Examining repertoire size and seasonal variation in male song and temporal variation in various behaviours in the Purple sunbird *(Cinnyris asiaticus)*

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A dissertation submitted for the partial fulfilment of BS-MS dual degree in Science

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Certificate of Examination

This is to certify that the dissertation titled "**Examining repertoire size and seasonal variation in male song and temporal variation in various behaviours in the Purple sunbird *(Cinnyris asiaticus)***" submitted by **Pankhuri Singhal (MS15149)** for the partial fulfilment of BS-MS dual degree programme of the Institute, has been examined by the thesis committee duly appointed by the Institute. The committee finds the work done by the candidate satisfactory and recommends that the report be accepted.

Dr. N.G. Prasad | Dr. Rhitobhan Roy Chaudhary | Dr. Manjari Jain

(Supervisor)

Dated: April 24, 2020

Declaration

The work presented in this dissertation has been carried out by me under the guidance of **Dr. Manjari Jain** at the Indian Institute of Science Education and Research Mohali. This work has not been submitted in part or in full for a degree, a diploma, or a fellowship to any other university or institute. Whenever contributions of others are involved, every effort is made to indicate this clearly, with due acknowledgement of collaborative research and discussions. This thesis is a bonafide record of original work done by me and all sources listed within have been detailed in the bibliography.

Pankhuri Singhal
(Candidate)
Dated: April 24, 2020

In my capacity as the supervisor of the candidate's project work, I certify that the above statements by the candidate are true to the best of my knowledge.

Dr. Manjari Jain
(Supervisor)

I would like to dedicate my thesis to my Nani.

She left us when I was very young. I hardly have any memories of her and most them are stories that were told to me by my family. My mother always tells me that she was a woman beyond her time. She always believed in helping others and received most joy from charity. She always encouraged my mother to study hard and become independent. She encouraged her to always have faith in herself and become successful. She understood the importance of education because she herself did not get such opportunities. If she were alive today, she would have been extremely proud watching me fulfilling my dreams.

Thank you, Nani for being the person you were. You were possibly the first feminist in our family. You supported Mummy to become the person she is and thus, paved a path full of opportunities for me. You are and always will be in my thoughts.

Acknowledgement

“मैं अकेला ही चला था जानिब-ए-मंज़िल मगर , लोग साथ आते गए और कारवाँ बनता गया”

\- मजरूह सुल्तानपुरी

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The prefect bridge from academic to personal acknowledgements would be the one person who has helped me through it all. Thank you, Imran! You have helped me with field work by capturing the beautiful photographs, with analysis by writing the beautiful R code which made my work much easier, and through these five years by always being there for me. You were my first friend on campus and that bond is still strong.

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This person can be the most irritating and most lovable all at the same time. Thank you Puneeth for being you! I cannot put in words how much I adore you. The “Singhal-Deraje theorem” is one of the best memories I have with you!

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Having juniors has been one of the most fun part of college. Through them I have felt both old and a kid. I am glad to have been in a place where this divide is hardly visible. Thank you, Jennifer, Aiswarya, Nandu for the funniest conversations. Thank you Sonell, Nikhil and Samyak for some of the best memories, especially the backstage. Thank you Ardra and Ruchira for the warmest hugs. And thank you Saumya for the weirdest yet most endearing smile.

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Notation

BS: Breeding season

NBS: Non-breeding season

MWU: Mann-Whitney U test

P: Prefix

B: Body

PS: Pre-suffix

S: Suffix

Contents

Abstract

Birds are some of the most acoustically active animals on Earth. Many studies trying to understand and decipher their vocal communication have been published over the years. Song is one of the widely studied vocalisations by ornithologists. Attempts to understand the song began with informal field notes describing their attributes as perceived by human ear. With advancement in science, newer and more robust methods of quantification opened a plethora of questions that can be asked about the song. From an evolutionary perspective, many studies provide evidence that song functions as sexual display in many birds. This thesis attempts to explore the similar theme in a highly abundant species of sunbird in the Indian subcontinent, the Purple sunbird (*Cinnyris asiaticus*). It is a small passerine with a characteristic long-curved bill. Very few studies have tried to explore the structural aspects of the song in this species. This thesis looks at both note structure and phrase structure of the song in both breeding and non-breeding season. Such a comparative account has provided evidence in the changes that occur between the seasons highlighting season specific characters. Many birds are known to utilise multimodal sexual displays. Thus, to identify any such behaviour in this species, a behavioural study was also conducted in the non-breeding season. An overall time-activity budget analysis showed that the bird displaces from one position to another the most, which agrees with the dynamic nature of this bird. It was found that the male is usually stationary during the song bout and performs body movements at the perching position. On comparing this data with a similar study in breeding season can yield more insight into whether visual mode aids in sexual display in this sunbird species.

Chapter 1: Introduction

Animal communication is defined as the mutually beneficial production of a signal by a signaller resulting in a behavioural change in a receiver (Alcock, 2010). The signalling takes place through the environment.

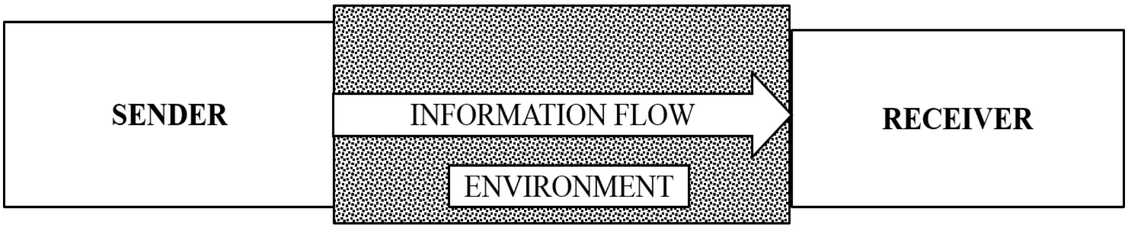


Fig 1.1: Pictorial representation of animal signalling

There are four modes of communication: visual, acoustic, olfactory, and tactile, each utilising a different sensory organ. Signals can either be transmitted through one mode (unimodal) or multiple modes (multimodal).

Acoustic is one of the most common modes of communication in the animal kingdom. This mode of communication incurs many benefits which are summarised below:

	Acoustic	*Visual*	*Chemical*	*Tactile*
Nocturnal use	Good	Poor	Good	Good
Around objects	Good	Poor	Good	Poor
Range	Long	Medium	Long	Short
Rate of change	Fast	Fast	Slow	Fast
Locatability	Medium	Good	Poor	Good
Energetic cost	Low	Low	Low	Low

Modified from Alcock 1989.

Fig 1.2: Four modes of communication in animals with their pros and cons (adopted from C. Cathchpole & Slater, 2008).

Birds are some of the most acoustically active animals. The vocalisations of birds are categorized as songs and calls. A general definition of the song is "long, spontaneous, complex vocalisations produced by males in breeding season" (C. Catchpole & Slater, 2008). This definition is modified according to the characteristics of the study species. Song bouts have been also been observed in non-breeding season in some birds (Song sparrow: Voigt, Leitner, & Gahr, 2001). Females are known to sing as well in some species (Garamszegi, Pavlova, Eens, & Møller, 2007; Langmore, 1998; Ota, Gahr, & Soma, 2015). Calls are "shorter, less spontaneous, simpler vocalisations produced by both sexes throughout the year" (C. Catchpole & Slater, 2008). An important difference, which is widely accepted is that calls have a behavioural, and often a social context. For instance, flight calls are made by individuals while flying, often to keep the flock together (Sibley, Elphick, & Dunning, 2009).

The song can be simple or complex. The complexity in song can arise in song output, song repertoire size, and element repertoire size. Studies have shown that individuals vary their song output and other parameters with respect to their pairing success (Hennin, Barker, Bradley, & Mennill, 2009). Some species show a single song type and others might show multiple song types (C. Catchpole & Slater, 2008). Studies in male chaffinch have shown that their song is made up of most basic unit called an element or note. These elements combine in sections to form phrases (C. Catchpole & Slater, 2008). Sometimes elements can overlap (or occur in very short time intervals) to form syllables, which may become the basic unit of the song (C. K. Catchpole, 1976). Variation in element/syllable repertoire has been reported (Harris & Lemon, 1972).

Song is hypothesised to play a role in sexual selection in many species. It is believed that song acts as an honest signal of fitness (Read & Weary, 1990). Also, different song traits provide information about different characteristics of the sender, including age and survival (Rivera-Gutierrez, Pinxten, & Eens, 2010). There are two main pathways in which sexual selection operates in song evolution; male- male competition (intra-sexual selection) or female choice (inter-sexual selection) (C. K. Catchpole, 1987). Hence, the song can be used for mate attraction and/or male competition. Female cowbirds, *Molothrus ater* (West, King, & Eastzer, 1981) responded to playbacks of male songs by displaying their readiness to mate, hence giving evidence that mate attraction can be the purpose of the song display. Female response is heightened by more song rate (Radesäter, Jakobsson, Andbjer, Bylin, & Nyström, 1987; Wasserman & Cigliano, 1991). Increase in number of song types can elicit more response from females depending on the species (Searcy & Marler, 2010). Other than song rate, repertoire size also shows positive correlation with pairing success (Howard, 1974). Females are also known to distinguish conspecific song from others (Searcy, Marler, & Peters, 1981) and prefer larger song repertoire (Searcy, 1984). Females canaries are known to be attracted to certain phrases more than the others (Vallet & Kreutzer, 1995). Female choice hence plays a role in the evolution of the song. Male songs also play a role in territorial defence from rival males, i.e the Beau-Geste hypothesis which states that new males move away from territories having males with higher repertoire because it seems like the location is already crowded (Alatalo, Lundberg, & Björklund, 1982; Krebs, Kacelnik, & Taylor, 1978). Variation in song at an individual level provides information about the competitive ability of a male (Cate, Slabbekoorn, & Ballintijn, 2002). A large song repertoire size leads to more female response (Searcy & Marler, 2010) and holding resourceful territories for longer periods (Hiebert, Stoddard, & Arcese, 1989), both possibly leading to more reproductive success.

Since song is associated with sexual selection, it is likely to vary depending on the breeding physiology of the organism. Seasonal variation on song production has been studied greatly. Some species, especially in tropics are continuous breeders, and hence song can be heard all year long (Stutchbury & Morton, 2008). In some seasonal breeders, song output increases rapidly just before clutches are laid (C. K. Catchpole, 1973) and reduces gradually towards the end of breeding season. On the other hand, in other seasonal breeders, song can be heard in non-breeding season as well, but the song properties amongst the two seasons may differ. In Island canary, song length and structure varies between seasons (Voigt et al., 2001). Nuttall's white crowned sparrow shows variation in length and complexity of its song in different seasons (Brenowitz, Baptista, Lent, & Wingfield, 1998). Breeding season songs contain more attractive elements, and temporal variations is seen across seasons (Voigt & Leitner, 2008). In Pied flycatcher, the song becomes less frequent, shorter with lower repertoire size once the male is paired, hence showing variation within the breeding cycle itself (Espmark & Lampe, 1993). At a physiological level, song production has shown to depend on levels of testosterone in the males, which increases during breeding season (Rost, 1990).

Thus, song makes an important component of reproductive fitness in songbirds. But these sexual displays to attract a mate can be multimodal. This helps in enhancing the female sexual response (O'Loghlen & Rothstein, 2010). Females are also known to eavesdrop on multiple male-male interactions including song display and aggression to choose a mate (Amy et al., 2008). Blue capped cordon bleu uses visual, acoustic and tactile modes in its sexual display (Ota et al., 2015). Male superb lyrebirds vocalise four different song type and each is accompanied by a different set of dance movements (Dalziell et al., 2013).

The order Passeriformes is known to have the most developed song. Purple sunbird (*Cinnyris asiaticus*) is a passerine bird species which is resident in the Indian subcontinent. It is the most commonly reported sunbird species in Northern India (Grimmett, Inskipp, & Inskipp, 2011a). It is about 10 cm long with a characteristic long bill. The breeding season is noted from the months of March-June in areas of Northern India (Ali & Ripley, 2001). (But the breeding plumage has been observed till August in the study area for this thesis).The breeding plumage of the male is metallic dark blue and purple. The belly is dark purple separated from the breast by an inconspicuous reddish-brown band. The pectoral tufts are bright yellow and scarlet (Ali & Ripley, 2001). The pigmentation and structure of these feathers have been studied via microscopy and diffraction (Mahapatra, Marathe, Meyer-Rochow, & Mishra, 2016). In the non-breeding season, the males adorn an eclipsed plumage with pale olive-brown back and a characteristic broad blue-black band runs down the middle of throat and breast. The females are olive-brown with a dull yellow breast, throughout the year (Ali & Ripley, 2001). Its bill and tongue are adapted to feeding on nectar, as it forms majority of the diet (Ghadirian, Qashqaei, Dadras, & Abbas, 2008). It can be seen on many flowering trees, like *Madhuca indica*, Borassus palms and loranthus clumps. It also catches insects and small spiders specially to feed the young. Some examples of insects used as food are Tinied and Geometridae larvae, weevils (*Myllocerus* sp.), bugs (*Cydnus nigritus*), jassids and small flies (Ali & Ripley, 2001). Flycatching has also been noted in this species (Nair, 1994).

