PCoA.

ANOSIM showed a significant variation within three species of bulbuls (p = 0.048 and R = 0.14) under 999 permutations. Pairwise results shows a significant dissimilarity between RVBB-RWBB with p = 0.04. There was similarity between RVBB-WBBB, p = 0.20 and RWBB-WBBB, p = 0.46.

The two-dimensional data reduction map in PCoA with Principal component 1 (PC1) and PC2 showed the distance between the members of the group. PC1 contributed 49.051 % and PC2 with 11.395 %. The first 3 PCs summarized 66.45 % of the total variation

(Table 5.5). There was a reasonable consensus between the visual representation of center-frequency values and the clusters found by hierarchical analysis (Figures 5.22 & 5.23; Table 5.5)

The singletons RVBB-F and RWBB-B overlaps in NMDS plot and PCoA and clustered together, as their values are similar.

5.3.1.3 Prinias

Prinia syllables' low-frequency ranges from 1851.5 to 3787.2 Hz, range = 1935.7 (N=247), mean 2816 ± 361.97. The high-frequency occupies from 5302.1 to 7957.9 Hz, range = 2655.8 (N=247), mean 6893 ± 533.28. 2403.9 to 5553.9 Hz was the delta-frequency bandwidth, with range = 3150.0 (N=247), mean 4077 ± 592.62. The center-frequency ranges from 2928.5 to 5857.0 Hz, range = 2928.5 (N=247), mean 4506 ± 476.57. There was only single syllable for all the three Prinias and hence One-way ANOVA and post-hoc tests were done across the three species to find the similarities and /or dissimilarities. Classical clustering showed a commonality between JNPR and ASPR, leaving GBPR separately. ANOVA showed a significant variation of low-frequency values between groups, F = 10.83 and p = 0.00. Tukey's post-hoc test showed there was a variation between GBPR and JNPR with the significance of p = 0.000. On comparing the high-frequency values, there was significant variation between the studied groups, F = 28.85 and p = 0.000. The pairwise analysis in Tukey's HSD test showed a significant difference of call characteristic between ASPR with GBPR and ASPR with JNPR with p = 0.000. Comparison of delta frequencies showed a significant variation between groups (F = 33.98, p = 0.000) and post-hoc Tukey HSD test showed significant variation among each group with p = 0.000. ASPR showed a significant variation in center-frequency values with GBPR (p = 0.000) and GBPR with JNPR (p = 0.000) in Tukey HSD test. One-way ANOVA test showed a significant difference among the groups – F = 21.71 and p = 0.000. Both ANOVA and Tukey's test were performed in SPSS ver 16.0.

5.3.2 Call characteristics comparison of three co-existing bird species' group

The box-plot shows a distinct separation of the studied three groups based on the frequency values. Sunbird syllables – i.e., six syllables of PRSB (1-6), five syllables of

PLSB (7-11) and two syllables pf LTSB (12&13); Bulbul syllables – i.e., 14 syllables of RVBB (14-27), six syllables of RWBB (28-33), two syllables of WBBB (34&35); one syllable each from three species of prinias – ASPR (36), GBPR (37) and JNPR (38) as mentioned in figures 5.24, 5.25, 5.26 & 5.27.

The Sunbirds occupy the high-frequency bandwidth speakers, whereas Bulbuls occupy the lower-frequency bandwidth and Prinia settles as mid-frequency bandwidth speakers (Figures 5.24, 5.25, 5.26 & 5.27).

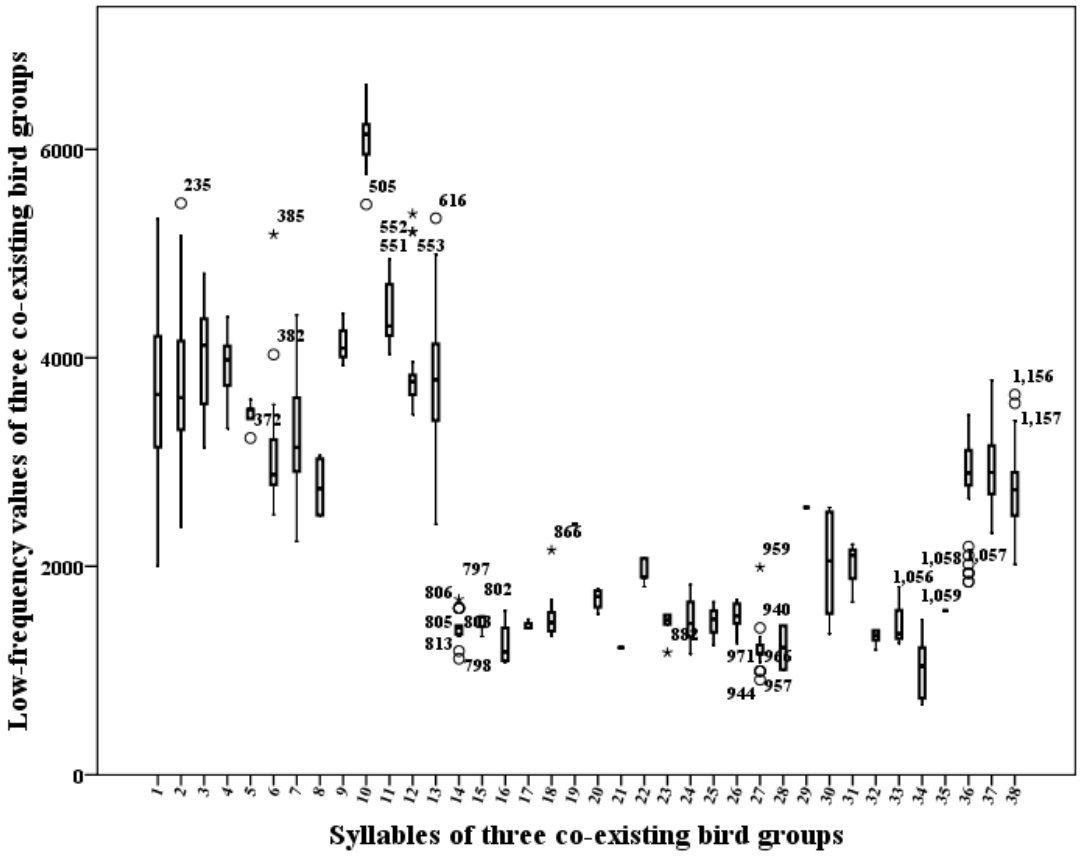

Figure 5.24 Box-plot depicting the low-frequency values of all three co-existing species, sunbirds, bulbuls and prinias during the study period in Anaikatty hills. Sunbird syllables – six syllables of PRSB (1-6), five syllables of PLSB (7-11) and two syllables pf LTSB (12&13); Bulbul syllables – i.e., 14 syllables of RVBB (14-27), six syllables of RWBB (28-33), two syllables of WBBB (34&35); one syllable each from three species of prinias – ASPR (36), GBPR (37) and JNPR (38).

Low-frequency values

The low-frequency of the nine species of co-existing groups' ranges from 669.9 to 6624 Hz, range = 5954.1 (N = 1256), mean 3153 ± 1038.51. The independent-samples Kruskal-Wallis test showed a distinct variation among the low-frequency values (N = 1256, *df* = 37), *p* = 0.000. The pairwise comparison showed a significant variation between WBBB-A with Sunbird syllables such as, PRSB-A, B, C & D; PLSB-A, C, D & E; and LTSB-A & B. The larger frequency bandwidth occupying RVBB-N syllable had significant variation with the following syllables; PRSB-A, B, C, D, E and F; PLSB – A, C, D & E; LTSB-A and B; ASPR; GBPR; and JNPR (Figure 5.24).

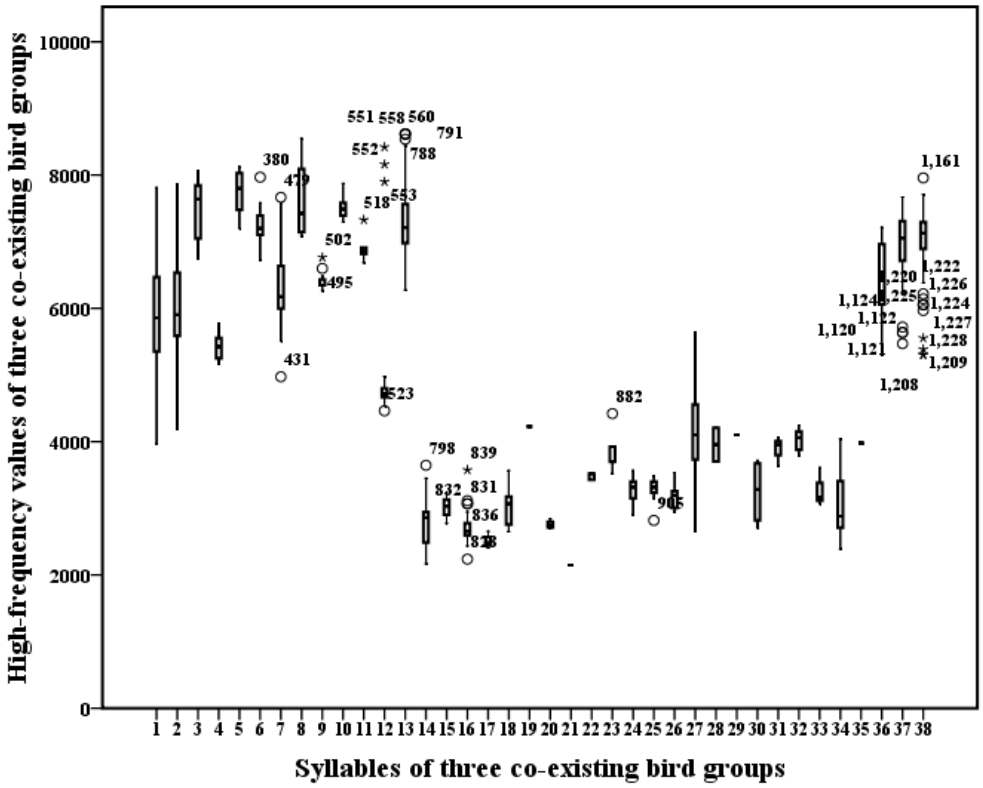

Figure 5.25 Box-plot depicting the high-frequency values of all three co-existing species, sunbirds, bulbuls and prinias during the study period in Anaikatty hills. Sunbird syllables – six syllables of PRSB (1-6), five syllables of PLSB (7-11) and two syllables pf LTSB (12&13); Bulbul syllables – i.e., 14 syllables of RVBB (14-27), six syllables of RWBB (28-33), two syllables of WBBB (34&35); one syllable each from three species of prinias – ASPR (36), GBPR (37) and JNPR (38).

High-frequency values

The high-frequency of the nine species of co-existing groups' ranges from 2146.1 to 8621.1 Hz, range = 6475 (N=1256), mean 6064 ± 1495.86. The independent-samples Kruskal-Wallis test presented a significant variation across the category of the studied groups, p = 0.000; N = 1256; df = 37. The pairwise categories comparison showed that RVBB-D is distinct significantly from PRSB-C, E and F; PLSB-D; LTSB-B; and JNPR-A syllables. Similarly, RVBB-C is significantly different from PRSB-A & B; A, C & E; and ASPR (Figure 5.25).