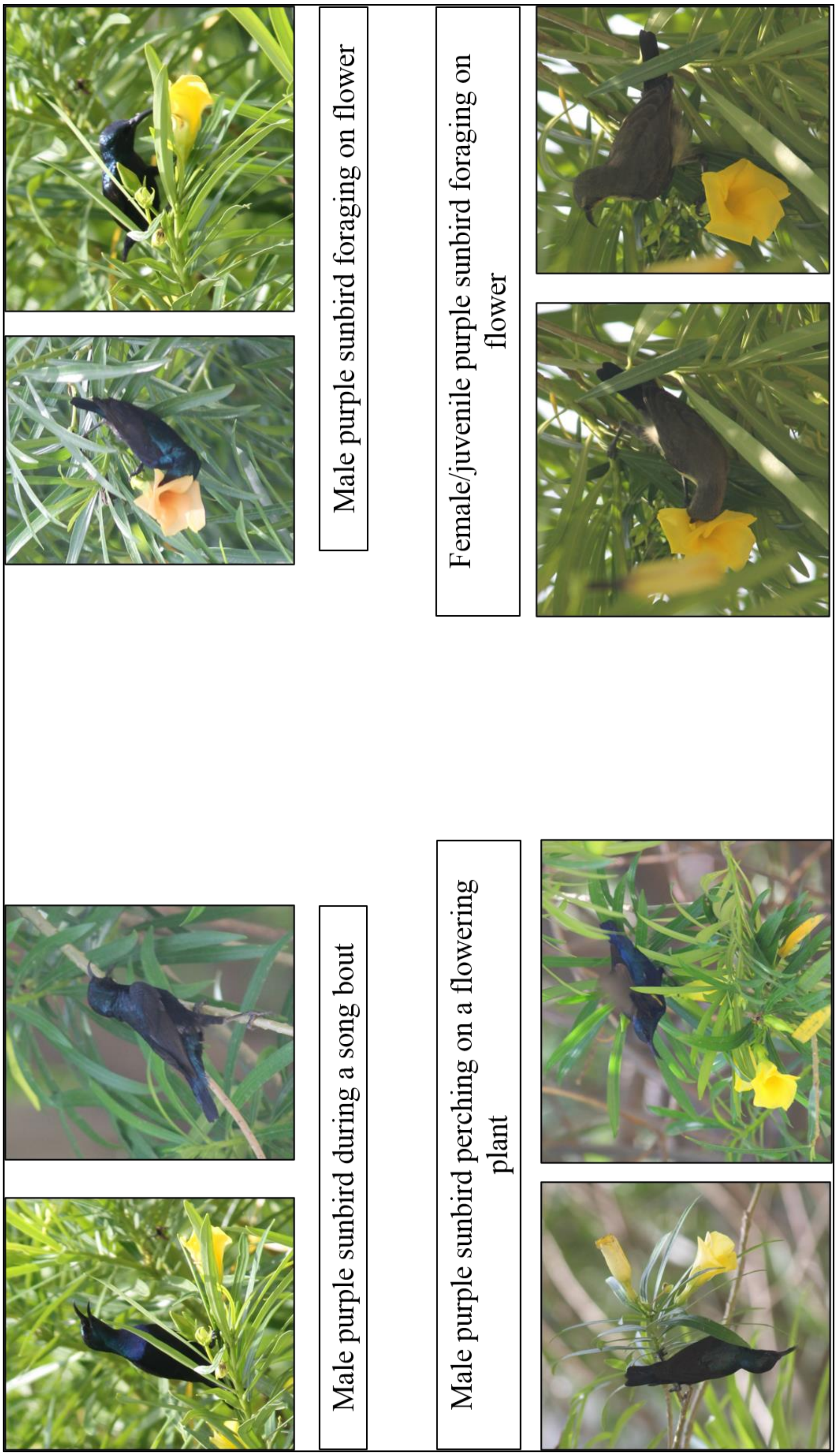
It has been seen that males in breeding season perch on a high open space and utter a “cheewit cheewit” rapidly two to six times, while pivoting side to side and raising and lowering its wings, to displays its pectoral tufts which are erected laterally. In non-breeding season it utters a low twittering, continuous song without any pause (Ali & Ripley, 2001). A previous study in our lab has shown that the sunbird song in the early-middle breeding season is made up of 27 defined phrases which are composed of a set of 24 notes. The phrases have a well-defined structure with a prefix, body and suffix (Chorol & Jain, unpublished 2019) This species also shows vocal adjustments in the song in response to background noise levels by modifying its amplitude to overcome the masking (Lombard effect) (Singh, Jaiswal, Ulman, & Kumar, 2019).

Females contribute to nest building significantly higher than males which takes from about six days to three weeks to build (Ali & Ripley, 2001). The nest is oval-shaped, the materials (dry leaves and grass, paper, wires, narrow pipes) and construction time of which can vary significantly in rural and urban settings (Mazumdar & Kumar, 2014). Incubation is only performed by the female for 14 or 15 days. Nesting period is of 13 to 17 days where nestlings are fed and attended to by both parents (Ali & Ripley, 2001).

Very few evidence-based studies have been conducted on this widespread species. Most accounts are field based observations. My work is an attempt to understand the male song in this species, quantify it and study the structural variations over breeding and non-breeding seasons. A structural comparison could highlight parts that may indicate sexual attractiveness (Hill, Amiot, Ludbrook, & Ji, 2015; Howard, 1974; Searcy, 1984). This study also gives a glimpse of other behaviours that are portrayed by the species in non-breeding season. Comparing this behaviour study with a subsequent one in breeding season can highlight presence of a visual sexual display.

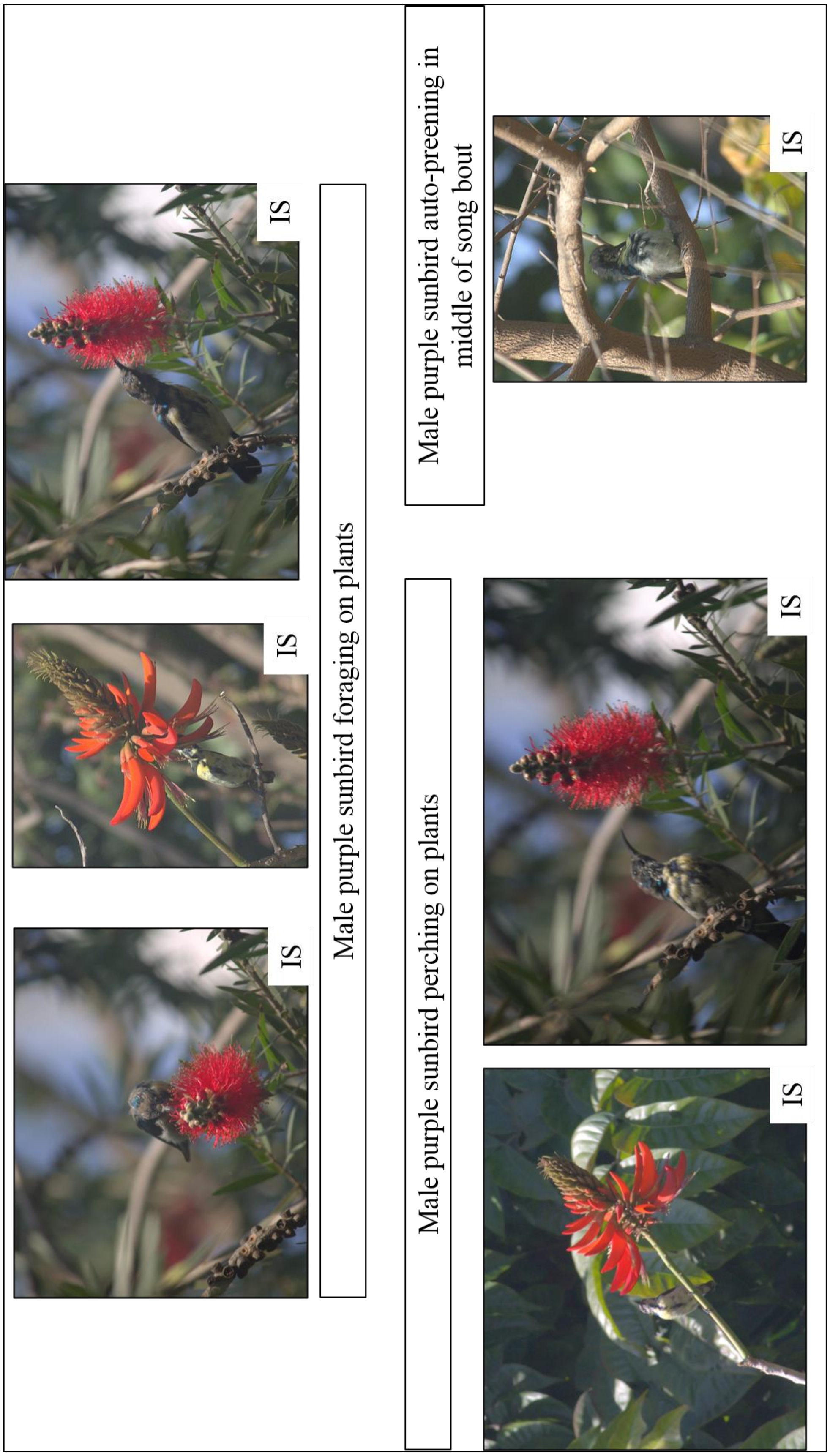
Thus, the objectives of this study are:

1. To study song diversity of Purple Sunbird in breeding season by characterising note diversity and phrase diversity.
2. To study song diversity of Purple Sunbird in non-breeding season by characterising note diversity and phrase diversity.
3. To compare song diversity of Purple Sunbird in breeding and non-breeding season by characterising note diversity variation and phrase diversity variation.
4. To study temporal variation in various behaviour of Purple sunbird in non-breeding season



P1: Purple sunbird (male and female/juvenile) during breeding season showing various behaviours

P2: Male purple sunbird showing change in plumage colour from breeding to non-breeding season (Picture credits-IS: Imran Sayyed)



P3: Male purple sunbird in non-breeding season showing various behaviours (Picture credits-IS: Imran Sayyed)

Chapter 2

2.1 Objective

To study song diversity of Purple Sunbird in breeding season by characterising note diversity and phrase diversity.

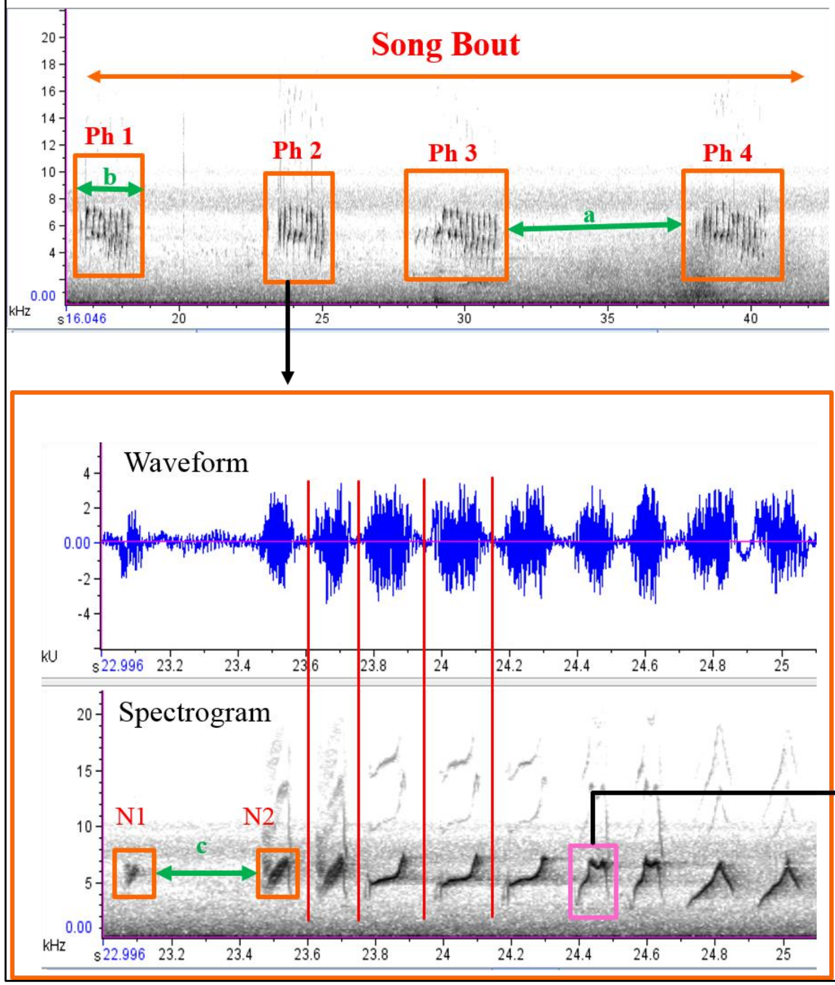
2.2 Methodology

2.2.1 Sampling location and acoustic recordings

Recordings were made opportunistically during the day from various locations on the IISER Mohali campus (30.6650° N, 76.7300° E, Punjab) from June to August 2019. A solid-state recorder (Marantz pmd 661 *MK II*, frequency response: 20 Hz-24 kHz) attached to a directional shotgun microphone (Sennheiser K6 frequency response: 40 Hz-20 kHz) with a foam windshield was used to make focal male recording of the song bout (sampling rate: 44100 Hz and 16-bit rate). The place, date, and time of the bout were said into microphone at the end of the recording. All recordings were tagged, and clean recordings were selected for further analysis. Sampling used were from June 2019 to July 2019.