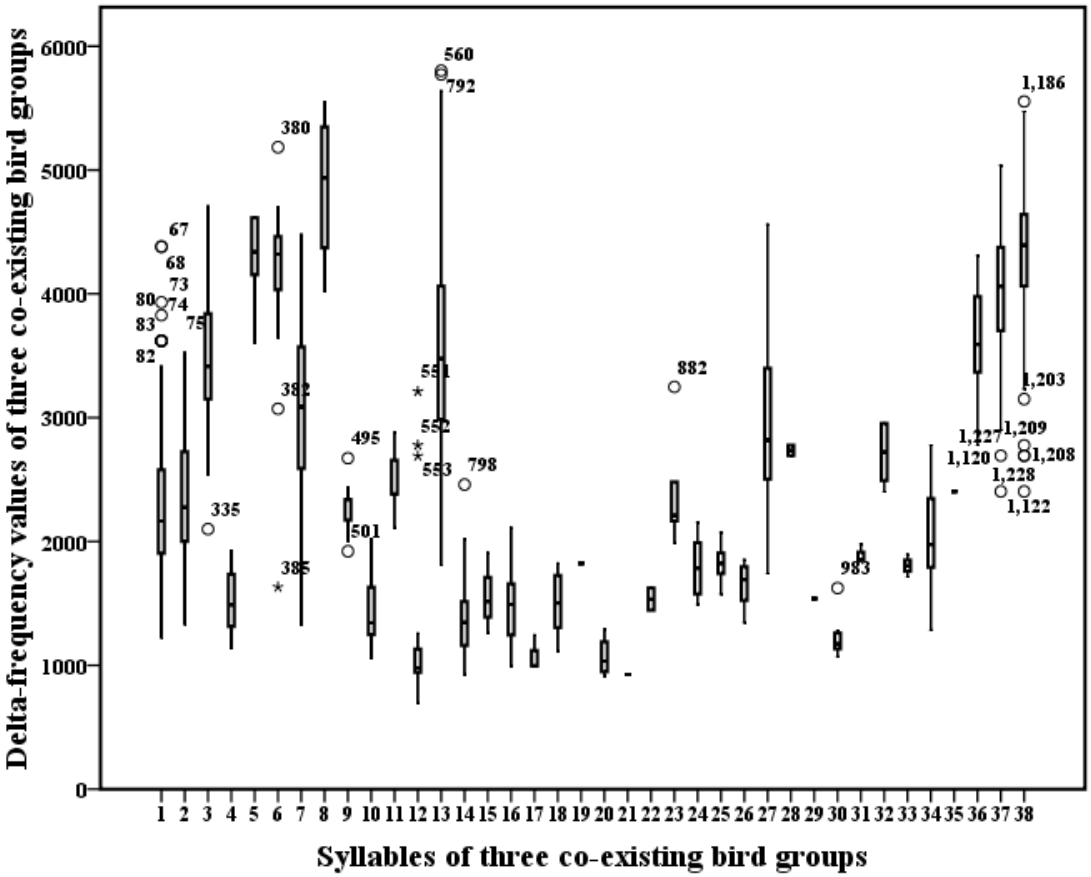

Figure 5.26 Box-plot depicting the delta-frequency values of all three co-existing species, sunbirds, bulbuls and prinias during the study period in Anaikatty hills. Sunbird syllables – six syllables of PRSB (1-6), five syllables of PLSB (7-11) and two syllables pf LTSB (12&13); Bulbul syllables – i.e., 14 syllables of RVBB (14-27), six syllables of RWBB (28-33), two syllables of WBBB (34&35); one syllable each from three species of prinias – ASPR (36), GBPR (37) and JNPR (38).

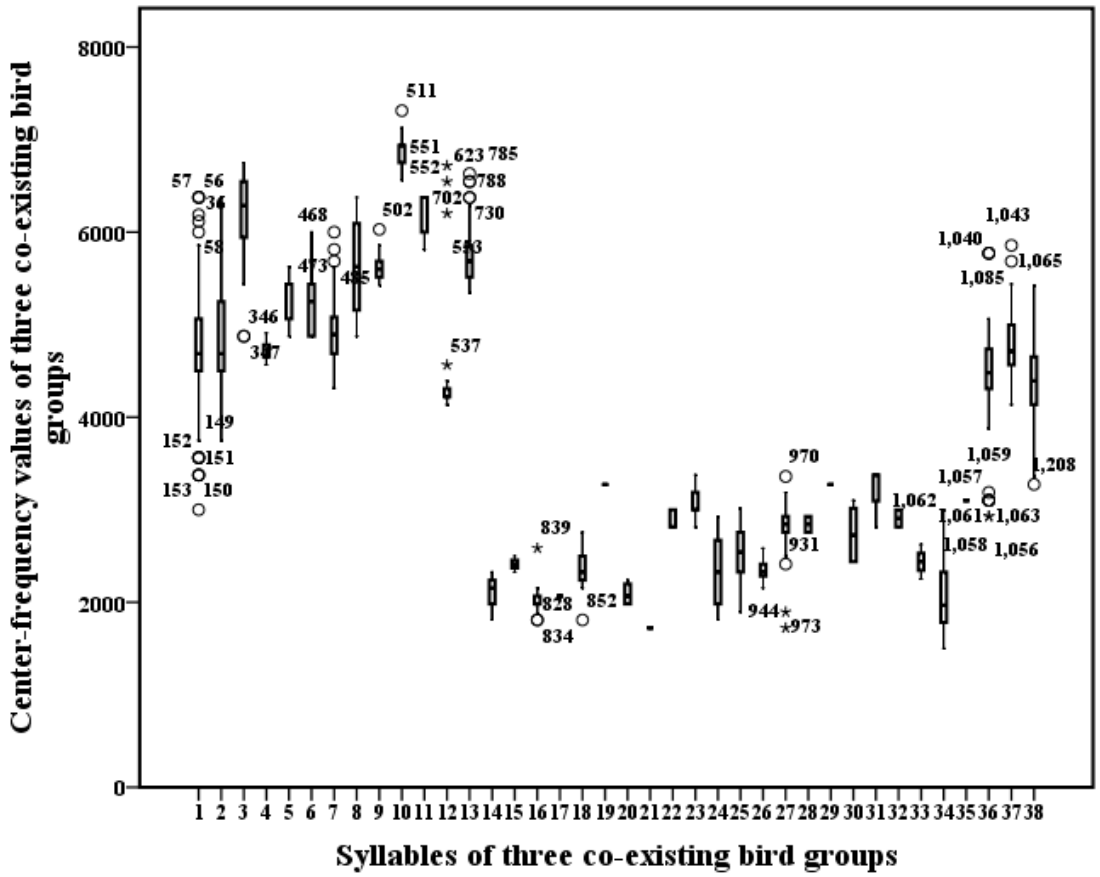

Figure 5.27 Box-plot depicting the center-frequency values of all three co-existing species, sunbirds, bulbuls and prinias during the study period in Anaikatty hills. Sunbird syllables – six syllables of PRSB (1-6), five syllables of PLSB (7-11) and two syllables pf LTSB (12&13); Bulbul syllables – i.e., 14 syllables of RVBB (14-27), six syllables of RWBB (28-33), two syllables of WBBB (34&35); one syllable each from three species of prinias – ASPR (36), GBPR (37) and JNPR (38).

Delta-frequency values

The delta-frequency of the nine species of co-existing groups' ranges from 691.6 to 5802.6 Hz, range = 5111 (N=1256), mean 1092.43 ± 1193.00. The independent-samples Kruskal-Wallis test presented a significant variation across the category of the studied groups, p = 0.000; N = 1256; df = 37. The pairwise categories comparison showed that RVBB-D is distinct significantly from PRSB- E and F; PLSB-B; GBPR; and JNPR-A syllables (Figure 5.26).

Center-frequency values

The center-frequency of the nine species of co-existing groups' ranges from 1500 to 7312.5 Hz, range = 5812.5 (N=1256), mean 4611 ± 1180.39. The independent-samples Kruskal-Wallis test presented a significant variation across the category of the studied groups, p = 0.000; N = 1256; df = 37. The pairwise categories comparison showed that RVBB-C is distinct significantly from all the syllables of PRSB, PLSB, and LTSB-B, ASPR, GBPR; and JNPR syllables (Figure 5.27).

5.4 DISCUSSION

PRSB and PLSB syllables are clustered together and ANOSIM showed no dissimilarities between their syllables. This suggested that there is a lack of competition among the co-existing species with the more facilitative environment. Or the vocal parameters studied were not enough to project the species uniqueness. In the spectral parameters' analysis, LTSB syllables stand out separately in cluster branches. PRSB and PLSBs were seen together (aggregations) on *Tecoma stans* plants for nectar feeding. They move in pairs and are observed always together and make vocalisations on arriving a new food plant or while moving to a new plant. These two co-existing species have least dissimilarities in call characteristics. On the contrary, Loten's Sunbird remains in pairs and do not mix with other sunbirds. They have unique call features among all three sunbirds.

The PRSB-C and PLSB-E syllables were placed together in PCoA and cluster analysis. The similarities of songs among co-existing species were observed earlier. Kroodsma (1973) found that co-existing, closely related species have a convergence of vocalisations. Among 3,574 songs analysed from a House Wren individual, 1,183 were exact duplicates of Bewick's Wren song (33.1 %), whereas only 7.5% accounting for 266 songs were of House Wren songs. Two sympatric *Thryothorus* wrens have undistinguishable songs in Mexico (Grant, 1966). House Wren showed similarities of the song with Carolina Wren *Thryothorus ludovicianus* or Kentucky Warbler *Oporornis formusus* (Murray, 1944).

ASPR, GBPR and JNPR syllables were distinct from each other. The GBPR calls have variable introductory notes, followed by the syllable repeated several times that occupy a

broad frequency range. The song rate, syntax, the phrase composition and the loudness were the species-specific recognition parameters in birds (Emlen, 1972; Coles et al., 1980). House Wrens showed highly variable songs with a broad frequency spectrum and trills, with swiftly repeated syllables (Bent, 1948). Del Hoyo et. al (2006a) explained that many Cisticoloides species co-exist in a few hundred meters area with delicate microhabitat variation. Similarly, the three prinia species were observed several times in a small patch during the study period. Hence, for species-specific recognition, they might require unique notes that account for the significant variation of call characteristics among three Prinia species. Hartley (1953) found that co-existing species have few delimiting factors that allow them to co-exist, especially, no two species are identical in their feeding behaviour.

Grant (1966) demonstrated the similarities of songs among *Thryothorus sinaloa* and *T. felix* at Tepic in 1963. The song composition and structure were also like Bewick's Wren *T. bewickii* songs (Borror, 1964). Further investigation revealed that these species have overlapping territory and all the songs were for territorial maintenance. Functional implication of the calls was not analysed during this study. The male and female vocalisations were different (Grant, 1966). *T. felix* produces dissimilar calls during foraging in the non-breeding season (Grant, 1965). The song similarity helps in the territory maintenance of the co-existing species for their mutually exclusive territories (Grant, 1966; Dixon, 1961). These species have similarities in feeding behaviour, food items, bill and body size. (Grant, 1966).

Among the three bulbul species, White-browed Bulbuls (WBBB) have distinct syllable characteristics. Similarly, among the co-existing three Wren species in Puebla, Mexico, the morphologically dissimilar *T. pleurostictus* have distinct songs than *T. sinaloa* and *T. felix* from Jalisco and Nayarit regions (Grant, 1966). The WBBB-A and RVBB syllables C, D and N are distinct from other syllables. WBBB-A and RVBB-N syllables sympatrically wide frequency range and were unique among other syllables. Grant (1966) posits that the species distinction was not realized by vocal signal similarities, but through morphological characters – plumage, posture and movement. The co-existing species have either mutually exclusive habitat (Grinnell & Storer, 1924; Marshall, 1957) or occupy different patches of the same habitat due to overt aggression and dispersion (Brooks, 1934; Miller, 1941; Newman, 1961).

Table 5.1 Spectral parameters of three Sunbird species of Anaikatty hills. Six syllables (A to F) of Purple-rumped Sunbird; five syllables of Purple Sunbird (A to E) and two syllables of Loten's Sunbird (A &B). Sunbird spectral parameters studied for similarities and/or dissimilarities among three Sunbird species of Anaikatty hills

Syllable type	N	Low-frequency				High-frequency				Delta-frequency				Center-frequency			
		(Mean ± S.D)	C.V	Min	Max	(Mean ± S.D)	C.V.	Min	Max	(Mean ± S.D)	C.V.	Min	Max	(Mean ± S.D)	C.V.	Min	Max
PRSB-A	184	3662.96 ± 692.18	18.9	2000	5333.3	5950.44 ± 840.20	14.12	3969.2	7809.5	2287.48 ± 598.51	26.16	1225	4381	4790.92 ± 568.54	11.87	3000	6375
PRSB-B	148	3727.95 ± 565.14	15.2	2381	5482.8	6071.64 ± 707.59	11.65	4190.5	7862.1	2339.83 ± 471.59	20.15	1333	3524	4845.41 ± 534.98	11.04	3750	6375
PRSB-C	26	3999.47 ± 487.02	12.2	3139	4807.9	7505.71 ± 426.18	5.68	6737.5	8064	3506.23 ± 641.48	18.3	2100	4708	6193.23 ± 526.59	8.50	4875	6750
PRSB-D	12	3905.08 ± 299.49	7.67	3325	4393.4	5435.48 ± 184.09	3.39	5162.5	5775	1530.39 ± 265.64	17.36	1138	1925	4715.78 ± 110.95	2.35	4565	4909.6
PRSB-E	6	3461.55 ± 127.23	3.68	3231	3600	7738.47 ± 357.13	4.61	7200	8123.1	4276.93 ± 381.35	8.92	3600	4615	5312.50 ± 282.29	5.31	4875	5625
PRSB-F	15	3142.40 ± 688.90	21.9	2496	5184	7238.40 ± 303.14	4.19	6720	7968	4096 ± 833.49	20.35	1632	5184	5237.50 ± 357.63	6.83	4875	6000
PLSB-A	94	3272.43 ± 465.41	14.2	2240	4410	6330.90 ± 480.73	7.59	4973.7	7665.8	3058.47 ± 679.80	22.23	1323	4479	4945.98 ± 322.73	6.53	4312.5	6000
PLSB-B	4	2760.30 ± 313.85	11.4	2488	3062.4	7619.50 ± 662.18	8.69	7081.7	8545.5	4859.20 ± 653.35	13.45	4019	5546	5625.00 ± 631.22	11.22	4875	6375
PLSB-C	13	4124.78 ± 162.33	3.94	3926	4426.7	6399.16 ± 144.19	2.25	6264.2	6765.3	2274.38 ± 205.18	9.02	1921	2673	5631.76 ± 163.19	2.90	5426.4	6029.3

Syllable type	N	Low-frequency				High-frequency				Delta-frequency				Center-frequency			
		(Mean ± S.D)	C.V	Min	Max	(Mean ± S.D)	C.V.	Min	Max	(Mean ± S.D)	C.V.	Min	Max	(Mean ± S.D)	C.V.	Min	Max
PLSB-D	15	6073.60 ± 275.06	4.53	5472	6624	7513.60 ± 171.99	2.29	7296	7872	1440.00 ± 273.94	19.02	1056	2016	6912.50 ± 185.71	2.69	6562.5	7312.5
PLSB-E	5	4440.32 ± 374.89	8.44	4032	4946.6	6922.68 ± 241.99	3.50	6687	7328.2	2482.38 ± 294.06	11.85	2112	2880	6187.50 ± 265.17	4.29	5812.5	6375
LTSB-A	31	3876.16 ± 480.14	12.4	3458	5382.3	5050.81 ±1042.93	20.65	4463.8	8420.7	1174.65 ± 591.10	50.35	691.6	3212	4476.12 ± 678.03	15.15	4134.4	6718.4
LTSB-B	243	3766.30 ± 503.53	13.4	2404	5340.2	7331.85 ± 486.38	6.63	6275.8	8621.1	3565.54 ± 802.12	22.5	1809	5803	5736.87 ± 237.38	4.14	5340.2	6632.2

Table 5.2 Spectral parameters of three Bulbul species of Anaikatty hills. Fourteen syllables (A to N) of Red-vented Bulbul; six syllables of Red-whiskered Bulbul (A to F) and two syllables of White-browed Bulbul (A & B)

Syllable type	N	Low-frequency				High-frequency				Delta-frequency				Center-frequency			
		(Mean ± S.D)	C.V.	Min	Max	(Mean ± S.D)	C.V.	Min	Max	(Mean ± S.D)	C.V.	Min	Max	(Mean ± S.D)	C.V.	Min	Max
RVBB-A	21	1424.02 ± 136.71	9.60	1113.7	1683.2	2811.82 ± 372.65	13.25	2168.8	3646.7	1387.80 ± 369.15	26.60	925.8	2459.4	2128.72 ± 174.72	8.21	1808.8	2325.6
RVBB-B	3	1452.03 ± 108.89	7.50	1326.3	1514.9	3013.33 ± 228.25	7.57	2777.3	3232.9	1561.30 ± 324.60	20.79	1262.4	1906.6	2411.73 ± 86.15	3.57	2325.6	2497.9
RVBB-C	27	1248.73 ± 157.35	12.60	1077.6	1575	2726.72 ± 261.37	9.59	2238.2	3575.5	1477.99 ± 283.76	19.20	994.7	2110.2	2015.43 ± 144.54	7.17	1808.8	2584
RVBB-D	3	1436.83 ± 47.86	3.33	1409.2	1492.1	2514.43 ± 126.63	5.04	2403.9	2652.6	1077.60 ± 143.59	13.32	994.7	1243.4	2067.20 ± 0.00	0.00	2067.2	2067.2
RVBB-E	16	1502.18 ± 202.66	13.49	1326.3	2155.3	3006.29 ± 254.29	8.46	2649.4	3564.5	1504.12 ± 231.87	15.42	1111	1823.7	2347.13 ± 219.04	9.33	1808.8	2756.2
RVBB-F	1	2403.9	n/a	n/a	n/a	4227.6	n/a	n/a	n/a	1823.7	n/a	n/a	n/a	3273	n/a	n/a	n/a
RVBB-G	4	1687.48 ± 105.93	6.28	1545.2	1782.2	2756.25 ± 61.37	2.23	2694.1	2839.8	1068.80 ± 166.60	15.59	911.9	1294.6	2088.75 ± 129.19	6.18	1981.1	2239.5
RVBB-H	1	1220.3	n/a	n/a	n/a	2146.1	n/a	n/a	n/a	925.8	n/a	n/a	n/a	1722.7	n/a	n/a	n/a
RVBB-I	5	1948.86 ± 121.07	6.21	1804.5	2075.2	3482.72 ± 49.40	1.42	3428.6	3518.8	1533.84 ± 90.25	5.88	1443.6	1624.1	2887.50 ± 102.70	3.56	2812.5	3000
RVBB-J	6	1443.58 ± 139.78	9.68	1172.9	1533.8	3827.05 ± 318.28	8.32	3518.8	4421.1	2383.45 ± 453.29	19.02	1985	3248.1	3062.50 ± 193.65	6.32	2812.5	3375
RVBB-K	14	1470.22 ± 197.93	13.46	1160.5	1823.7	3264.75 ± 174.54	5.35	2901.3	3564.5	1794.53 ± 223.74	12.47	1492.1	2155.3	2313.29 ± 371.40	16.05	1808.8	2928.5

Syllable type	N	Low-frequency				High-frequency				Delta-frequency				Center-frequency			
		(Mean ± S.D)	C.V.	Min	Max	(Mean ± S.D)	C.V.	Min	Max	(Mean ± S.D)	C.V.	Min	Max	(Mean ± S.D)	C.V.	Min	Max
RVBB-L	24	1474.83 ± 122.18	8.28	1243.4	1657.9	3315.80 ± 142.54	4.30	2818.4	3481.6	1840.97 ± 133.85	7.27	1575	2072.4	2512.20 ± 321.93	12.81	1894.9	3014.6
RVBB-M	8	1522.20 ± 140.96	9.26	1262.4	1683.2	3174.64 ± 194.52	6.13	2945.6	3534.7	1652.44 ± 176.12	10.66	1346.6	1851.5	2347.14 ± 136.20	5.80	2153.3	2584
RVBB-N	44	1185.86 ± 154.60	13.04	911.8	1989.5	4104.93 ± 610.36	14.87	2652.6	5636.8	2919.05 ± 592.33	20.29	1740.8	4559.2	2797.35 ± 280.79	10.04	1722.7	3359.2
RWBB-A	2	1220.30 ± 297.55	24.38	1009.9	1430.7	3955.55 ± 357.02	9.03	3703.1	4208	2735.20 ± 59.54	2.18	2693.1	2777.3	2842.35 ± 121.83	4.29	2756.2	2928.5
RWBB-B	1	2564	n/a	n/a	n/a	4102.3	n/a	n/a	n/a	1538.4	n/a	n/a	n/a	3273	n/a	n/a	n/a
RWBB-C	8	2019.19 ± 542.50	26.87	1353.4	2564	3247.26 ± 453.26	13.96	2706.8	3717.7	1228.08 ± 173.51	14.13	1068.3	1624.1	2736.83 ± 321.23	11.74	2437.5	3100.8
RWBB-D	3	1991.57 ± 292.94	14.71	1658.8	2210.5	3884.07 ± 220.70	5.68	3636.5	4060.2	1892.53 ± 73.84	3.90	1849.6	1977.8	3187.50 ± 324.76	10.19	2812.5	3375
RWBB-E	6	1323.07 ± 75.36	5.70	1200	1384.6	4030.75 ± 181.52	4.50	3784.6	4246.2	2707.68 ± 231.08	8.53	2400	2953.9	2906.25 ± 102.70	3.53	2812.5	3000
RWBB-F	3	1473.70 ± 290.01	19.68	1263.2	1804.5	3278.20 ± 290.01	8.85	3067.7	3609	1804.50 ± 90.20	5.00	1714.3	1894.7	2437.50 ± 187.50	7.69	2250	2625
WBBB-A	12	1014.53 ± 280.51	27.65	669.9	1489.8	3049.48 ± 533.40	17.49	2391	4039.7	2034.93 ± 430.12	21.14	1284.9	2777.3	2086.43 ± 460.08	22.05	1500	3000
WBBB-B	1	1575	n/a	n/a	n/a	3978.9	n/a	n/a	n/a	2403.9	n/a	n/a	n/a	3100.8	n/a	n/a	n/a