2.2.2 Data Analyses

Around 1.3 hours of data was analysed comprising of 5453 note instances and 445 phrase instances. The recordings were annotated for various note types in sound analysing software, (Raven Pro 1.5, developed by Cornell Laboratory of Ornithology, Ithaca, New



The following schematic represents a song bout in Purple sunbird (*Cinnyris asiaticus*). A single song bout is made up of multiple phrases (eg: Ph1,Ph2). These phrases are separated by some time-interval called the inter-phrase duration. Each phrase is made up of a collection of notes (eg: N1, N2). When visualised as a spectrogram (frequency vs time, value or intensity indicates energy of note), many structural characters can be seen as compared to the corresponding waveform (energy vs time). The notes are separated by a time interval called inter-note duration. Various note parameters are studied to quantify their structure. Spectral characters which depend on frequency are based on energy integrals (in Raven Pro 1.5).

a: Inter-phrase duration; b=Phrase duration; c: Inter-note duration; d:Note duration

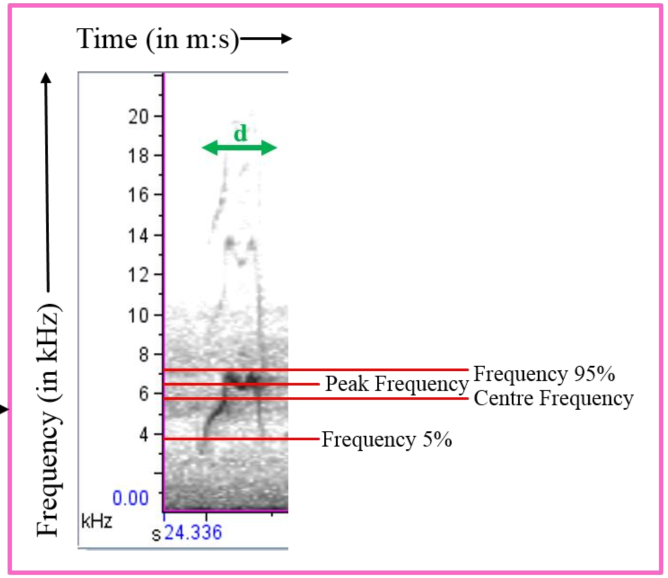


Fig 2.1(a) Structural description of male song in Purple sunbird

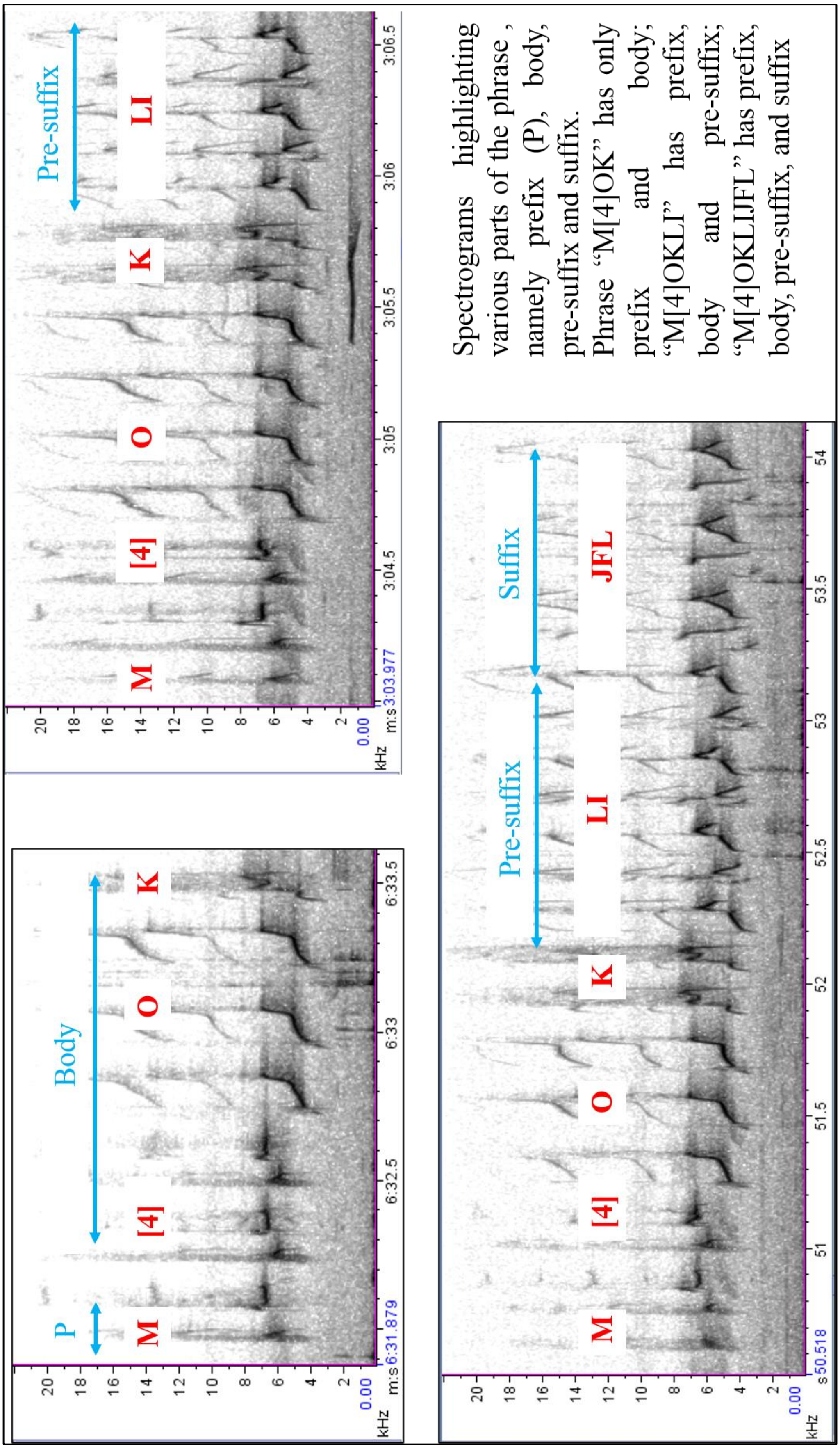


Fig 2.1(b) Structural description of male song in Purple sunbird

York, USA) based on audio-visual analysis. The spectro-temporal characters of fundamental frequency were also used for analysis (spectral: Frequency 5% (Hz), Frequency 95% (Hz), Bandwidth 90% (Hz), Peak Frequency (Hz), Centre Frequency (Hz); temporal: note duration (s)) (adopted from Chorol & Jain, 2019 unpublished). Notes with n>=5 were considered for analysis.

Notes occurring together in a short time frame (inter-phrase vs intra-phrase duration) were considered as a phrase. Naming of phrases was based on combinations of notes and their ordering pattern.

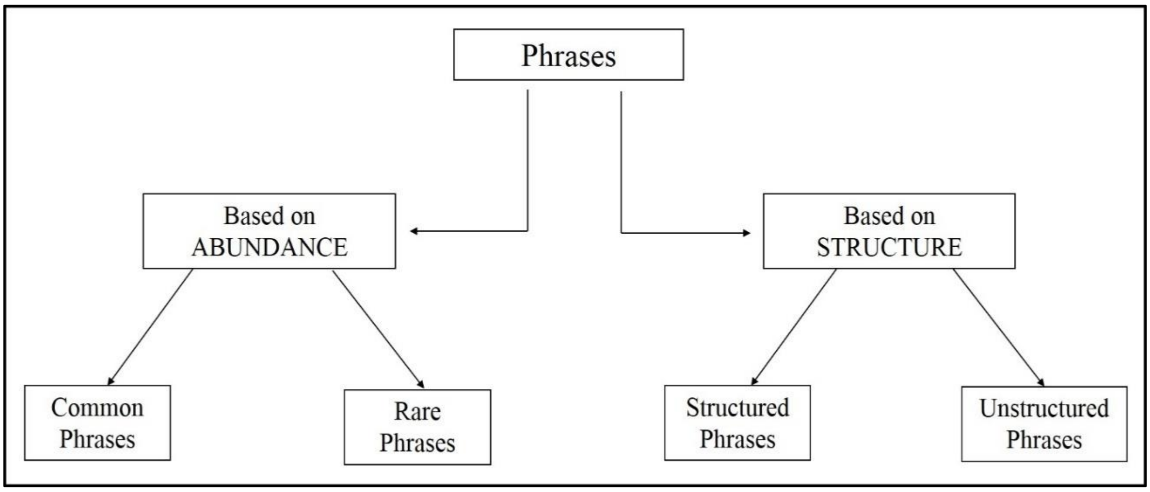


Fig 2.2: Classification of phrases based on "Abundance" and "Structure"

For analysis, the phrases have been classified based on two characters: Abundance and Structure (Fig 2.2). Abundance is the number of repetitions that are observed for each phrase: common phrases have n>=3 and rare phrases have n<3. Structure is the presence and organisation of various parts of the phrases. Structured phrases have well-defined parts (eg: prefix, body, suffix). This includes presence of other phrases that are devoid of those parts. This comparison helps ascertain presence/absence of these parts. Unstructured phrases lack such a comparison.

An overall abundance graph highlighting the common phrases has been plotted. The prefix graph shows the abundance of prefix in all phrases. "M" acts as the prefix in the breeding season (Chorol & Jain, 2019 unpublished). Phrases that start with a "M" note have been considered as "With prefix". Intra-phrase duration is the entire length of the phrase, whereas inter-phrase duration is the distance between simultaneous phrases. Some phrase pairs have shown a specific pair of notes present between the body and suffix. This has been termed as pre-suffix (PS). Phrases have been observed without PS and S, with just PS, with just S, and with both PS and S. For the suffix and pre-suffix graphs, only structured phrases have been considered. Some phrases show sudden appearance of certain notes. Since the sample size of each is very small, the word 'sudden' is used. These are termed as erratic parts. They are mostly seen in unstructured phrases. They are classified into three categories: trill parts, extended body and incomplete suffix. Trill parts occur in short series, anywhere in the phrase, giving a trilling sound. Very rarely the trill notes are present independent of one another. Extended body includes notes after PS or S or between S. Incomplete suffix arises when the most common suffices are incompletely represented in the phrases. The graphs of erratic parts have been plotted in unstructured and rare phrases. Inter-note duration graphs have been plotted for both structured and all phrases (which includes unstructured phrases). For the latter, already identified suffix is treated as such. Inter-note duration means the time-interval between two consecutive notes in a phrase. For P, B and E parts, inter-note duration of all notes is plotted. For S, inter-note duration between certain notes is plotted, to highlight a possible mini breath (as seen in Chorol & Jain, 2019 unpublished). Similar method is used for PS. All trill notes are considered together as "Tr" due to their tendency to occur together and combine to give a trilling sound.

2.2.3 Statistical Analyses

Statistical tests were run in Statistica version 10. Test for normality (Kolomogorov-Smirnov and Lilliefors test, Shapiro-Wilk test) showed that the dataset for the notes was not normal and hence non-parametric tests were employed. Kruskal-Wallis ANOVA showed significant differences (alpha=0.05) between various parameters of different note types. Hence, a post-hoc Mann-Whitney test was run. To negate the effect of sample sizes on the Mann-Whitney U test, bootstrapped iterations (DiCiccio & Efron, 1996; Efron & Tibshirani, 1993) were performed on the test for various parameters in R (MWU-i test, Fig A 3.1). The bootstrapping was designed in such that for a given pair of notes with unequal sample sizes (say $n1<n2$), the iterations were performed by randomly choosing data points from the note set with larger sample size (making $n1=n2'$). MWU test (alpha=0.05) was then performed on these two sets of notes, for each parametr. The algorithm performed 1000 such test iterations for each parameter of all note combinations. To consider significant difference between notes, for a given parameter, at least 800 out of 1000 cases (i.e 80%) had to show a significant p-value (alpha=0.05). A hierarchy of parameters have been chosen to represent the statistically different notes. More weightage is given to

spectral parameters due to the robustness of their measurement in the Raven Pro 1.5 program.

Statistical tests were run for inter-phrase duration vs intra-phrase duration and inter-note duration (for structured and all) phrases. Test for normality (Kolomogorov-Smirnov and Lilliefors test, Shapiro-Wilk test) showed that the data was not normal and hence non-parametric tests were employed. Kruskal-Wallis ANOVA (for inter-note duration) showed significant (alpha=0.05) differences. Hence, a post-hoc Mann-Whitney test was run (alpha=0.05).

2.3 Results

Based on aural-visual analysis, a total of 29 distinct notes (Fig A 3.2) have been found in the song of the purple sunbird in breeding season. Majority of these notes are significantly different at least by one parameter, based on the post hoc analysis (MWU-i test; $p<0.05$ for at least 80% cases, Fig 2.4). The mean values of all spectral and temporal parameters are given in table 2.1. From abundance plot (Fig 2.3), it was seen that note type "L" is most common note followed by A, whereas notes R, W, g52 are rare. Out of the 29, 10 notes show spectro-temporally different morphs (Table 2.2, Fig A 3.2).