Table 5.3 Spectral features of syllables of three co-existing Prinia species

Syllable type	N	Low-frequency				High-frequency				Delta-frequency				Center-frequency			
		(Mean ± S.D)	C.V.	Min	Max	(Mean ± S.D)	C.V.	Min	Max	(Mean ± S.D)	C.V.	Min	Max	(Mean ± S.D)	C.V.	Min	Max
ASPR-A	54	2837.57 ± 417.27	14.71	1851.5	3450.6	6457.13 ± 534.33	8.27	5302.1	7211.8	3619.55 ± 412.03	11.38	2777.3	4310.5	4394.24 ± 639.62	14.56	2928.5	5770.9
GBPR-A	74	2957.69 ± 316.24	10.69	2321.1	3787.2	6971.99 ± 457.47	6.56	5470.4	7669.2	4014.30 ± 522.53	13.02	2403.9	5038.2	4788.31 ± 318.30	6.65	4134.4	5857
JNPR-A	119	2719.11 ± 332.89	12.24	2019.8	3647.4	7042.50 ± 470.95	6.69	5302.1	7957.9	4323.38 ± 572.33	13.24	2403.9	5553.9	4380.46 ± 394.76	9.01	3273	5426.4

Table 5.4 Results of principal coordinate analysis of distance matrix of low, high, delta and center-frequencies of select three sunbird species' syllables.

Variable explained	Correlation with principal coordinate							
Syllable types	Low-frequency		High-frequency		Delta-frequency		Center-frequency	
	PC 1 (69.91 %)	PC 2 (07.89 %)	PC 1 (64.94 %)	PC 2 (9.38 %)	PC 1 (62.28 %)	PC 2 (11.05 %)	PC 1 (69.01 %)	PC 2 (8.90 %)
PRSB_A	-0.06	0.08	0.24	0.08	0.15	0.30	-0.25	0.12
PRSB_B	0.06	-0.33	0.11	0.64	0.12	0.38	-0.10	-0.78
PRSB_C	0.10	0.33	-0.23	0.00	-0.09	-0.08	0.31	0.15
PRSB_D	0.02	0.22	0.38	-0.24	0.32	-0.18	-0.31	-0.02
PRSB_E	-0.10	-0.07	-0.31	-0.36	-0.32	-0.23	-0.04	0.07
PRSB_F	-0.28	-0.21	-0.15	-0.04	-0.31	-0.19	-0.08	0.13
PLSB_A	-0.34	0.09	0.16	0.18	-0.06	0.06	-0.20	-0.03
PLSB_B	-0.31	-0.57	-0.27	-0.25	-0.45	-0.31	0.07	0.19
PLSB_C	0.09	0.11	0.10	-0.14	0.14	-0.17	0.06	-0.15
PLSB_D	0.76	-0.37	-0.23	0.00	0.31	-0.29	0.58	-0.30
PLSB_E	0.26	0.32	-0.07	-0.21	0.11	-0.03	0.32	0.39
LTSB_A	-0.03	0.26	0.59	-0.12	0.44	0.09	-0.47	0.13
LTSB_B	-0.17	0.15	-0.32	0.47	-0.36	0.65	0.12	0.09

Table 5.5 Results of principal coordinate analysis of distance matrix of low, high, delta and center-frequency values of select three bulbul species' syllables.

Variable explained	Correlation with principal coordinate							
Syllable types	Low-frequency		High-frequency		Delta-frequency		Centre-frequency	
	PC 1 (50.64 %)	PC 2 (10.38 %)	PC 1 (51.74 %)	PC 2 (10.50 %)	PC 1 (47.81 %)	PC 2 (12.27 %)	PC 1 (49.05 %)	PC 2 (11.39 %)
RVBB_A	-46.99	-1488.10	0.11	-0.27	1542.40	-2640.60	0.15	-0.08
RVBB_B	-1121.20	-652.25	0.17	0.17	1404.50	1330.10	0.06	-0.08
RVBB_C	-1959.10	-1251.60	0.25	-0.30	2498.20	-942.22	0.24	-0.20
RVBB_D	-1231.90	-579.65	0.31	0.09	4306.40	2199.60	0.26	-0.07
RVBB_E	-430.56	294.21	0.10	-0.27	2065.10	-1269.20	0.16	-0.24
RVBB_F	5083.50	-1345.90	-0.35	-0.13	-894.10	-21.69	-0.33	-0.15
RVBB_G	720.75	-62.54	0.23	-0.03	4905.40	870.61	0.20	-0.18
RVBB_H	-2892.30	766.47	0.46	0.22	4937.30	2003.70	0.41	0.41
RVBB_I	2068.40	1085.00	-0.03	-0.03	1900.10	-1895.80	-0.17	0.06
RVBB_J	-562.21	135.85	-0.12	0.24	-3023.00	1553.90	-0.16	0.33
RVBB_K	-1484.30	423.21	0.08	0.00	45.77	-1074.60	0.27	-0.06
RVBB_L	-914.78	865.74	-0.02	-0.16	-702.45	-1718.90	-0.07	-0.34
RVBB_M	-284.08	884.33	0.04	-0.16	895.09	-1322.40	0.13	-0.04
RVBB_N	-1974.00	-454.68	-0.19	0.55	-6182.00	4423.60	-0.07	-0.09
RWBB_A	-2160.80	-2029.60	-0.28	-0.08	-6669.90	-1852.00	-0.15	-0.02
RWBB_B	6162.30	-1631.70	-0.30	-0.10	958.78	621.86	-0.33	-0.15
RWBB_C	5202.60	1370.90	-0.08	-0.32	4355.60	-992.47	-0.17	0.03
RWBB_D	1606.80	2698.80	-0.16	0.19	-1213.50	226.71	-0.26	0.51
RWBB_E	-1611.70	-400.62	-0.22	0.15	-5651.40	-942.03	-0.17	0.07
RWBB_F	-2039.40	1195.80	0.05	0.16	-645.41	439.06	0.07	0.02
WBBB_A	-1629.00	42.96	0.20	0.20	-170.81	2333.30	0.18	0.35
WBBB_B	-502.10	133.43	-0.25	-0.08	-4662.20	-1330.50	-0.25	-0.09

Chapter - VI

ACOUSTIC COMMUNICATION OF COMMON IORA *AEGITHINA TIPHIA* AND THEIR SONG REPERTOIRE

Cleaving her way with the beat of her rapid wings.
Led by a distant call her vague swift flight
Threaded the summer morns and sunlit lands.
- Sri Aurobindo.

CHAPTER VI

ACOUSTIC COMMUNICATION OF COMMON IORA *AEGITHINA TIPHIA* AND THEIR SONG REPERTOIRE

6.1 INTRODUCTION

Variations of the vocal signals produced by a bird constitute it's 'syllable repertoire' (Searcy, 1992). The syllable could be of 'trills' (wide frequency ranged syllable), 'whistles' (smaller amplitude of vibration), or a combination of both making into 'complex notes' (Greenewalt, 1968). The syllables can be of varied length (Brackenbury, 1980; Brackenbury, 1982). Some are either monotonic syllables with uniform frequency range (Beeman,1998) or frequency modulated (FM) types. The sound is produced through syrinx and associated respiratory muscles and brings out amplitude and frequency modulation in calls (Greenewalt, 1968; Fletcher, 1988; Stein, 1968).

Among passerine species, the 'continuous singers' have extensive complexity in their song, for example, Robin *Erithecus rubecula*, and Blackbird *Turdus merula.* With more than 100 song types, they can navigate from one song to the next eloquently without any gap (Hartshorne, 1973). Whereas, 'discontinuous singers' (Hartshorne, 1973) or 'discrete repertoire species' (Irwin, 1990) have small repertoires and are less complex than the former group of passerines. For example, Chaffinch *Fringilla coelebs*, Western Meadowlark *Sturnella neglecta*, Song Sparrow *Melospiza melodia* and Great Tit *Parus major* have repertoire size varying from 2 to 20 song types (Hartshorne, 1973). These temperate species have enormous variation across different geographic locations (Tubaro & Segura, 1995; Doutrelant et al., 2000) and are excellent learners from their tutors (Catchpole & Slater 2008; Brainard & Doupe, 2002; Payne & Payne, 1997; McGregor & Krebs, 1989; Espmark & Lampe, 1993; Gil et al., 2001) that add up new additions of song variation in every breeding season.

Call repertoire of birds is of considerable interest. Baseline information about the syllables, their spectral characteristics and contextual preferences are important for any detailed study of songbirds. Time duration, element composition, frequency bandwidth,

harmonic structure and noisiness are biologically significant spectral traits of bird vocalisation. Birds respond to these temporal and spectral structures (Beeman, 1998). The quantitative characteristics of a syllable can be viewed by scrolling across the spectrographic display (Beeman, 1991; 1996) and hence, is the advantageous and preferred mode of bioacoustics analysis (Beeman 1998). The spectrogram is used to measure individual notes or the entire call sequence (Beeman, 1996).

During a vocal signal transfer, as the distance increases, more the chance for signal loses by absorption and scattering effects through the air, ground (spherical spreading) and vegetation (Wiley & Richards, 1978; Forrest, 1994). The higher frequency signals prone to get dissipated (attenuation) (Wiley & Richards, 1978) and suffer from energy loss (Ryan, 1988) upon interacting with objects. Longer wavelength (low frequency) signals tend to pass around the objects (Marten & Marler, 1977) and experience less attenuation (Marten & Marler, 1977; Morton, 1975; Marten et al., 1977; Waser & Brown, 1986). The bird species broadcast low frequency syllables for long-distance transmission (Wiley & Richards, 1982; Wiley, 1991); (i) in open habitats (Morton, 1975), (ii) in temperate forest and grassland habitats (Marten & Marler, 1977); (iii) on tilled ground (Aylor, 1972), and/or (iv) in tropical monsoon forest, thick undercover habitat and tropical forest edges (Marten et al., 1977). The frequency modulated signals were avoided in the habitat with signal scattering surfaces such as leaves and branches (Wiley & Richards, 1982).

Exploration of Common Iora vocalisations for its varied syllables, characterization of spectral features and time duration of delivery of the calls were studied.