S.No.	Note Type	Sample Size		Duration (s)	Freq. 5% (Hz)	Freq. 95% (Hz)	BW 90% (Hz)	Peak Freq. (Hz)	Center Freq.(Hz)
1	A	659	Mean	0.159	4370.286	5587.915	1600.850	5036.477	4990.342
			Std.	0.027	711.519	542.448	486.615	320.674	218.401
2	B	89	Mean	0.144	5166.031	6893.537	1934.608	6867.561	6434.925
			Std.	0.019	1799.676	341.695	2122.369	351.461	857.477
3	Y	153	Mean	0.095	5155.580	7034.750	1879.174	6831.522	6470.103
			Std.	0.010	186.263	172.497	208.995	243.919	209.104
4	C	49	Mean	0.192	4871.605	6084.775	1213.166	5586.949	5544.610
			Std.	0.011	200.581	300.407	264.904	296.850	237.186
5	D	308	Mean	0.080	4863.704	6660.476	1912.269	6191.594	5928.115
			Std.	0.021	782.851	336.941	1105.197	508.768	461.972
6	E	270	Mean	0.151	4674.775	6627.449	2180.762	5900.551	5571.707
			Std.	0.011	940.807	477.817	1239.026	866.647	614.457
7	F	295	Mean	0.058	4940.223	6737.345	1976.390	6304.930	6293.835
			Std.	0.009	664.944	799.695	675.246	812.290	758.842
8	G	89	Mean	0.154	4735.366	6566.419	2229.787	5492.179	5350.884
			Std.	0.017	617.163	746.161	241.339	902.726	623.671
9	g1	17	Mean	0.105	6014.106	5573.300	2021.594	6601.829	6520.759
			Std.	0.017	786.032	1550.334	912.104	243.506	237.383
10	g39	12	Mean	0.099	6237.450	4880.858	2906.975	4780.358	4751.658
			Std.	0.011	1598.560	1181.194	577.360	612.906	120.882
11	g4	67	Mean	0.107	6362.600	6838.203	475.603	6516.138	6536.110
			Std.	0.014	138.500	197.757	184.272	152.680	133.386
12	g42	11	Mean	0.102	5919.664	5896.200	2262.945	6264.209	6256.391
			Std.	0.029	1540.859	938.314	422.117	877.610	484.602
13	g50	73	Mean	0.131	3581.133	6563.772	2982.614	5138.149	4959.259
			Std.	0.021	295.946	353.472	457.900	881.219	335.042
14	g52	6	Mean	0.144	3746.767	6646.583	2899.800	5397.667	5440.750
			Std.	0.009	235.908	100.700	193.894	117.684	138.002
15	H	312	Mean	0.152	4784.235	5598.078	906.056	5324.226	5246.374
			Std.	0.036	592.520	277.672	618.613	278.404	251.404
16	I	69	Mean	0.093	4477.616	4817.007	1375.563	4967.421	4924.996
			Std.	0.009	760.335	729.683	323.666	393.398	277.657
17	J	362	Mean	0.042	3284.217	4419.179	1282.479	3997.678	3898.783
			Std.	0.010	671.123	578.828	761.316	456.285	412.510
18	K	315	Mean	0.117	4636.950	6645.084	2573.867	6299.909	6207.617
			Std.	0.017	869.593	853.673	887.329	685.923	520.747
19	L	991	Mean	0.134	4079.873	6347.759	2700.454	5286.617	5049.648
			Std.	0.019	708.467	755.196	808.819	858.087	565.076
20	M	495	Mean	0.058	4951.156	6048.093	1246.061	5782.452	5657.153
			Std.	0.011	861.323	342.884	978.918	316.873	331.004
21	O	308	Mean	0.143	4363.684	6576.863	2501.495	5255.331	5027.089
			Std.	0.012	766.285	612.392	1167.561	619.200	371.220
22	Q	110	Mean	0.102	4352.834	6547.668	2355.343	5899.130	5576.383
			Std.	0.009	860.114	521.124	1201.810	645.107	633.625
23	R	9	Mean	0.128	4392.767	6421.678	2028.922	5512.489	5368.944
			Std.	0.016	311.885	839.143	568.613	546.256	391.564
24	S	158	Mean	0.137	4360.056	6710.185	2350.117	5492.873	5471.615
			Std.	0.013	263.129	233.073	441.445	817.358	544.033
25	T	24	Mean	0.133	4367.642	6241.038	1873.396	4931.096	4959.813
			Std.	0.007	214.729	404.791	382.035	220.337	147.919
26	Tr	82	Mean	0.051	3773.784	6365.909	2592.105	4903.864	4924.599
			Std.	0.008	442.320	635.550	563.564	636.039	563.584
27	V	27	Mean	0.159	3547.385	7177.744	3630.326	5502.926	5362.567
			Std.	0.028	281.686	393.272	421.758	1218.877	832.562
28	W	9	Mean	0.138	4919.133	6345.133	1732.222	5732.611	6077.156
			Std.	0.006	474.590	610.577	249.073	836.317	546.646
29	Z	64	Mean	0.064	4471.414	7167.758	3474.041	7213.723	6525.981
			Std.	0.006	1397.586	681.714	2236.122	845.625	893.057

Table 2.1 Mean and std. values of various parameters of different notes in breeding season

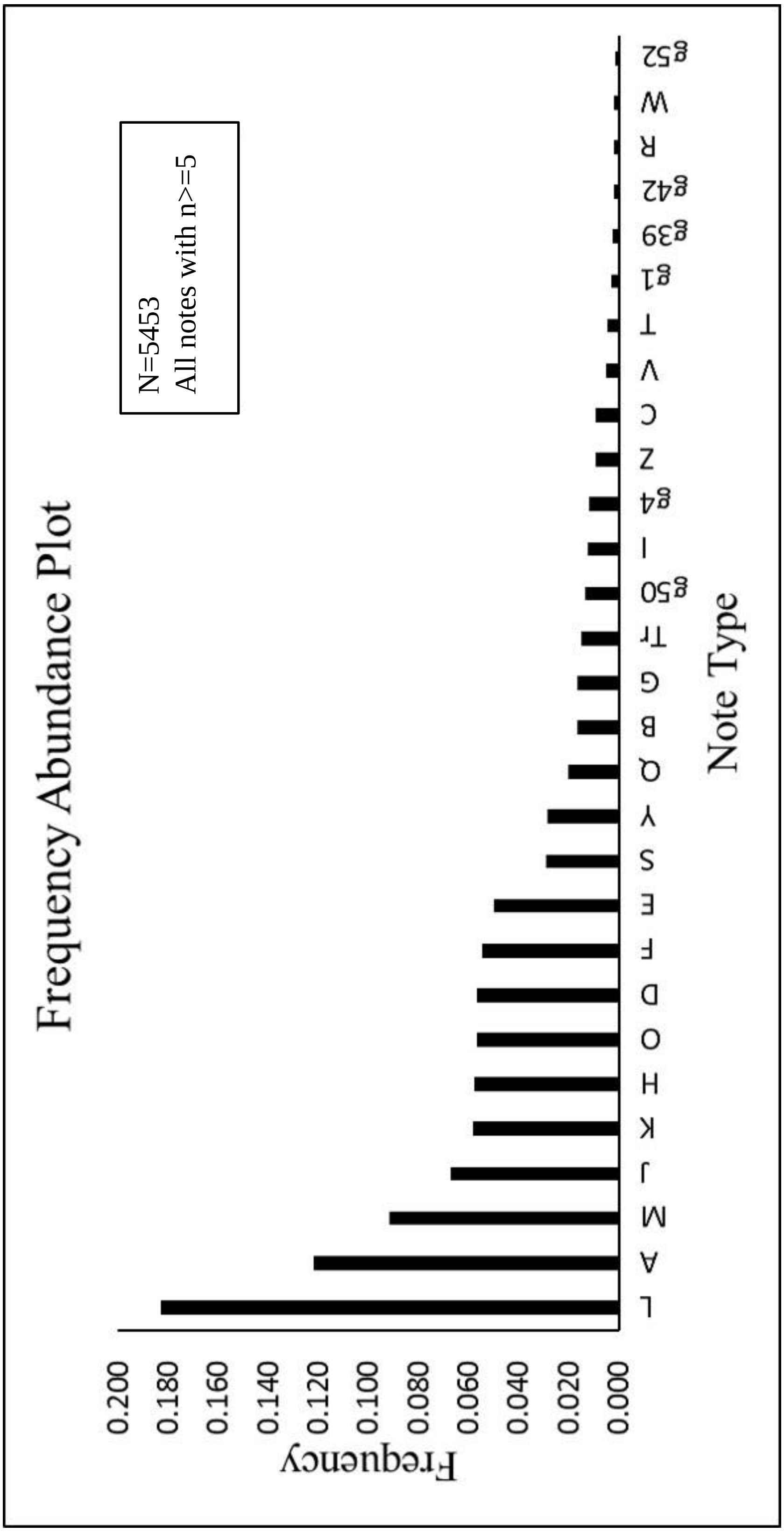


Fig 2.3: Graph depicting abundance of various note types (n>=5) in breeding season

Note	Morph	Sample Size		Duration (s)	Freq. 5% (Hz)	Freq. 95% (Hz)	BW 90% (Hz)	Peak Freq. (Hz)	Center Freq. (Hz)
D	D	292	Mean	0.079	4840.542	6654.355	1935.637	6193.112	5918.147
			Std.	0.021	796.372	342.074	1129.740	519.591	471.802
	D2	16	Mean	0.095	5286.394	6772.188	1485.800	6163.894	6110.044
			Std.	0.009	196.104	198.602	184.735	243.543	111.053
F	F	148	Mean	0.060	5250.026	6992.480	2042.749	6675.887	6650.863
			Std.	0.008	655.613	732.317	642.363	545.818	464.065
	F10	33	Mean	0.054	4537.168	5788.632	1251.468	5233.832	5190.762
			Std.	0.009	451.672	586.407	419.420	481.226	443.940
	F2	73	Mean	0.056	4659.425	7012.162	2468.360	6653.475	6662.912
			Std.	0.007	572.636	502.210	492.122	472.161	312.002
	F9	41	Mean	0.053	4636.456	6115.437	1478.976	5239.393	5268.812
			Std.	0.011	442.932	672.177	327.929	542.336	522.830
T	g6	13	Mean	0.131	4220.500	6141.915	1921.423	4889.692	4902.946
			Std.	0.007	111.187	336.147	380.956	263.509	151.085
	T	11	Mean	0.136	4541.536	6358.182	1816.636	4980.027	5027.018
			Std.	0.004	172.644	461.959	393.689	153.214	117.301
J	J	243	Mean	0.041	3193.635	4175.487	1201.609	3888.559	3760.729
			Std.	0.011	785.434	521.129	902.539	474.631	395.624
	J2	119	Mean	0.043	3469.187	4916.803	1447.617	4220.500	4180.690
			Std.	0.006	247.697	309.868	248.288	316.771	283.195
K	K	266	Mean	0.112	4678.268	6625.134	2614.307	6275.973	6188.380
			Std.	0.013	930.136	925.067	950.791	722.063	550.349
	K9	49	Mean	0.144	4408.582	6755.290	2346.682	6433.598	6315.827
			Std.	0.009	300.268	102.524	285.405	409.393	286.413
L	L	735	Mean	0.137	3951.555	6370.201	2753.675	5348.443	5076.042
			Std.	0.017	557.833	659.011	882.111	855.343	566.775
	L1	194	Mean	0.133	4581.463	6122.982	2384.202	5194.635	5033.936
			Std.	0.016	947.691	948.168	456.025	777.464	494.759
	L2	29	Mean	0.090	4279.897	7425.245	3145.328	5263.010	5224.400
			Std.	0.008	206.031	296.934	322.780	1047.436	544.393
	g7	33	Mean	0.103	3813.330	6222.448	2983.321	4471.073	4400.585
			Std.	0.010	961.140	892.789	334.853	753.165	543.210
Q	Q	83	Mean	0.103	4386.543	6346.855	2173.043	5958.486	5575.369
			Std.	0.010	985.720	428.967	1329.427	579.316	677.137
	Q1	27	Mean	0.098	4249.207	7164.981	2915.744	5716.667	5579.500
			Std.	0.006	149.190	183.556	221.144	800.256	486.859
S	S	151	Mean	0.137	4381.356	6697.826	2316.460	5494.816	5475.424
			Std.	0.013	240.076	223.883	407.905	804.402	520.567
	S1	7	Mean	0.141	3900.571	6976.771	3076.143	5450.957	5389.443
			Std.	0.027	336.222	285.652	544.109	1141.304	980.619
Tr	Tr1	22.000	Mean	0.053	4040.395	6115.445	2075.018	5332.400	5187.545
			Std.	0.009	500.764	356.629	527.564	549.864	549.236
	Tr2	27.000	Mean	0.049	3726.030	6156.896	2430.859	5059.511	5021.215
			Std.	0.010	407.948	789.911	560.401	637.256	634.223
	Tr3	33.000	Mean	0.050	3554.927	6825.385	3270.436	4319.682	4565.036
			Std.	0.008	418.249	760.111	602.728	720.996	507.293
g50	g50	59	Mean	0.131	3554.323	6582.441	3028.092	5170.655	4980.895
			Std.	0.014	199.649	344.473	456.344	906.754	338.870
	g51	14	Mean	0.128	3703.693	6478.429	2774.714	4989.550	4860.350
			Std.	0.042	553.069	394.246	419.484	765.537	309.105

Table 2.2: Abundance, mean and std. values of various parameters of the morphs of note types in breeding season

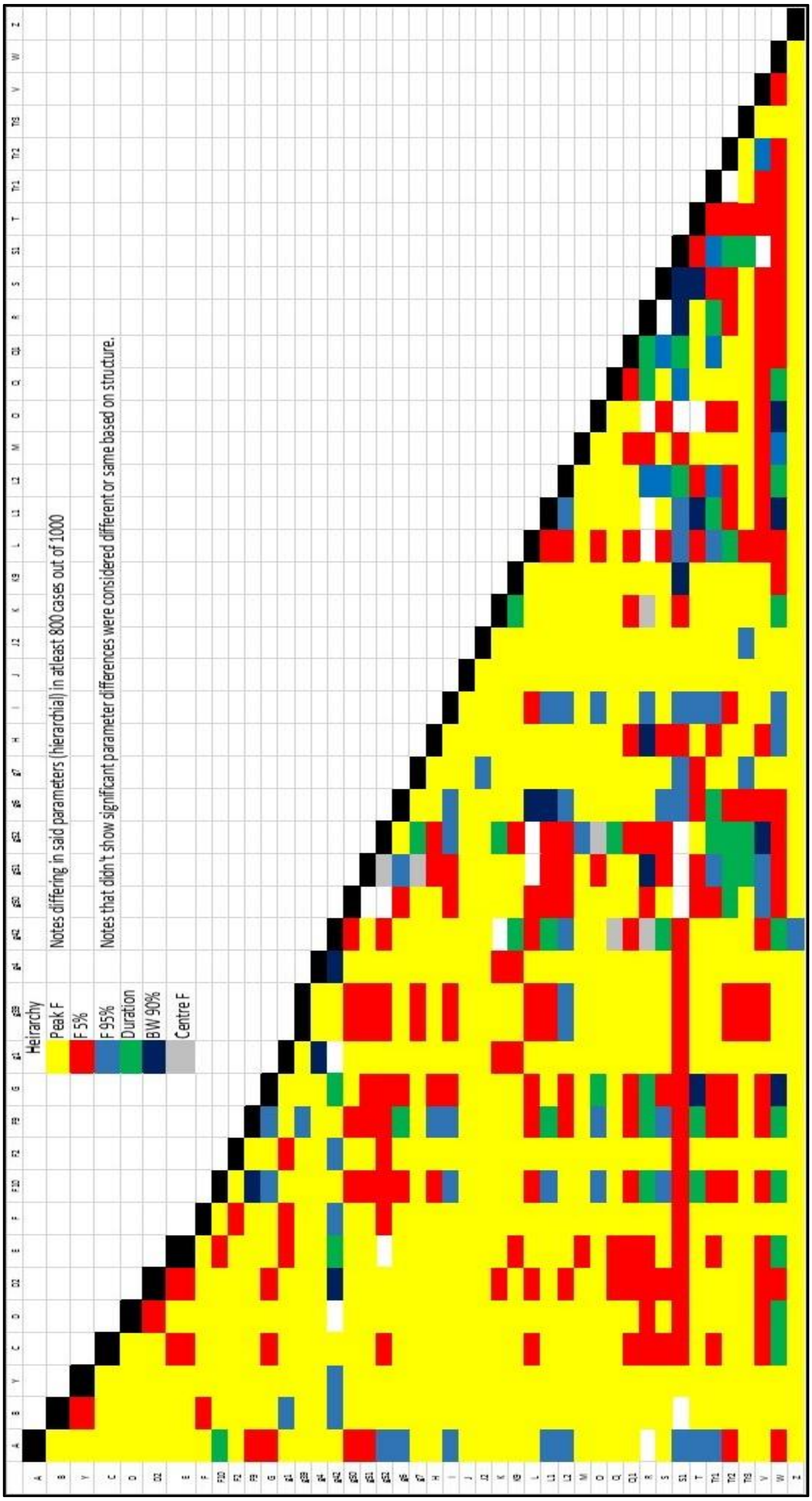


Fig 2.4: Hierarchical classification of notes showing significant result for MWU-i test in breeding season (Order of hierarchy is represented in figure)

A total of 117 different types of phrases were found in the song of the purple sunbird in breeding season. The abundance plot (Fig 2.5, Table A 1.1) showed that “MBEQL” is the most common phrase, followed by “HA”. There are multiple phrases with just one occurrence. Table (2.3) shows the mean values of various parameters for common phrases. There is a significant difference ($p<0.05$) between the inter-phrase duration and intra-phrase duration, with the latter being higher (Fig 2.6, Table A 2.1). Hence, most space in the song bout is empty. Prefix is present in more than half the total phrases (Fig 2.7). Suffix is present in one-fourth of the structured phrases (Fig 2.8, Table A 1.2), out of which “JFL” is the most abundant and “UN” the least (in agreement with Chorol and Jain, 2019 unpublished). “JZ” is a new suffix observed (Fig 2.9). Pre-suffix is a new part introduced which is present in around 15% of the structured phrases (Fig 2.10, Table A 1.3). Amongst the structured phrases, prefix lies the farthest away. Inter-note duration of pre-suffix (less than 40ms) lies mostly between body and suffix. The inter-note duration of suffix is least (less than 20ms) (Fig 2.11, Table A 2.2). Erratic parts are present in more than half of the rare and unstructured phrases (Fig 2.12, Table A 1.4), out of which “Extended Body” is most abundant (Fig 2.13). Amongst all phrases prefix still lies farthest. Erratic parts have an inter-note duration which lies between the inter-note duration for body and pre-suffix (Fig 2.14, Table A 2.3).

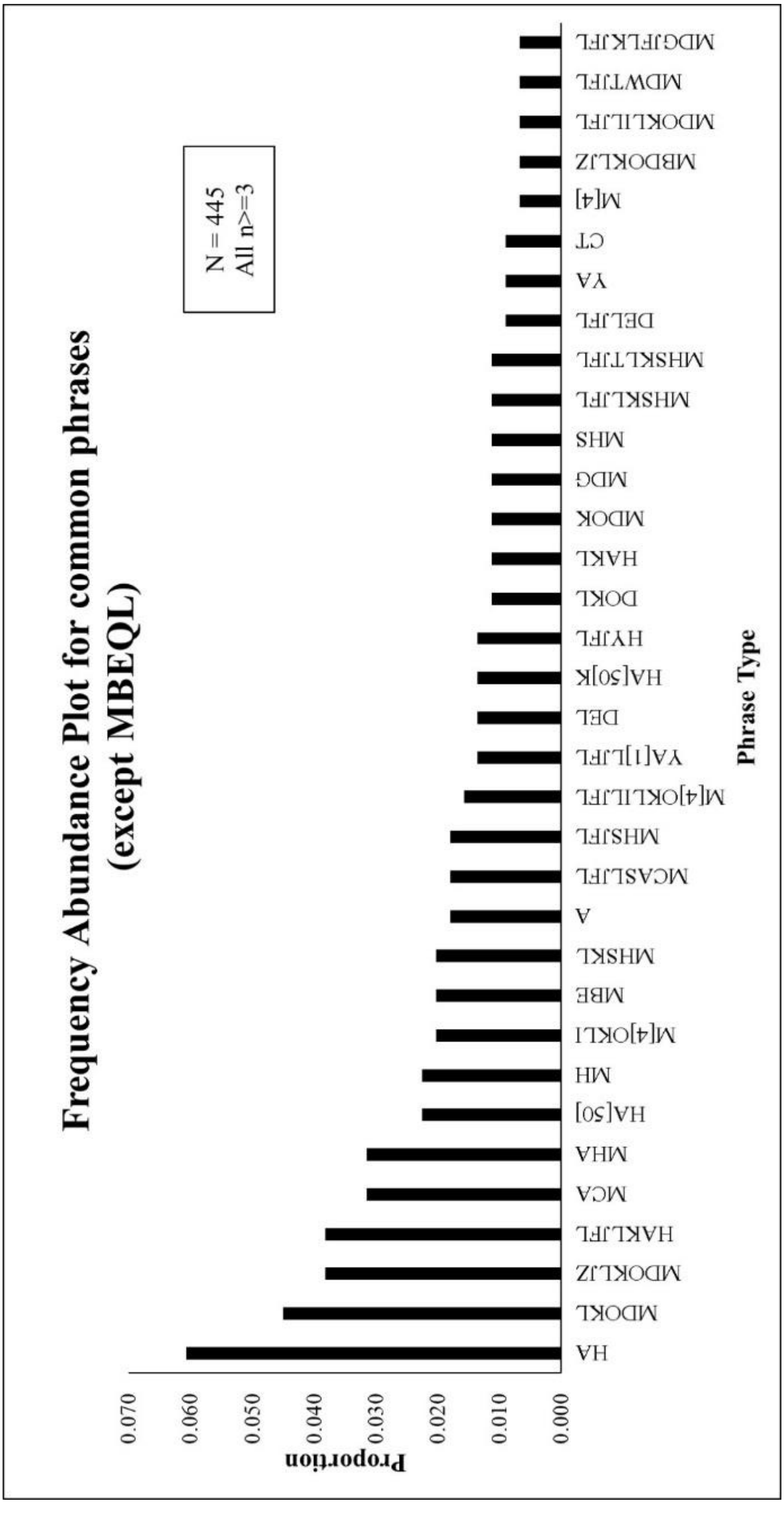


Fig 2.5: Graph depicting abundance of common phrases observed in breeding season (Table A 1.1)

S. No.	Phrase			Temporal Characters			Spectral Characters				
			Note number	Duration (s)	Internote duration (s)	Phrase duration (s)	Freq 5% (Hz)	Freq. 95% (Hz)	BW 90% (Hz)	Peak Freq. (Hz)	Centre Fre. (Hz)
1	MBEQL	Mean	10.38	0.13	0.07	2.01	4303.36	6469.08	2470.27	5799.45	5397.97
		Std.	1.62	0.03	0.03	0.34	1074.03	607.48	1436.06	928.93	820.94
2	HA	Mean	4.85	0.17	0.09	1.16	4401.31	5584.17	1322.25	5066.71	5014.77
		Std.	2.60	0.03	0.06	0.67	489.68	360.74	356.57	272.27	184.83
3	MDOKL	Mean	11.05	0.12	0.07	2.04	4407.97	6456.85	2433.16	5701.53	5564.34
		Std.	1.00	0.03	0.04	0.20	954.30	725.48	1437.12	687.96	494.35
4	MDOKLIZ	Mean	17.65	0.10	0.05	2.61	4159.35	6171.71	2345.98	5692.35	5346.10
		Std.	2.23	0.04	0.04	0.18	1175.32	1123.32	1571.91	1167.55	1105.30
5	HAKLIFL	Mean	15.75	0.12	0.06	2.67	4235.88	6026.91	1791.02	5225.73	5165.57
		Std.	1.98	0.05	0.03	0.27	572.71	874.32	583.40	903.63	832.23
6	MCA	Mean	4.86	0.16	0.10	1.14	4643.57	5701.23	1057.66	5351.63	5274.37
		Std.	1.10	0.06	0.03	0.29	326.29	342.04	179.11	295.35	267.08
7	MHA	Mean	7.86	0.16	0.08	1.85	4162.55	5518.77	1653.76	5189.89	5149.17
		Std.	2.21	0.05	0.05	0.59	998.15	533.61	1191.37	390.02	318.12
8	HA[50]	Mean	10.30	0.14	0.07	2.16	3972.14	6205.75	2233.60	5143.71	4978.14
		Std.	0.67	0.02	0.02	0.13	457.73	433.60	789.25	653.13	294.54
9	MH	Mean	2.20	0.09	0.43	0.71	4968.30	6138.92	1170.64	5684.77	5665.20
		Std.	1.40	0.04	0.88	0.97	295.26	503.78	299.15	491.58	413.44
10	M[4]OKLI	Mean	17.00	0.11	0.05	2.64	4884.80	6519.64	1634.84	5645.36	5616.65
		Std.	2.55	0.03	0.02	0.38	751.07	568.88	855.72	719.22	689.60
11	MBE	Mean	4.11	0.13	0.09	0.81	4413.72	6425.05	2372.15	6454.71	5619.01
		Std.	0.60	0.05	0.09	0.23	1590.60	588.22	1947.00	783.61	915.97
12	MHSKL	Mean	13.44	0.11	0.05	2.11	4510.48	6338.66	1828.17	5582.85	5538.34
		Std.	1.59	0.03	0.04	0.26	492.84	582.31	937.86	654.07	488.60
13	A	Mean	4.00	0.16	0.09	0.93	5329.47	4653.86	1606.93	4939.17	4982.24
		Std.	1.69	0.02	0.02	0.44	912.80	613.93	255.71	260.34	125.89
14	MCASLIFL	Mean	15.00	0.12	0.06	2.65	4343.37	6080.60	1737.23	5363.03	5357.97
		Std.	1.58	0.06	0.04	0.16	530.82	829.77	661.02	899.61	834.31
15	MHSIFL	Mean	14.38	0.10	0.05	2.08	4503.62	6162.61	1659.00	5320.01	5376.94
		Std.	3.38	0.04	0.02	0.37	683.83	831.68	684.63	961.26	898.61
16	M[4]OKLILIFL	Mean	19.86	0.10	0.04	2.71	4664.18	6329.22	1665.04	5479.65	5528.61
		Std.	3.18	0.04	0.02	0.41	839.78	898.20	822.40	961.46	885.68
17	YA[1]LIFL	Mean	19.67	0.11	0.06	3.14	4584.02	6179.67	1595.65	5616.88	5540.97
		Std.	2.42	0.04	0.03	0.32	616.31	702.21	320.06	993.16	887.66
18	DEL	Mean	7.83	0.14	0.06	1.49	4629.18	6652.40	2023.22	5607.80	5463.02
		Std.	1.47	0.03	0.02	0.29	330.42	188.54	279.31	711.47	354.11
19	HA[50]K	Mean	13.50	0.13	0.07	2.69	4064.18	6330.23	2266.04	5300.89	5223.27
		Std.	0.55	0.02	0.03	0.13	465.46	530.98	723.93	853.98	592.43
20	HYJFL	Mean	17.17	0.10	0.04	2.46	4682.64	6474.04	1791.41	5976.29	5735.29
		Std.	3.76	0.04	0.03	0.41	708.45	909.74	455.52	1077.90	918.84
21	DOKL	Mean	8.40	0.12	0.07	1.53	4329.20	6591.21	2549.12	6192.01	5316.23
		Std.	3.78	0.02	0.02	0.72	1010.22	504.49	1322.38	1026.88	964.56
22	HAKL	Mean	11.00	0.14	0.08	2.32	4283.14	6082.55	1799.40	5307.36	5224.35
		Std.	0.71	0.02	0.02	0.11	275.62	490.19	450.52	709.01	633.87
23	MDOK	Mean	7.50	0.11	0.08	1.29	4417.65	6484.85	2283.48	6025.29	5398.53
		Std.	2.59	0.03	0.04	0.36	1146.89	496.03	1477.05	873.22	785.22
24	MDG	Mean	7.60	0.09	0.06	1.07	4973.04	6586.90	1613.87	5721.03	5691.57
		Std.	3.85	0.04	0.03	0.61	295.45	301.54	415.11	611.89	450.64
25	MHS	Mean	5.80	0.12	0.06	1.01	4957.09	6079.79	1122.70	5542.21	5491.72
		Std.	1.30	0.03	0.02	0.26	275.85	474.86	687.71	484.66	343.49
26	MHSKLIFL	Mean	17.60	0.09	0.04	2.37	4343.82	5950.99	1607.17	5376.45	5280.53
		Std.	2.19	0.04	0.04	0.26	618.20	899.93	892.82	907.49	731.84
27	MHSKLTJFL	Mean	18.40	0.10	0.04	2.54	4436.77	6202.50	1765.73	5368.32	5359.89
		Std.	0.89	0.03	0.02	0.04	548.86	889.04	835.82	873.47	786.43
28	DELIFL	Mean	12.25	0.12	0.05	2.01	4463.08	6519.73	2056.65	5725.20	5468.55
		Std.	1.26	0.04	0.02	0.16	510.08	832.34	508.85	861.18	677.56
29	YA	Mean	8.50	0.11	0.07	1.47	4846.23	6510.62	1664.40	6242.10	5965.97
		Std.	2.38	0.02	0.02	0.53	382.45	601.30	285.06	820.77	667.63
30	CT	Mean	5.25	0.16	0.06	1.09	4831.63	6529.70	1698.06	5549.40	5533.00
		Std.	4.43	0.03	0.02	0.88	346.57	238.43	330.41	552.58	480.27
31	M[4]	Mean	6.67	0.08	0.18	1.58	5555.57	6438.44	882.87	6068.05	6059.45
		Std.	1.15	0.03	0.49	1.25	587.84	270.77	369.55	404.47	384.47
32	MBDOKLIZ	Mean	19.33	0.10	0.05	2.73	2595.87	5485.78	4660.09	6289.01	4637.28
		Std.	3.21	0.04	0.03	0.18	1511.82	1312.66	2137.74	1446.09	1372.02
33	MDOKLILIFL	Mean	20.00	0.09	0.04	36.61	4369.80	6195.83	1826.02	5591.46	5492.40
		Std.	1.00	0.04	0.02	58.96	720.79	1123.47	739.04	1122.18	1026.69
34	MDWTJFL	Mean	24.67	0.08	0.04	2.99	4465.92	6220.44	1754.52	5468.85	5516.04
		Std.	2.89	0.04	0.05	0.12	657.18	827.94	626.49	1056.68	978.01
35	MDGJFLKJFL	Mean	25.33	0.08	0.04	3.01	4366.70	6364.76	1998.06	5354.96	5268.84
		Std.	2.31	0.04	0.02	0.28	545.85	780.42	732.48	967.91	726.85