Study species

Common Iora (Figure 6.1) is a tropical scrub jungle and dry deciduous forest species, generally seen in pairs. The breeding season extends from January to August. They forage by gleaning on the barks and tree leaves. While they actively feed, the male and female calls frequently for contacting the partner (Ali, 2001) and show acrobatic poses during feeding. They search for food on the tree and hops actively from one branch to another and across trees (personal observation). Both the male and female vocalises frequently (Ali, 2001) and produce short syllables that are repeated consecutively (personal observation).

Figure 6.1 Common Iora *Aegithina tiphia* male (left) in beginning to assume breeding plumage and female (right).

6.2 DATA ANALYSES

From the 48 recordings comprising 240 minutes of song recordings, 142 vocalisation events of Common Iora was extracted for further analysis. The vocalisations with the least background noise were selected from the audio recordings. The calls or syllable sequence with overlapping sound was avoided, as it may give erroneous value.

Delta time and frequency range

The delta time and the delta frequency (in kHz) values were analysed for studying the variation among the syllables using random effect in ANOVA test (Fisher, 1925). To diagnose any significance in the difference in high frequency, ANOVA test was performed. The behaviour of the bird such as perching, feeding and hopping were taken for analysis. The calling bird without a conspecific partner in a perch was referred to as 'solitary', whereas the vocalising individual along with a partner during feeding and hopping behaviour was presented as 'active'. Student's t-test (Gosset, 1908) was performed to check for the significant difference of high frequency and in delta time between the syllables of solitary males and the ones with conspecific partners. All the above statistical tests were performed using SPSS ver. 16 (SPSS Inc., 2007).

Non-metric multidimensional scaling (NMDS) Analysis

Euclidean similarity index with 3D dimensionality (plot axes 1+2) was performed using PAST ver. 3.07 (Hammer et al., 2001), to assess the similarities and dissimilarities among Common Iora syllables. The spectral and temporal parameters such as; low-frequency value, high-frequency value, delta frequency (frequency range), delta time of the 15 syllables were included in NMDS for grouping them against their respective behaviour and partner presence.

6.3 RESULTS

6.3.1 Syllable types

Common Iora species were observed not vocalising during flight. A total of 240 minutes of Common Iora calls from 48 recordings were analysed. 142 vocalisation events were observed. Totally, 34 syllable types were identified, among them, 15 syllables (44.12%; Figure 6.2) were the most frequent and selected to study their spectral and temporal characteristics (Figure 6.3 & 6.4). The associated behaviour noted while delivering these syllables are presented in Table 6.1. Common Iora has short stereotyped songs; where male-produced whistles i.e. COIO ID 1 to 12, 14 & 15 and females exerted trills or rapid-notes syllable i.e. COIO ID 13 (frequency modulated (FM) types). COIO ID 6, 11, 12 and 14 have three elements and were termed as tri-elemental syllables. Whereas COIO ID 10 and 15 have two elements and named as di-elemental syllables (Table 6.1). The significant observations while considering the activity along with the syllable delivery were; (i) birds repeated one syllable continuously during solitary perch and (ii) frequently changed the syllables during activity (hopping, feeding) among the foliage. Syllables COIO 1 to 7 and 15 were uttered by solitary males when they have perched at a height of approx. 5 – 7 m on trees. Syllables 8 to 14 were ‘contact calls’ performed by birds when conspecific partners (are close by) in shrubs within 2 m height during feeding or hopping activity (Table 6.2). COIO 12 & 13 syllables were response syllables to their partner.

6.3.2 Delta time and frequency range

The delta time of COIO syllables were presented in Figure 6.3. The mean values of low, high frequencies, delta frequency (frequency range) and mean delta time (time duration) were presented in Table 6.2. The median delta time of syllable ID 1, 2, 5, 13 and 15 were longer than one second, wherein the median values were 1.63 seconds (n=10, range = 0.54 to 2.37 seconds), 1.84 seconds (n= 7, range = 1.11 to 2.12 seconds), 1.23 seconds (n = 10, range = 0.76 to 1.55 seconds), 1.18 seconds (n = 10, range = 0.40 to 2.16 seconds) and 2.33 seconds (n = 7, range 2.23 to 2.48 seconds) respectively. The remaining syllables were shorter than one second, of which the shortest were ID 7 and 8 that lasted for 0.15 seconds (n = 10, range = 0.12 to 0.16 seconds) and 0.15 seconds (n = 10, range 0.14 to 0.20 seconds) respectively. The change in delta time significantly varied across 15 syllables (random effect in ANOVA, $F_{14,127} = 70.41$, $p < 0.0001$). Outliers were observed in COIO IDs 1, 11 and 14 syllables that are placed above their delta time range as 0.54, 0.92 and 0.66 seconds, respectively.

The mean low frequency ranges from 1300 to 2800 Hz and the mean high frequency between 2300 and 6700 Hz. The female trills (rapid frequency variation) have an extended frequency range ~ between 1290 Hz and 6700 Hz (Figure 6.2 & 6.4). The frequency range of 13 syllables was below 2000 Hz (Figure 6.4). The median values of the syllable ID 13 and 15 were 5088 Hz (n = 10, range = 4155 to 5859 Hz) and 3399 Hz (n = 7, range = 3315 to 3398 Hz). The syllable ID 1, 2, 5 and 6 were lower than 500 Hz, wherein the median values were 293 Hz (n = 10, range = 175 to 351 Hz), 455 Hz (n = 7, range = 290 to 628 Hz), 293 Hz (n = 10, range = 207 to 373 Hz) and 419 Hz (n = 10, range = 410 to 539 Hz) respectively. The change in frequency range also significantly varied across 15 syllables (random effect in ANOVA, $F_{14,127} = 268.66$, $p < 0.0001$). The Pearson correlation between delta time and high frequency of Common Iora syllables shows a negative significance ($r = -0.286$, $p = 0.002$). The overall high frequency mean value is $3193 \pm 94.67_{SE}$ Hz which significantly varies with syllable type (ANOVA $F_{14,127} = 111.793$, $p < 0.0001$). There was a significant difference between mean low-frequency values across 15 syllable types (ANOVA $F_{14,127} = 15.022$, $p < 0.0001$) with a total low frequency mean value of $1853.08 \pm 473.25_{SE}$. However, Pearson correlation explains no significant correlation between delta time and low frequency.

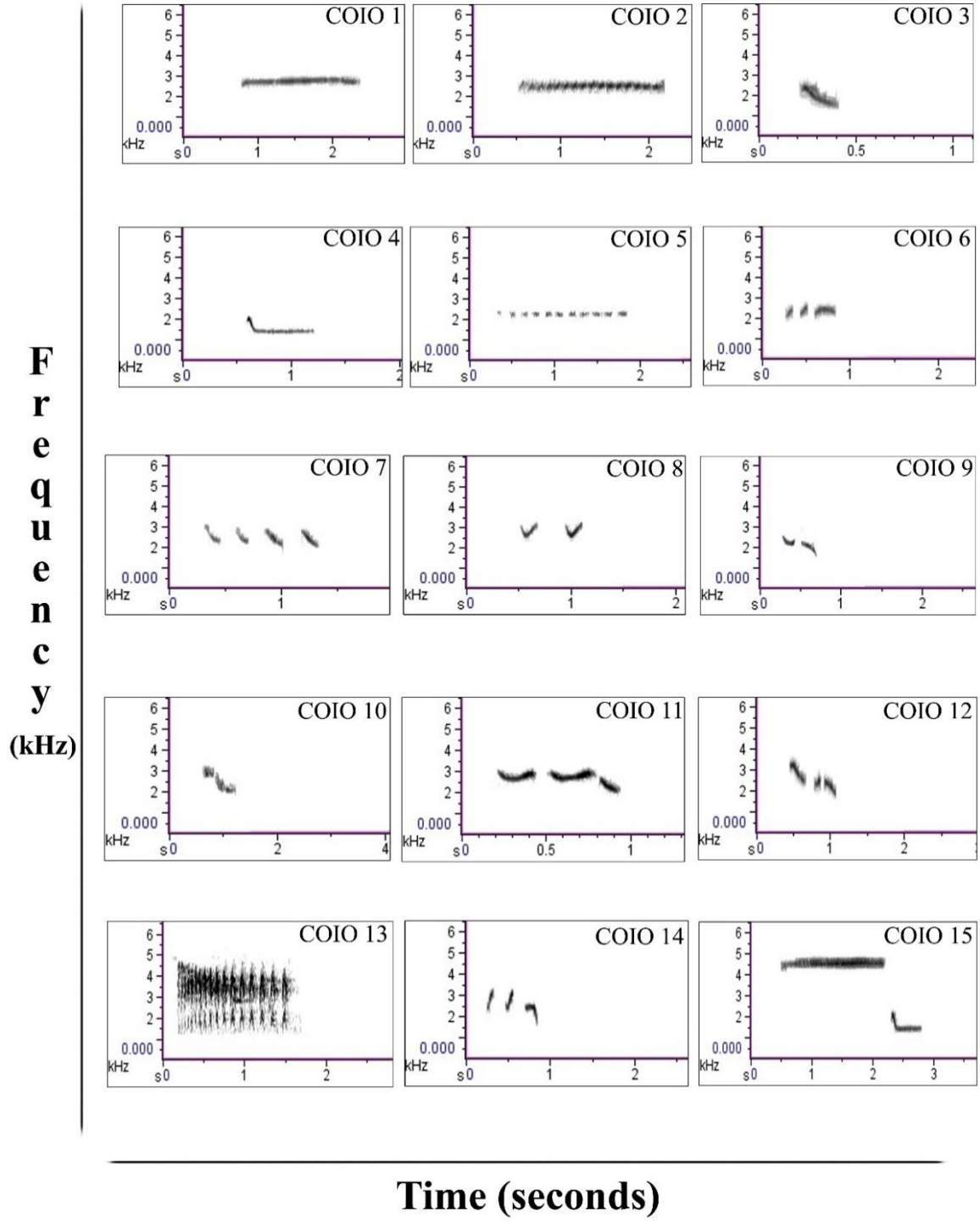

Figure 6.2 Males produce a wide variety of whistles and female produce trill (COIO ID 13 (n=10)) with a male in proximity. COIO ID 1 (n=10), 2 (n=7), 3 (n=8), 4 (n=10), 5 (n=10), 6 (n=10) and 7 (n=10) and 15 (n=7) were performed by solitary male. COIO 8 (n=10), 9 (n=10), 10 (n=10), 11 (n=10), 12 (n=10) and 14 (n=10) were pronounced by male in proximity of female.