Table 2.3: Mean and std values of various parameters for common phrases in breeding season

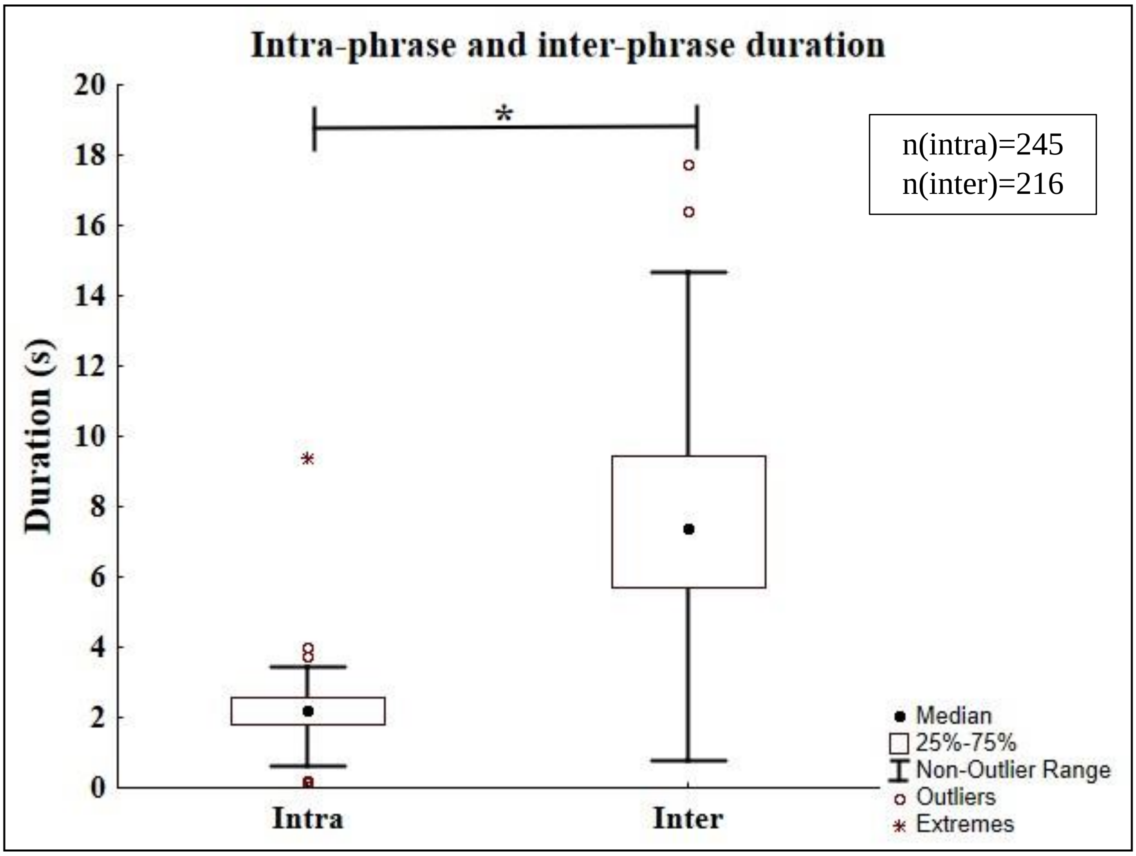


Fig 2.6: Graph depicting intra-phrase and inter-phrase duration in breeding season. Mann-Whitney U test showed significant difference between them ($p<0.05$). (Table A 2.1). * represents significant difference. Extreme outliers may be omitted.

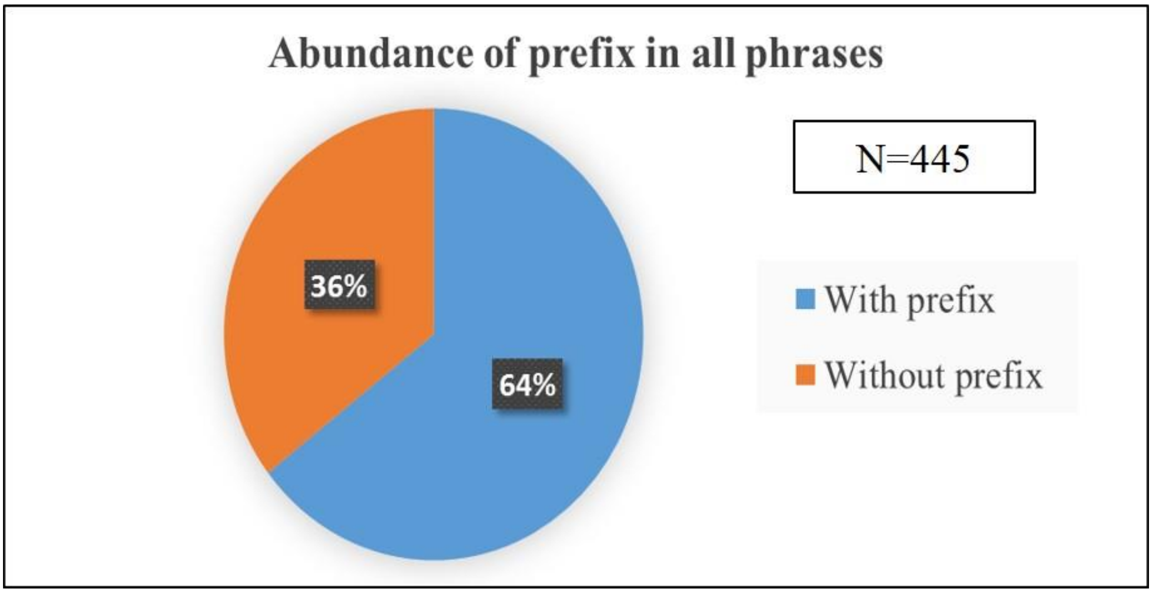


Fig 2.7: Pie-chart depicting abundance of prefix in all phrases in breeding season

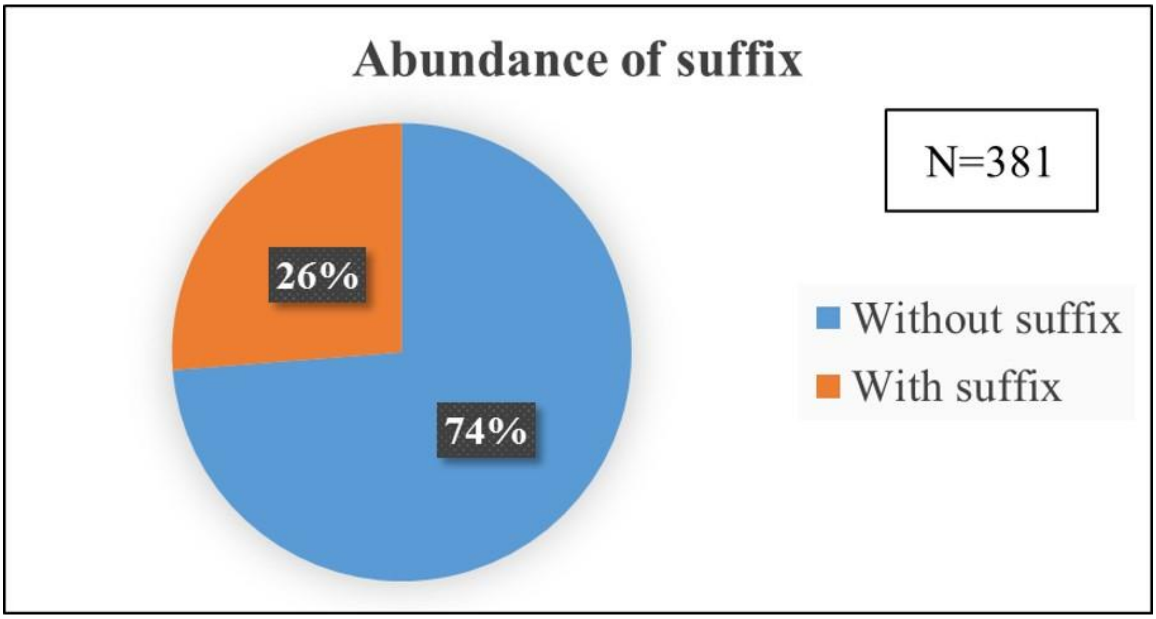


Fig 2.8: Pie-chart depicting abundance of suffix in structured phrases in breeding season (Table A 1.2)

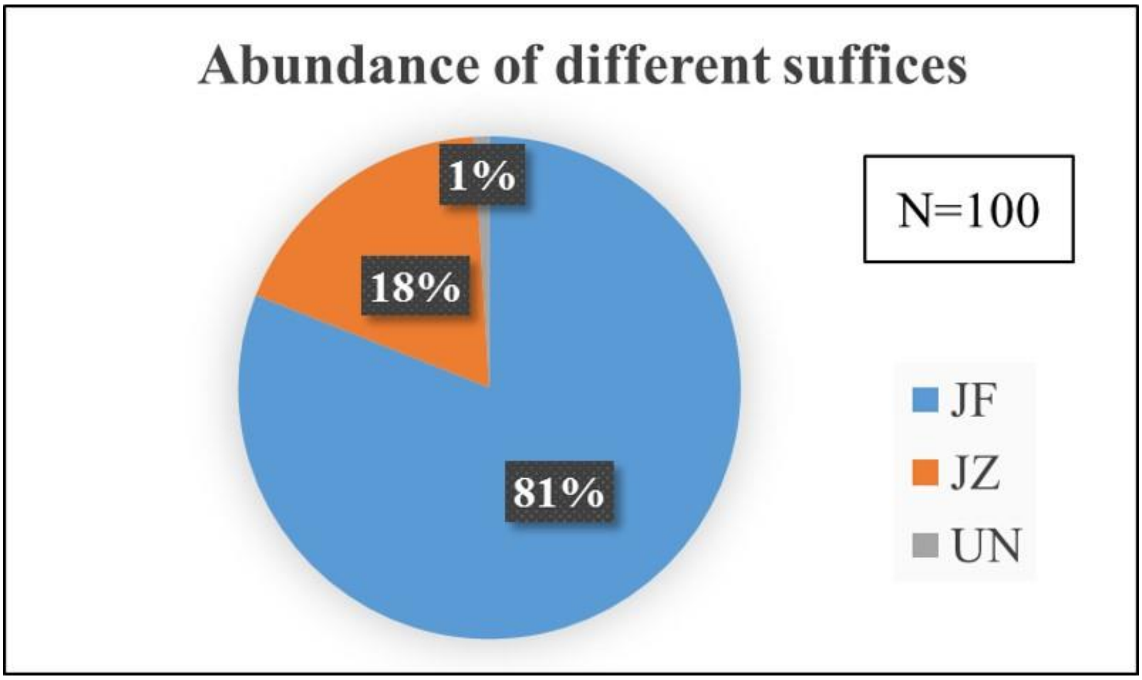


Fig 2.9: Pie-chart depicting abundance of various suffices in suffixed phrases in breeding season