Table 6.1 The description of the Common Iora syllables observed during the study period in Anaikatty hills

COIO ID	Physical characteristics of the syllable	Definition	Partner presence	Context
COIO 1	Monotonic flat whistle	A stretch of monotonic flat whistle made by the male when perched at height ~ 7m repeated continuously and gives a melancholy feel for the observer.	M	LDC
COIO 2	Whistle with FM*	Frequency modulated (FM) whistle uttered by the male at perch height 6-7 m in the middle of the territory. It is also uttered when there is competition with other males, at the boundary of the territory. Observed only during the breeding season.	M	LDC
COIO 3	Whistle ending in the lower frequency	Whistle with a gradual drop in frequency, delivered during their inactive period at perch height 6 m at the territory boundary.	M	LDC
COIO 4	Whistle dropping in frequency with a drag	Males perform this type of syllable continuously when perched in a tree (5m height) during no activity, at territory boundary. The frequency drops initially and dragged for about 0.5 seconds.	M	LDC
COIO 5	Short 8 consecutive flat whistles	Male utters during the breeding season (March to July) in their territory and during male-to-male vocal aggressive competition. Males either repeat the same syllable continuously (8 to 10 repeats) and changes to another syllable only when the competitor gives up.	M	LDC
COIO 6	Tri-elemental[#] whistle with a frequency-modulated third element	A syllable with the frequency-modulated third element. It is performed by the male when perched at ~ 5 m height.	M	LDC

COIO ID	Physical characteristics of the syllable	Definition	Partner presence	Context
COIO 7	Short 4 consecutive curvy whistles	The syllable with a decrease in frequency and is seen in 4 repeats made mostly when perched at 4-5 m height.	M	LDC
COIO 8	Frequency modulated whistle	The syllable is uttered in single or in 2 repeats when they are actively hopping in trees or shrubs, seen along with females.	M-P	CC
COIO 9	Tri-elemental[#] whistle with FM*	Females are seen around when male utter this frequency-modulated whistle.	M-P	CC
COIO 10	Di-elemental[#] whistle	Male utter this syllable when they are active. Females are seen along with.	M-P	CC
COIO 11	Tri-elemental[#] whistle with FM*	Commonly uttered syllable by males and is mostly in repeats. Male duets using this syllable.	M-P	CC
COIO 12	Tri-elemental[#] whistle with FM*	"*pheeu-phe-pheu"* – males utter during hopping and feeding on shrubs. Female partner was seen along. The syllable has enthused quality.	M-P	CC
COIO 13	Indistinct harsh phrase	Female's indistinct harsh phrase noted during their hopping and feeding activity. Female performs this in between their feeding action and male responds about his presence.	F	CC
COIO 14	Tri-elemental[#] whistle with FM*	Male performs this as a response to female syllable (COIO 13) during their feeding activity.	M-P	CC
COIO 15	Di-elemental[#] monotonic whistle	Continuous repetition of this drowsy syllable occurs when males are perched at height ~ 7m, mostly in the center of their territory.	M	LDC

FM* - Frequency modulated syllable. [#] - the total number of elements. M – Syllable performed by 'solitary' male; M-P denotes male syllable when a partner is nearby; F- denotes syllable performed by the female with male presence; LDC denotes 'long-distance calls' and CC denotes 'contact calls'.

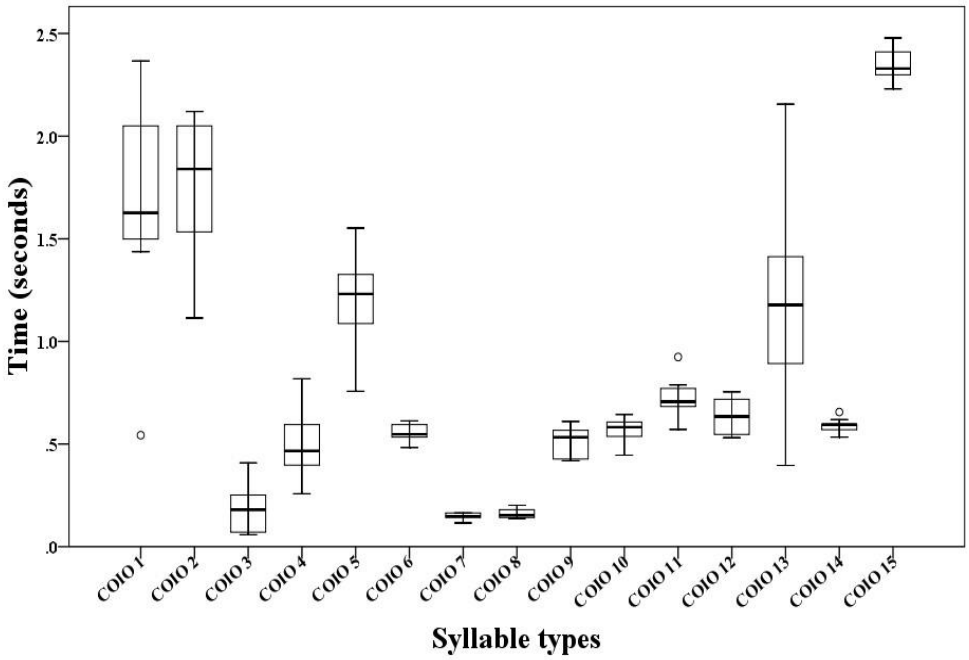

Figure 6.3 The time duration across 15 syllables. The COIO IDs 1, 2 and 13 occupies more time (seconds) than other syllables. Female syllable COIO ID 13 forms the maximum time duration with more variability in each utterance (N = 10). COIO ID 7 and 8 maintains lesser time duration with lesser variability in each utterance.

6.3.3 Partner presence and song performance

There was a significant difference in mean of high frequency between solitary male vocal signals (2757 ± 86.75_{SE} Hz) and vocal signals made by male when female is around (3642 ± 153.06_{SE} Hz) in Common Iora (t = 5.065, df = 140, p < 0.001) (Fig. 6.5 (a) & Table 6.1). Similarly, there was significant difference in mean delta time between solitary male (0.98 ± 0.09_{SE} seconds) and syllables made by partner-associated male (0.63 ± 0.04_{SE} seconds) of Common Iora (t = 3.471, df = 140, p < 0.001) (Figure 6.5 (b)). Male use different syllable types in these two different contexts (Table 1). For example, solitary male syllables (COIO ID 1 to 7 and 15 (presented as 'M') were low frequency and the syllables made during partner presence were of high frequency (COIO ID 8 to 13 & 15; presented as 'M-P'). COIO ID 13 was performed by the female ('F').

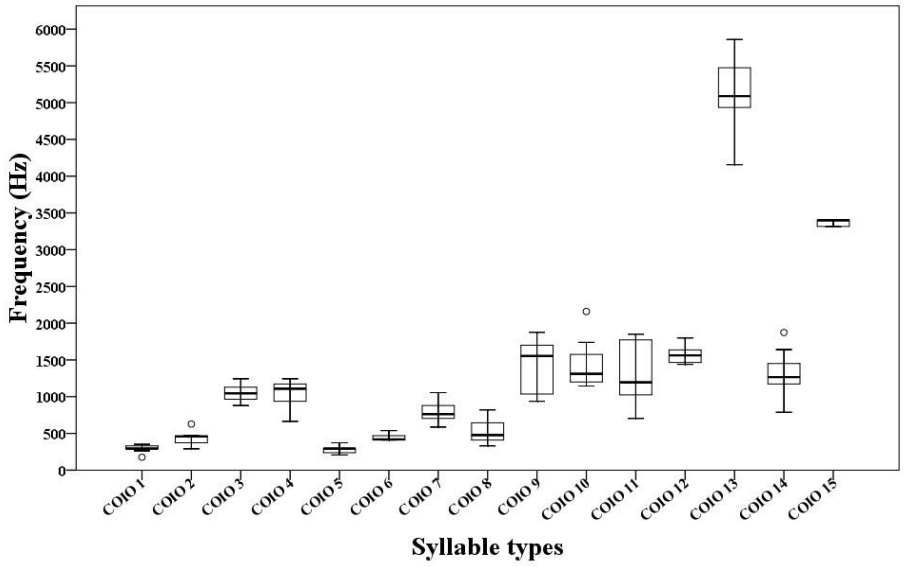

Figure 6.4 The frequency range of 15 syllables. The frequency range is higher in COIO ID 13 (uttered by females) with more frequency modulation (FM) with higher variability in each utterance (N = 10). COIO IDs 1, 5, 6 remains with less frequency variation. COIO IDs 1, 2, 3, 4, 5, 6, 7 and 8 forms lower section of the frequency bandwidth. COIO IDs 9, 10, 11, 12, 14 forms the middle section and COIO IDs 13 and 15 in the upper section of the frequency bandwidth, respectively.

COIO 1 to 12, 14 and 15 were male syllables and COIO 13 is uttered by females. The low frequency varies ~ between 1300 to 2800 Hz. The high frequency ranges ~ between 2300 to 6700 Hz. COIO ID 1 and 5 have a lower frequency range (293.10 Hz). Female uttered syllable COIO 13 have lesser low frequency and higher high frequency among other syllables forms wider spectrum of the frequency range (5088 Hz).

6.3.4 Non-metric multidimensional scaling (NMDS) Analysis

The Euclidean similarity index in NMDS (stress value 0.0001) showed a separate acoustic spacing of male and female syllables. The male syllables such as COIO ID 1 to 12 and 14 were grouped together, in which the structurally simple syllables COIO ID 1, 2, 5 and 6 with lesser frequency range (~ 500 Hz) are closely packed. The whistles COIO ID 3, 4, 7 and 9 were clubbed. The syllables with similar median frequency range COIO ID 10, 11, 12, and 14 (male syllables) were grouped along leaving COIO ID 13 (female syllable) and COIO 15 (with the extended frequency range and delta time) into two separate clusters, respectively.

Table 6.2 The frequency, time duration of Common Iora syllables and observed activity.

COIO ID types.	Mean low frequency (Hz)	Mean high frequency (Hz)	Delta frequency (Hz)	Mean Delta time (s)	Activity
COIO 1	2065.07 ± 348.89	2362.64 ± 3.89	293.10 ± 51.92	1.646 ± 0.489	Solitary
COIO 2	1340.15 ± 234.45	2591.49 ± 2.59	455.90 ± 109.63	1.749 ± 0.379	Solitary
COIO 3	1928.44 ± 980.88	2788.54 ± 9.74	1046.00 ± 119.60	0.184 ± 0.123	Solitary
COIO 4	2154.64 ± 44.94	2373.51 ± 2.09	1108.00 ± 194.35	0.496 ± 0.153	Solitary
COIO 5	2028.49 ± 100.35	2611.29 ± 1.04	293.10 ± 50.04	1.203 ± 0.224	Solitary
COIO 6	1738.2 ± 131.33	2469.86 ± 5.54	419.85 ± 45.24	0.555 ± 0.039	Solitary
COIO 7	2452.25 ± 262.78	2731.46 ± 1.49	762.00 ± 153.97	0.147 ± 0.016	Solitary
COIO 8	1586.76 ± 222.4	3288.21 ± 8.17	476.65 ± 161.77	0.161 ± 0.024	Active
COIO 9	1590.82 ± 208.95	3036.13 ± 3.94	1553.00 ± 357.44	0.512 ± 0.079	Active
COIO 10	1545.89 ± 219.63	3224.53 ± 1.34	1311.00 ± 323.34	0.571 ± 0.062	Active
COIO 11	1842.63 ± 315.35	3133.28 ± 2.02	1195.00 ± 397.06	0.721 ± 0.094	Active
COIO 12	1802.18 ± 133.88	3117.48 ± 8.62	1562.00 ± 108.84	0.637 ± 0.084	Active
COIO 13	1290.77 ± 122.51	6686.45 ± 4.97	5088.00 ± 459.19	1.224 ± 0.491	Active
COIO 14	2766.59 ± 202.33	3007.15 ± 1.35	1266.00 ± 298.69	0.589 ± 0.034	Active
COIO 15	1683.02 ± 44.31	4653.94 ± 3.13	3399.00 ± 44.31	2.350 ± 0.086	Solitary

COIO ID 10, 11, 12, 14 with higher frequency values were clubbed into distinct group within the whole male syllable bunch. The whistle COIO ID 8 were discretely spread in the NMDS spread, probably due to its wide frequency range (~ 330 Hz to 820 Hz). Alternatively, the syllables COIO ID 3, 4, 7 and 9 with high frequency values ~ 1200 Hz to ~ 3400 Hz occupies the upper region of the male syllable cluster. The precise classification based on the positioning of the male bird and the partner association was not observed (Figure 6.6).

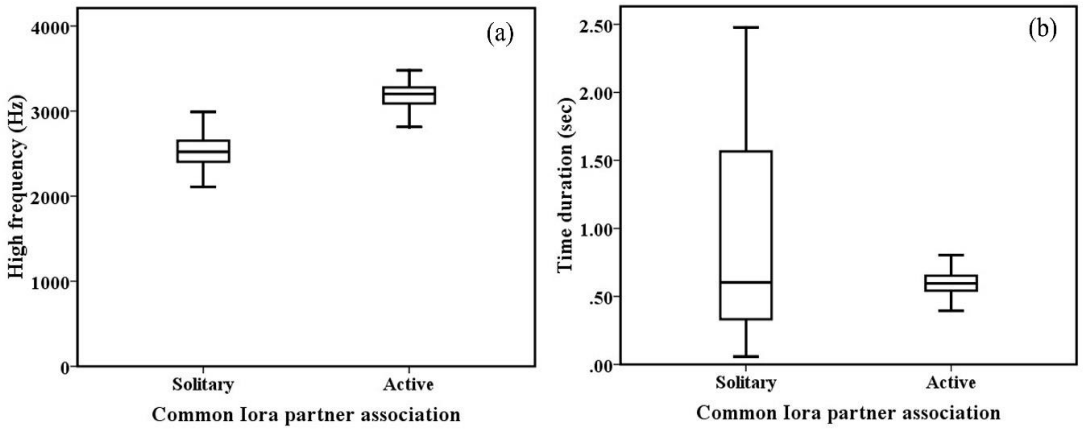

Figure 6.5 High-frequency values and time duration of male syllables – a comparison of vocalisation between solitary resting males and active males with partners. The syllables of paired male have a high-frequency range and are shorter duration, whereas the syllables of solitary males have lesser high-frequency value and sustain for a longer duration.

6.4 DISCUSSION

The findings illustrate that Common Iora males have varied syllables (34 syllables) recorded during the study period, whereas only one syllable type was recorded from females. Of these, 14 syllables were widely uttered by males. Larger syllable repertoire sizes of the male have complex songs and are a sign of good health (Leitner et al., 2001). Females may favour specific syllables, such as fast frequency-modulated (FM) syllables in Canary *Serinus canaria* (Vallet et al., 1998; Vallet & Kreutzer, 1995) or local syllable dialects (Beecher et al., 2000; Briefer et al., 2010; Laiolo & Tella, 2005; Węgrzyn & Leniowski, 2010; González & Ornelas, 2005). Thus, huge syllable repertoire of a male is beneficial for successful mating.

6.4.1 Common Iora – a 'discontinuous singer'

There was no observation of Common Iora vocalisation on a flight. In zebra finches *Taeniopygia guttata*, Waterslager canaries *Serinus canaria* and European starlings *Sturnus vulgaris* (Oberweger & Goller, 2001) had energy partitioning between syrinx and respiratory functioning; and during physical exercise, energy is focused towards respiratory system. Hence, the bird might deprive calling during flight.

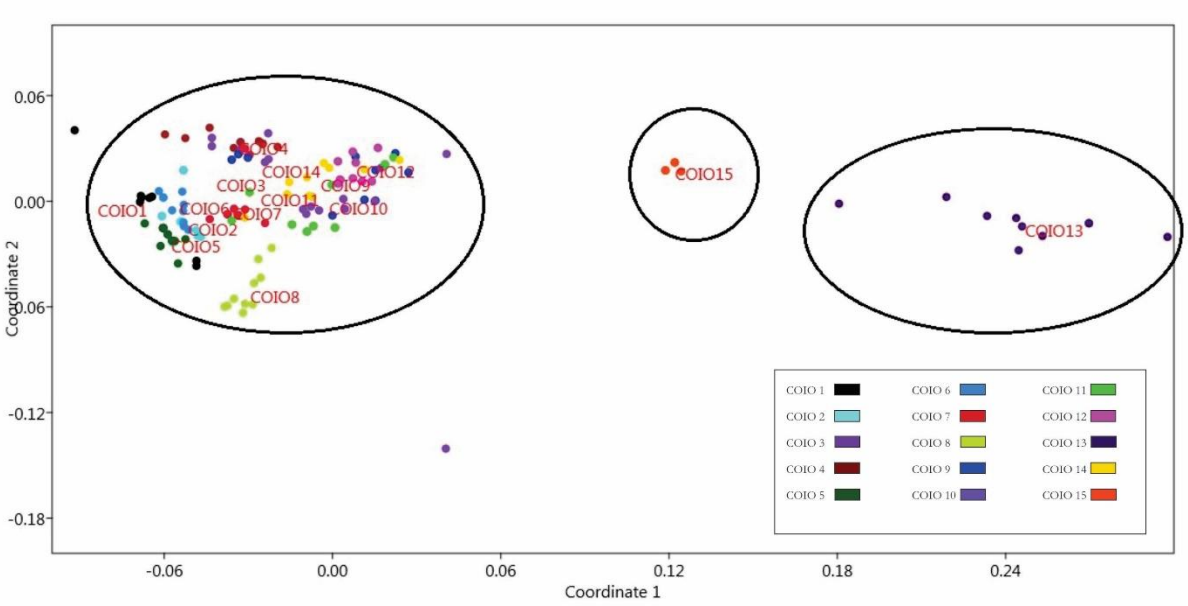

Figure 6.6 Non-metric multidimensional scaling (NMDS) plot using Euclidean similarity index. The NMDS with plot axes 1+2; 3D dimensionality (stress: 0.0001324) shows three distinct clusters. Male Common Iora syllables COIO ID 1 – 12 and 14 were clustered together. Female syllable COIO 13 branched as separate pool (at far right of the ellipse) and male syllable COIO 15 occupies unique consortium.

The stereotyped male whistles with less switching-over between syllables recommend the species to be a 'discrete repertoire' (Irwin, 1990) or 'discontinuous singers' (Hartshorne, 1973) with less variation in syllables during a song performance. The female note resembles the tonal sounds with periodic FM that are expressed as rapid pitch variation and resembles a harsh, buzzy vocal signal (Beeman, 1998). Common Iora females produce trills (COIO ID 13) that occupy wider frequency bandwidth which is in contrary with male passerine birds producing trills (Ballentine et al., 2004; Cramer, 2013) that require precise coordination between the syrinx, vocal tract and frequency bandwidth. Rapid sequences of notes (or trills) which could be controlled by syringeal muscles through pulsatile expiration were uttered by budgerigars *Melopsittacus undulates* (Suthers, 2001) canaries *Serinus canaria* (Hartley & Suthers, 1989) and northern cardinals *Cardinalis cardinalis* (Suthers & Goller, 1996).

6.4.2 Common Iora– an undergrowth and shrub stratum singer

Five of the six FM syllables are performed while they are active (Table 2) in the undergrowth and shrub. They have a rapid change in frequency within a short span of time and could result in possible dissipation, and hence the bird produces the lesser duration for uttering COIO ID 6 and 7 syllables with high-frequency values. Common Iora was observed feeding and hopping on trees and shrubs within 2 m height (Gokula & Vijayan, 2000). The syllables COIO ID 1, 2, 3, 4, 5, 6 and 7 were exerted approx. 5m above from ground (Table 1) and were heard from long distance, i.e. from the center and at edges of the assumed territorial boundary. These syllables were produced by solitary males possibly for long-range signal communication and termed as 'long-distance' calls. Vocal signals are preferred to be uttered above the ground; to lessen the ground attenuation (fading of signal); and to decrease the impacts of vegetation, wind, and temperature (Endler, 1992).

Birds tend to avoid rapidly frequency modulated signals when the habitat possess signal scattering surfaces such as leaves and branches (Wiley & Richards, 1978; Brenowitz, 1986; Wiley, 1991). In this study also, rapid frequency modulated (FM) syllables, COIO 2, 6 and 7 were uttered at open space on upper canopy and hence the species avoid the dissipation of signal, however, similar positioning during song performance is not seen for FM syllables COIO ID 11, 12 and 14 that are enunciated during partner presence. COIO ID 8 to 14 syllables were performed by males (during hopping or feeding) when a conspecific partner is alongside and hence, the signal transfer for longer distance is not required. These were 'contact calls' to communicate with a conspecific partner.

Thus, the study which was aimed to understand the spectral properties of the signals has witnessed the following functional implication.

6.4.3 Song of Common Iora during partner presence

Common Iora uses high-frequency syllables in a shrub (foliage) with shorter delta time to communicate with the proximate partner. The high-frequency syllables are prone to get dissipated by foliage. However, in the present study, the birds preferred to use them to

communicate with the proximate partner. Wiley (1991) explained that habitat may restrict the high-frequency notes. Ryan & Brenowitz (1985) elucidated that the fundamental higher frequencies are affected by various levels of ambient noise. As frequency increases, atmospheric absorption also increases resulting in more attenuation or fading of signal (Wiley & Richards, 1982). Though the higher frequencies syllables get dissipated due to scattering effect through foliage than lower frequencies (Wiley & Richards, 1982; Forrest, 1994), the proximity of partner makes the dissipation insignificant here. This indicates high-frequency syllables were uttered when long distant signal broadcasting is not required. This suggests that the context of the calls seems more important than the loss of signal.

The syllables with low-frequency values were pronounced at perch height of about 5 to 7 m by solitary males during the breeding season. These syllables can travel farther distance probably to attract distant females. Wiley and Richards (1982) expounded that low-frequency signals can travel the farthest regardless of habitat. The syllables uttered during rest/perch from treetop show more delta time value as it increases the chance of being heard by a distant female. Hence, these calls are probably intended for long-distance communication. However, there is no consistent correlation between their low-frequency values and delta time.

Chapter - VII

SUMMARY

There was a carol of birds and murmur of bees,

And all that is common and natural and sweet...