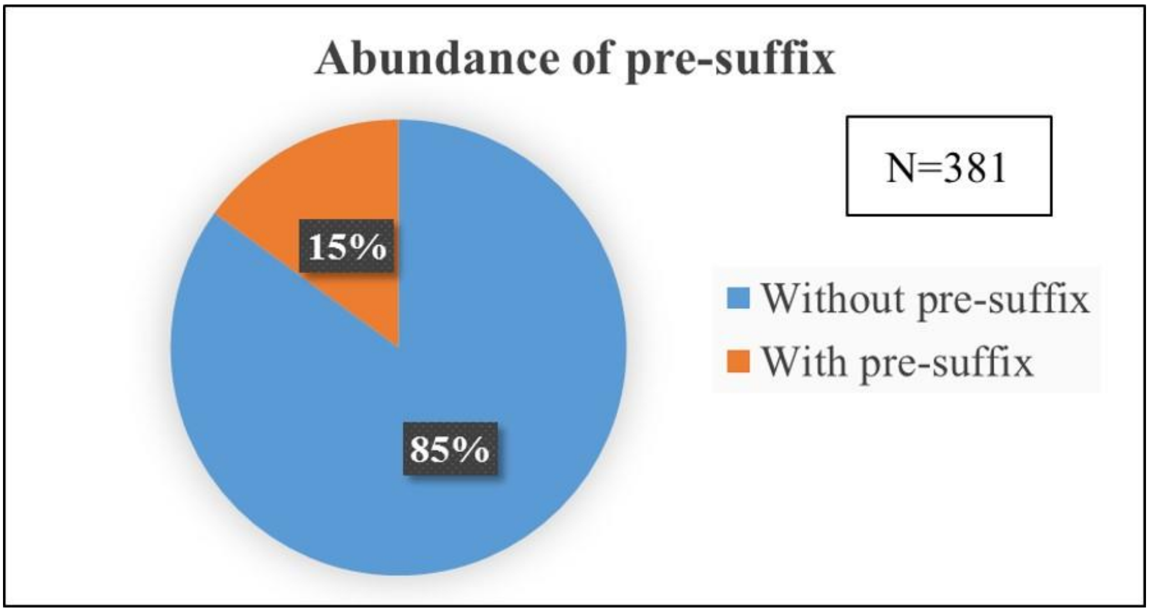


Fig 2.10: Pie-chart depicting abundance of pre-suffix in structured phrases in breeding season (Table A 1.3)

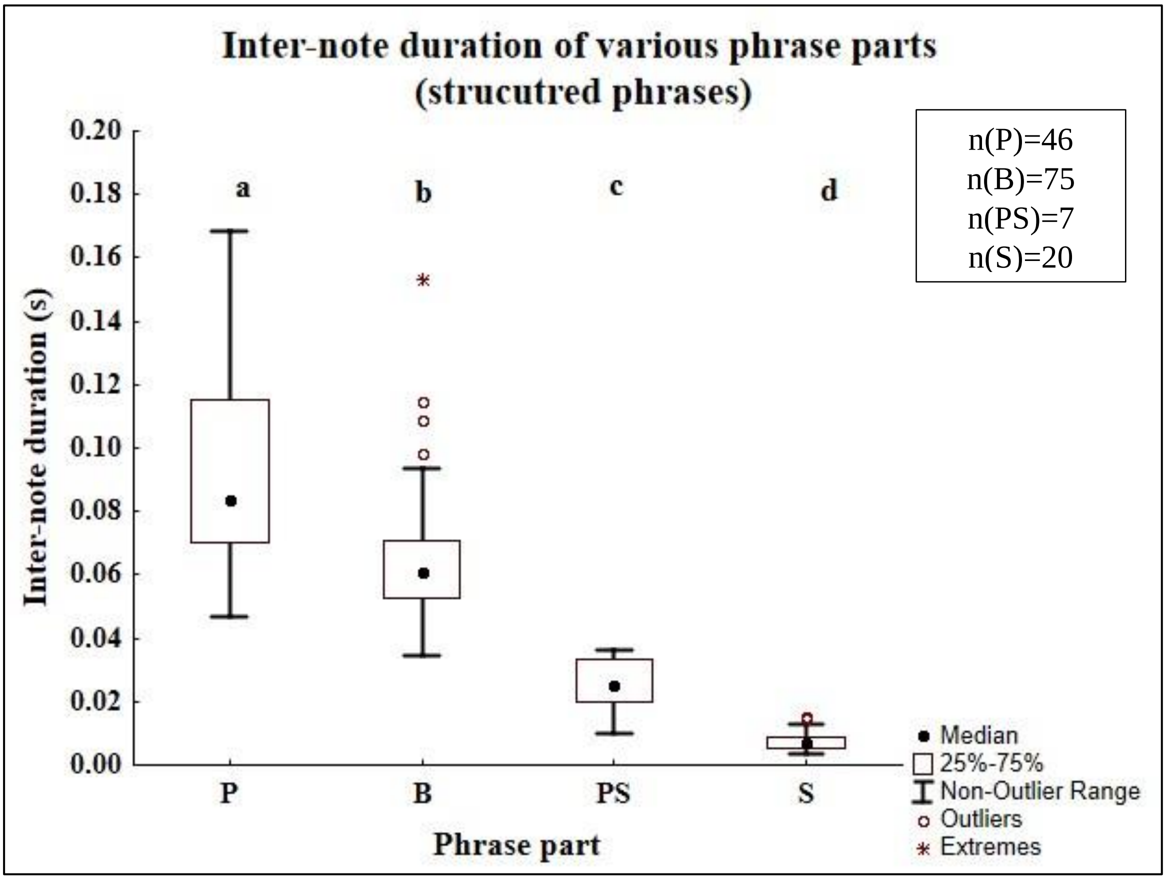


Fig 2.11: Graph depicting inter-note duration of various parts of phrases (structured phrases). Mann-Whitney U test showed significant difference between them ($p<0.05$) depicted by different letters (a,b,c,d). P: prefix; B: body; PS: pre-suffix; S: suffix. (Table A 2.2). Extreme outliers may be omitted.

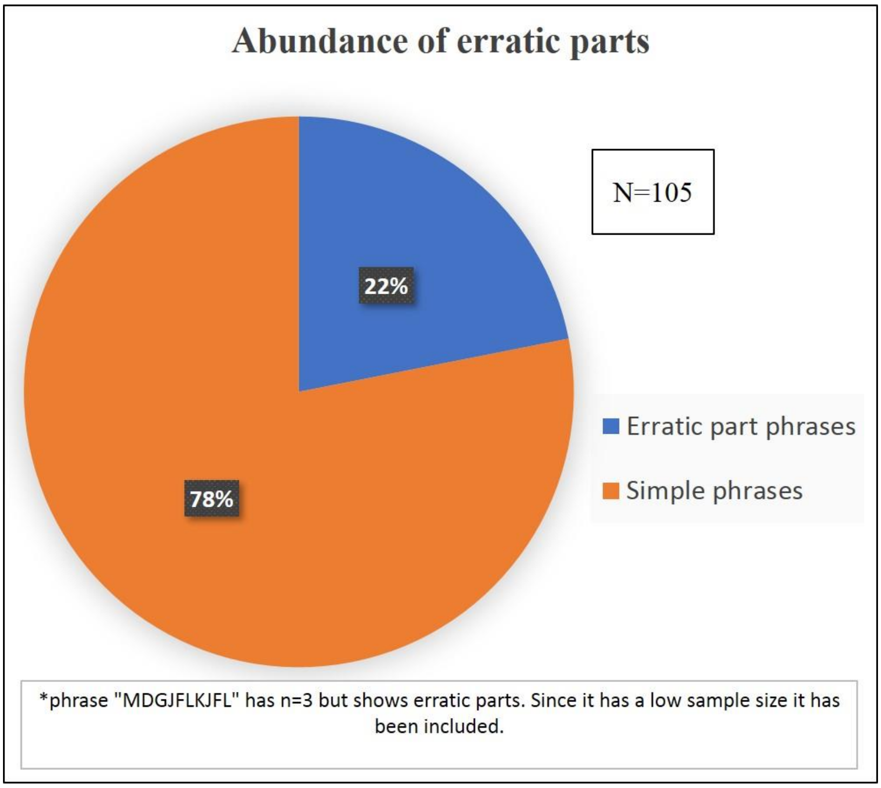


Fig 2.12: Pie-chart depicting abundance of erratic parts amongst unstructured and rare phrases in breeding season (Table A 1.4)

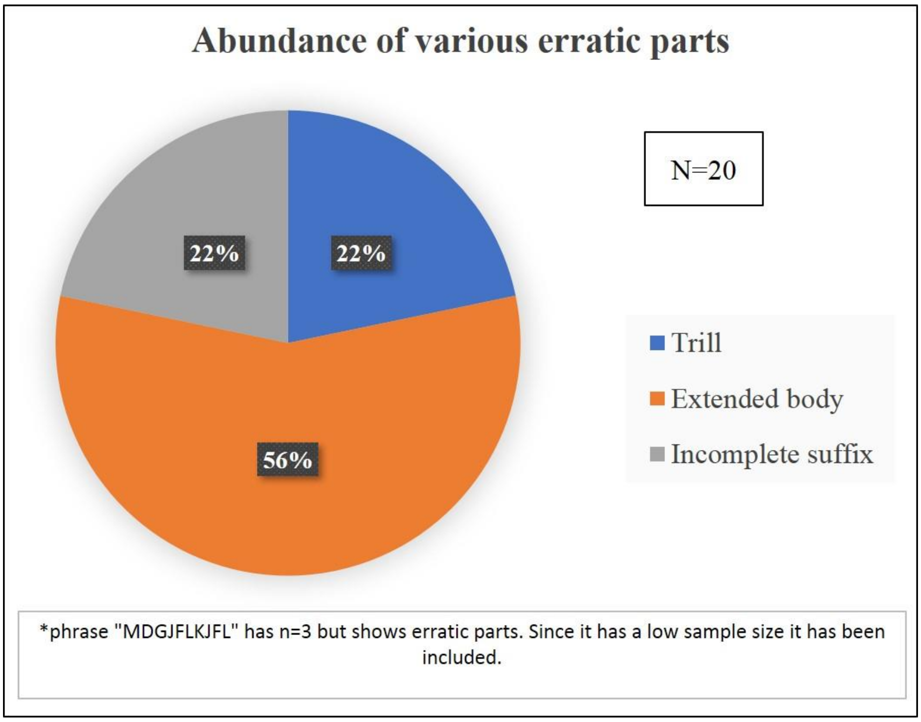


Fig 2.13: Pie-chart depicting abundance of various erratic parts in breeding season

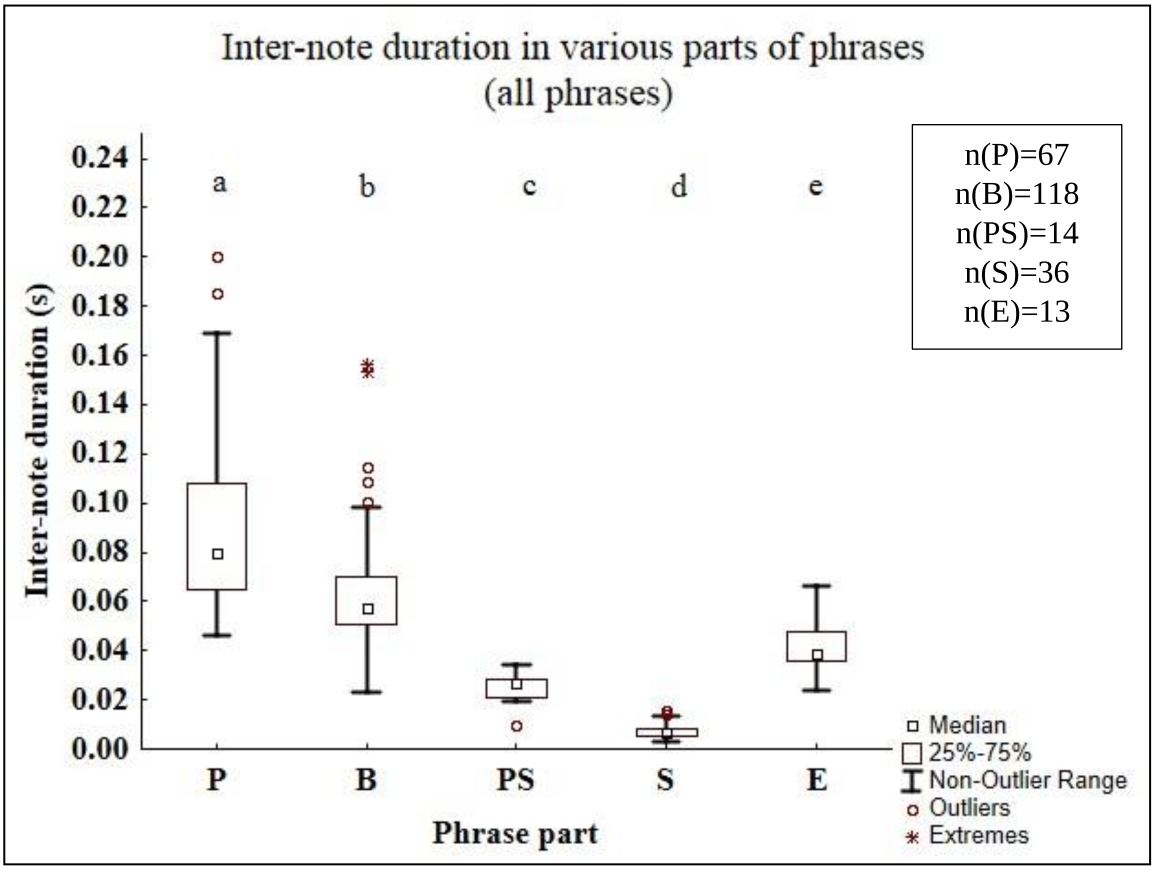


Fig 2.14: Graph depicting inter-note duration of various parts of all phrases (assumptions included) in breeding season. Mann-Whitney U test shows significant difference between them ($p<0.05$) depicted by different letters (a,b,c,d). P: prefix; B: body; PS: pre-suffix; S: suffix. (Table A 2.3). Extreme outliers may be omitted.

2.4 Conclusion

Out of the 29 note types, 20 note types have been observed before (Chorol & Jain, 2019 unpublished). Two note types, namely "U" and "N" (in Fig A 3.2) had low sample size (n<5). Whereas two other note types, namely "P" and "X" (in Fig A 3.2) described before (Chorol & Jain, 2019 unpublished) have not been observed here.