- Sri Aurobindo

CHAPTER VII

SUMMARY

The bird vocalisations or 'ornithophony' is observed as one of the dominant aspects of the soundscape of any natural ecosystem. Birds have species-specific songs with functional implications. They have an innate or acquired ability in recognizing the conspecific vocal signals and successfully defends the territory from the other co-existing birds. The variations of the vocal signals produced by a bird constitute their 'syllable repertoire'. The repertoire cataloguing of vocal signals renders a simplistic perception of communication and their hidden meaning. During a vocal signal transfer, the distance increases the signal lose by; (i) absorption and; (ii) scattering effects through the air, ground and vegetation. The higher frequency signals are prone to get dissipated (attenuation) and suffer from energy loss. Whereas, signals with longer wavelength (low frequency) pass around the objects and experience less attenuation. This study was carried out to understand the vocalisations of bird species of the Anaikatty hills with specific objectives of examining: 1) To study the extent of ornithophony in the soundscape of Anaikatty hills; 2) To analyse the song repertoires of three groups of closely related coexisting species; and 3) To analyse the song repertoire of a select species, Common Iora *Aegithina tiphia*, their call characteristics and contextual implications.

The ornithophony in the soundscape of Anaikatty hills was studied across 13 daylight hours from dawn to dusk (6 h – 19 h) between January 2015 to October 2016. Six replicates of a continuous 5-minute bird vocalisation were recorded from each hour window in the study area. Total 78 recordings which amount to 390 minutes were analysed. A total of 62 bird species were observed vocalising during the study period. Among the 11,700 observation units obtained, birds occupied 8629 (74%). Of these, passerines dominated the soundscape with 7279 (84.35 %) and non-passerines with 1272 (14.74 %) vocal units. A total of 73.75 % acoustic space was occupied by birds. The remaining 26 % of acoustic space was occupied by other biophonies (12.60 %), geophony (5.57 %), indistinct sound (7.66 %) and anthropogenic noise (0.41 %).

The study has recorded 39 passerine species (62.90 %) and 23 non-passerine species (37.09 %) from the study area. Eight dominant species alone contributed to 63.65 % of ornithophony of the soundscape.

Birds vocalised in all the 13 observation windows, with a peak in the first three hours of the day (6 – 9 h). Vocalisation of non-passerines was prominent in the dusk hour 18 – 19 h. ANOVA showed that the bird species and vocal units significantly varied across the 13 observation windows, i.e. $F_{12,65} = 4.220$, $p < 0.01$ and $F_{12,65} = 2.251$, $p = 0.019$, respectively. Kruskal-Wallis test showed no significant difference across the bird species between mid-day--afternoon hours against morning--evening hours, $\chi 2 = 3.47$, $df = 1$, $p = 0.063$ (N = 13). There was no significant variation in vocal units among the tested groups $\chi 2 = 0.73$, $df = 1$, $p = 0.39$ (N = 13). In any one-hour observational window, a minimum of 16 species was recorded to be vocally active. The low frequency showed a negative correlation with their body mass ($r^2 = -0.67$), however, there was no significant correlation between high frequency and body mass (in gm.). On studying the high frequency against body mass (in gm), 2-dimensional non-metric multi-dimensional scaling (NMDS) method showed a distinct separation between harmonic and non-harmonic speakers with stress value 0.

The bird calls of select three groups of coexisting species were done from January 2015 to July 2016. Selected groups were Sunbirds, Bulbuls and Prinias. 18, 16 and 22 calls were recorded with 69, 72, and 101 minutes of audio recordings of Sunbirds, Bulbuls and Prinias, respectively. The spectral features of the syllables such as low frequency, high frequency, delta frequency (frequency range), and center frequency (with equal energy on either side of the measurement) were measured by visual inspection method. Purple-rumped Sunbird *Leptocoma zeylonica* had six syllables- syllable A to F, Purple Sunbird (*Cinnyris asiaticus*) has 5 syllables A to E, and Loten's Sunbird *Cinnyris lotenius* has 2 syllables (A &B). Red-vented Bulbul *Pycnonotus cafer* pronounced 14 syllables (A to N), Red-whiskered Bulbul *Pycnonotus jocosus* with 6 syllables and syllables uttered by White-browed Bulbul *Pycnonotus luteolus* during the study period. The co-occurring Prinia species such as; Ashy Prinia *Prinia socialis,* Grey-breasted Prinia *Prinia hodgsonii and* Jungle Prinia *Prinia sylvatica* had one syllable each.

Sunbirds are high-frequency bandwidth vocalisers. Prinias occupy median range and bulbuls are low-frequency vocalisers. Spectral features of Purple-rumped Sunbird and Purple Sunbird were very similar. Loten's Sunbirds call characteristics were disparate. Call features of Red-vented Bulbul and Red-whiskered Bulbuls were distinct. The White-browed Bulbuls syllables are unique. All three Prinias were distinct from one another.

Spectral properties such as duration of signal and frequency range were studied in Common Iora *Aegithina tiphia* vocalisations. Bird calls were sampled from different locations to capture variability of their vocal signals. Along with call recordings, behaviour parameters such as; presence of male or female conspecific members and their activities were recorded. From a total of 240 minutes recordings, 34 syllables were obtained. The most commonly uttered fifteen syllables were identified, of which, 14 were produced by the males (COIO IDs 1 to 12, 14 & 15) and the remaining one (COIO ID 14) by females. Common Iora males use high-frequency syllables (COIO IDs 8 to 14) with shorter duration as 'contact calls' to communicate with the nearby conspecific members. This could possibly for giving advantage in avoiding the information dissipation and signal loss. While perching on the tree of 5 – 7 m height, the solitary males use low-frequency syllables (COIO IDs 1 to 7 and 15) as 'long-distance calls' for signalling the distant conspecifics.

There was a significant difference in the mean high frequency between solitary male vocal signals ($2757 \pm 86.75_{SE}$ Hz) and vocal signals made by male along with a partner ($3642 \pm 153.06_{SE}$ Hz; $t = 5.065$, $df = 140$, $p < 0.001$). Similarly, there was significant difference in mean delta time between solitary male ($0.98 \pm 0.09_{SE}$ seconds) and syllables made by partner-associated male ($0.63 \pm 0.04_{SE}$ seconds) of Common Iora ($t = 3.471$, $df = 140$, $p < 0.001$). Common Ioras produce short stereotyped syllables and repeats the same syllable several times and can be categorized as 'discrete repertoire species' or 'discontinuous singers'. Though these context preferences are not conclusive in nature based on this brief study, it suggests existence of context specificity of spectral characteristics in bird vocalisations.

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ARTICLE

Ornithophony in the soundscape of Anaikatty Hills, Coimbatore, Tamil Nadu, India

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Abstract: An attempt has been made to understand the extent of ornithophony (vocalization of birds) in the soundscape of Anaikatty Hills. The study was limited to 13 hours of daylight from dawn to dusk (06.00–19.00 h) between January 2015 and October 2016. Six replicates of 5-minute bird call recordings were collected from each hour window in 24 recording spots of the study area. Each 5-minute recording was divided into 150 '2-sec' observation units for the detailed analysis of the soundscape. A total of 78 recordings amounting to 390 minutes of acoustic data allowed a preliminary analysis of the ornithophony of the area. A total of 62 bird species were heard vocalizing during the study period and contributed 8,629 units. A total of 73.75% acoustic space was occupied by birds, among which the eight dominant species alone contributed to 63.65% of ornithophony. The remaining 26% of acoustic space was occupied by other biophonies (12.60%), geophony (5.57%), indistinct sounds (7.66%), and anthropogenic noise (0.41%). Passerines dominated the vocalizations with 7,269 (84.24%) and non-passerines with 1,360 (15.76%) units. Birds vocalized in all 13 observation windows, with a peak in the first three hours of the day (06.00–09.00 h). Vocalizations of non-passerines were prominent in the dusk hours (18.00–19.00 h).

Keywords: Acoustic community, bird acoustics, bird vocalization, diurnal singing, ornithophony, soundscape analysis.

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Spectral characteristics of Common Iora *Aegithina tiphia* vocalizations and their context-specific preferences

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Spectral properties such as duration of signal and frequency range were studied in Common Iora *Aegithina tiphia* vocalizations. Bird calls were sampled from different locations of the study area at different times to capture variability of their vocal signals in space and time. Along with call recordings, behaviour parameters such as presence of male or female conspecific members and their activities were recorded. From 48 bird call data, a total of 240 min of recordings was analysed. The most commonly uttered 15 syllables were identified, of which 14 were produced by males and the remaining one by females. Basic statistics of the spectral characteristics along with the observed behavioural parameters explain the natural history of Common Iora. The duration of syllable and frequency parameters such as low and high frequencies varied significantly across the 15 syllables. Common Iora males were recorded as using high frequency syllables with shorter duration as 'contact calls' with the nearby conspecific members, while low frequency 'long distance' calls were used by solitary males. Though these context preferences are not conclusive in nature based on this brief study, it suggests existence of context specificity of spectral characteristics in bird vocalizations.

Keywords: Acoustic parameters, bird acoustics, call syllable, Common Iora, frequency range.

CALL repertoire of bird songs is of considerable interest. Baseline information about the syllables, their spectral characteristics and contextual preferences is important for any detailed study of songbirds. Time duration, element composition, frequency bandwidth, harmonic structure and noisiness are biologically significant spectral traits of bird vocalization. Birds respond to these temporal and spectral structures of sound[1]. The fundamental units of the vocal spectrum of a bird, 'elements' combine to form a syllable[2]. The quantitative characteristics of a syllable can be viewed by scrolling across the spectrogram[3,4]. This yields quantitative comparisons of visually represented signals and hence, is the advantageous and preferred mode of bioacoustic analysis[1,5–9]. Spectrogram visualization is used to measure individual notes or the entire call sequence[4].

The vocal signal of birds comprises monotonic 'syllables' with uniform frequency range[1] or frequency modulated (FM) syllables. Syllable repertoire of birds contains 'trills' (wide frequency ranged signals) and 'whistles' (smaller amplitude of variation).

The forest bird species broadcast low frequency syllables for long distance transmission[10,11]. (i) in open habitats[12], (ii) in temperate forest and grassland habitats[13], (iii) on tilled ground[14] and (iv) in tropical monsoon forest, thick undercover habitat and tropical forest edges[15]. The FM signals are avoided in habitats with signal scattering surfaces, such as leaves and branches[10].

Exploration of bird calls for their varied syllables, characterization of spectral features and time duration of delivery of the calls are analysed in this study.

Study species

Common Iora *Aegithina tiphia*, the selected study species is a tropical scrub jungle and dry deciduous forest species, generally seen in pairs[16] (Figure 1). The birds forage by gleaning on the barks and leaves[17]. They are extremely agile and display acrobatic poses during feeding[16]. Their breeding season extends from January to August[16]. Both the male and female vocalize frequently[16] and produce short syllables that are repeated consecutively (pers. obs.).

Study area

The study area, viz. Anaikatty hills (11°05′N, 76°47′E), Coimbatore district, Tamil Nadu, India (Figure 2) is a part of the Nilgiri Biosphere Reserve (NBR). It is approximately 500–600 m asl and experiences temperature varying from 17°C to 36°C (ref. 18). The study site is on the leeward side of the Western Ghats and receives an average annual rainfall of about 700 mm, which is mainly contributed by the northeast monsoon. The study site is a secondary forest surrounded by dry deciduous forest rich

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