Out of 117 phrase types, 13 phrase types have been observed before (Chorol & Jain, 2019 unpublished). The most abundant phrase in the breeding season is "MBEQL" (whereas "MDOKL" in Chorol and Jain, 2019 unpublished). In a song bout, inter-phrase duration is significantly higher than the phrase duration. The prefix "M" has a high abundance and lies farthest from all phrases as already studied (as observed in Chorol and Jain, unpublished 2019). Suffix syllable has a low abundance and is produced in a very short time frame as studied before (Chorol and Jain, 2019 unpublished). Pre-suffix is less common that suffix and is produced in a time interval higher than the suffix but lesser than the body. Moving from prefix to body to pre-suffix and to suffix, shows a gradual and significant decrease in inter-note duration. Erratic parts have a low abundance overall but could be the reason for some phrases being unstructured and rare.

Chapter 3

3.1 Objective

To study song diversity of Purple Sunbird in non-breeding season by characterising note diversity and phrase diversity.

3.2 Methodology

3.2.1 Sampling location and acoustic recordings

Same as Chapter 1 (2.2.1). Sampling was done from October 2019 to February 2020. Recording utilised are from October 2019, December 2019, and February 2019.

3.2.2 Data Analyses

Around 40 minutes of data was analysed comprising of 8831 note instances and 1093 phrase instances.

Same as Chapter 2 (2.2.2)

An overall abundance graph highlighting the common phrases has been plotted. Intra-phrase duration v/s inter-phrase duration is also plotted. Since, “M” acts as the prefix in the breeding season a prefix graph for non-breeding season is also plotted. The abundance of trill parts in all phrases has been plotted, highlighting the abundance of phrases that start with a trill in a separate graph. The suffix and pre-suffix abundance graphs have been plotted.

3.2.3 Statistical Analyses

Same as Chapter 2 (2.2.3)

3.3 Results

Based on aural-visual analysis, a total of 32 distinct notes (Fig A 3.2) have been found in the song of the purple sunbird in non-breeding season. Majority of these notes are significantly different atleast by one parameter, based on the post hoc analysis (MWU-i test; $p<0.05$ for atleast 80% cases, Fig 3.2). The mean values of all spectral and temporal parameters are given in table 2.1. From abundance plot (Fig 3.1), it was seen that note type "Tr" is most common note followed by "D", whereas notes "E" and "W" are rare. Out of the 32, 13 notes show spectro-temporally different morphs (Table 3.2, Fig A 3.2), pointing to more distortion of notes.

S. No.	Note Type	Sample Size		Duration (s)	Freq. 5% (Hz)	Freq. 95% (Hz)	BW 90% (Hz)	Peak Freq. (Hz)	Center Freq.(Hz)
1	A	550	Mean	0.179	3865.475	5359.184	1493.707	4718.194	4669.176
			Std	0.031	357.876	418.502	423.684	398.368	283.323
2	C	391	Mean	0.174	4416.340	6671.884	2255.537	5939.424	5855.272
			Std	0.034	688.540	422.846	729.937	560.791	404.515
3	D	630	Mean	0.064	3561.924	6208.676	2646.738	5288.415	5035.484
			Std	0.012	540.804	439.809	594.032	820.391	531.722
4	E	5	Mean	0.120	3910.420	6597.800	2687.320	5116.280	5116.280
			Std	0.014	387.485	347.106	405.476	767.687	489.073
5	F	271	Mean	0.059	4291.376	6628.736	2337.348	5607.534	5565.577
			Std	0.013	662.359	811.391	755.565	1111.858	959.628
6	G	84	Mean	0.148	4088.232	6471.242	2383.013	5258.196	5171.049
			Std	0.018	457.021	373.039	530.838	887.292	603.734
7	H	189	Mean	0.173	4127.988	5652.413	1524.423	5059.043	5023.499
			Std	0.037	498.830	510.780	705.991	558.864	448.015
8	I	39	Mean	0.097	3405.546	5596.431	2190.867	4922.818	4732.882
			Std	0.017	496.847	542.832	570.602	685.891	439.606
9	J	179	Mean	0.039	3048.322	4347.056	1298.736	3878.855	3772.030
			Std	0.009	354.641	600.578	465.088	543.447	473.848
10	K	412	Mean	0.131	3600.426	6864.919	3264.467	5564.349	5513.127
			Std	0.024	529.391	527.192	682.347	1161.233	759.867
11	L	356	Mean	0.116	3707.087	6392.706	2685.599	4791.737	4741.411
			Std	0.025	477.462	602.915	687.607	814.409	522.618
12	M	483	Mean	0.065	4176.811	6031.263	1854.450	5407.463	5273.358
			Std	0.015	566.005	411.210	431.684	585.820	464.023
13	N	19	Mean	0.062	4252.232	7212.505	2960.247	6228.768	5802.632
			Std	0.015	979.769	524.926	910.343	1097.381	909.061
14	O	73	Mean	0.136	4043.512	6254.663	2211.140	4860.011	4798.652
			Std	0.020	417.099	517.905	618.818	589.539	369.711
15	P	23	Mean	0.094	3194.391	5961.896	2767.483	3973.343	4022.022
			Std	0.010	145.716	809.185	796.455	658.572	474.784
16	S	86	Mean	0.142	3662.638	6580.158	2917.491	5063.805	4922.584
			Std	0.018	412.184	388.377	516.927	1036.357	655.254
17	T	12	Mean	0.116	3868.792	5935.975	2067.192	4722.933	4672.700
			Std	0.020	599.282	456.403	508.348	405.278	440.758
18	V	410	Mean	0.162	3112.534	6995.463	3882.901	5080.574	4833.519
			Std	0.031	412.906	517.003	632.807	1303.365	671.654
19	W	5	Mean	0.157	4496.120	6615.020	2118.880	5012.920	5030.160
			Std	0.014	114.285	191.829	258.989	333.143	87.836
20	Y	208	Mean	0.081	3937.252	6738.658	2801.383	5782.498	5548.938
			Std	0.021	459.772	521.178	627.216	767.344	449.977
21	U	16	Mean	0.066	2869.288	5243.338	2374.044	4188.194	4204.344
			Std	0.018	389.657	295.049	394.647	739.612	470.024
22	g11	53	Mean	0.131	4033.611	6508.725	2475.100	5718.896	5662.019
			Std	0.021	406.672	350.785	535.978	837.830	406.820
23	g12	35	Mean	0.130	3969.486	6263.091	2293.597	5687.231	5433.754
			Std	0.021	490.867	258.461	430.945	617.514	466.516
24	g19	8	Mean	0.058	3445.300	5620.163	2174.850	4909.563	4791.138
			Std	0.009	362.885	583.784	410.244	406.297	443.273
25	g2	487	Mean	0.036	7749.135	8886.348	1137.241	8637.503	8519.892
			Std	0.007	480.527	348.242	448.071	475.949	400.157
26	g3	43	Mean	0.117	3936.056	6826.533	2890.447	5518.509	5476.437
			Std	0.024	523.279	402.755	485.563	956.876	695.111
27	g4	20	Mean	0.107	5969.010	7075.830	1106.820	6231.705	6287.690
			Std	0.017	485.793	520.585	252.995	475.120	387.124
28	g42	6	Mean	0.126	3330.467	6976.767	3646.283	5196.667	5110.533
			Std	0.011	429.710	140.642	418.044	932.542	752.007
29	g5	158	Mean	0.099	3279.580	7007.292	3727.689	4945.003	4695.865
			Std	0.024	470.031	812.411	969.015	1209.371	624.789
30	g52	16	Mean	0.113	2783.156	6271.556	3488.375	4844.956	4764.213
			Std	0.013	497.319	459.045	597.518	358.394	302.575
31	g95	21	Mean	0.103	3629.876	5729.895	2100.005	4532.219	4581.443
			Std	0.009	385.465	627.129	911.713	431.474	206.953
32	Tr	3543	Mean	0.057	3410.587	6359.781	2949.177	4971.341	4819.544
			Std	0.013	547.557	667.082	782.953	951.561	657.086

Table 3.1: Mean and std. values of various parameters of different note types in non-breeding season

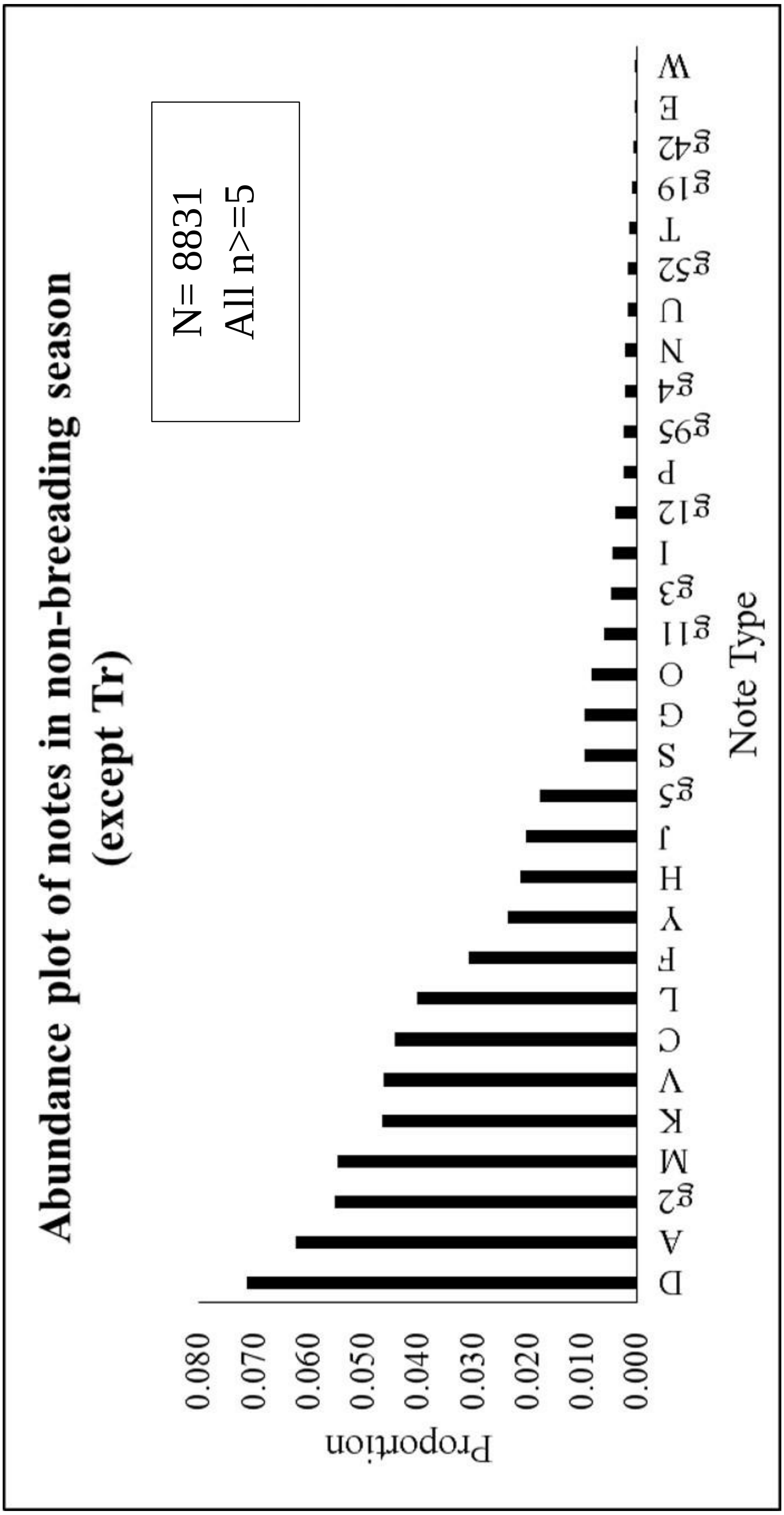


Fig 3.1: Graph depicting abundance of various note types (n>=5) in non-breeding season

Note	Morph	Sample Size		Duration (s)	Freq. 5% (Hz)	Freq. 95% (Hz)	BW 90% (Hz)	Peak Freq. (Hz)	Center Freq. (Hz)
C	C	265	Mean	0.174	4271.858	6572.100	2300.239	5896.365	5769.925
			Std	0.029	577.383	385.994	668.077	589.001	353.714
	g10	126	Mean	0.174	4720.212	6881.748	2161.521	6029.986	6084.771
			Std	0.044	796.113	420.124	837.645	483.908	443.963
F	F	92	Mean	0.067	4816.884	7069.149	2242.270	6246.508	6324.212
			Std	0.013	495.326	369.366	553.184	796.898	522.427
	F10	5	Mean	0.063	4651.140	5874.260	1223.100	5012.940	5080.140
			Std	0.016	196.417	394.317	257.840	350.522	334.082
	F2	70	Mean	0.053	4119.597	7149.034	3029.401	6093.286	5850.881
			Std	0.009	520.677	411.023	543.762	1154.833	858.787
	F9	22	Mean	0.050	4330.123	5904.018	1573.895	4713.809	4862.582
			Std	0.008	358.147	672.583	589.455	452.941	432.018
	g9	82	Mean	0.056	3816.089	5942.118	2126.013	4752.007	4692.130
			Std	0.013	580.717	813.415	705.646	738.106	650.046
H	H	130	Mean	0.179	4218.515	5419.080	1200.571	4910.225	4868.487
			Std	0.038	362.372	330.333	387.966	418.363	302.971
	H2	59	Mean	0.159	3928.522	6166.537	2237.997	5386.949	5365.053
			Std	0.029	670.766	459.381	724.371	677.155	520.693
J	J	116	Mean	0.037	2999.047	4071.998	1072.953	3679.942	3609.399
			Std	0.010	376.560	521.311	351.401	488.756	439.484
	J2	63	Mean	0.043	3139.052	4853.511	1714.465	4245.108	4071.478
			Std	0.005	289.062	358.655	347.167	438.504	379.412
K	K	316	Mean	0.129	3664.997	6921.163	3256.140	5624.529	5619.894
			Std	0.024	547.337	501.781	666.188	1169.800	746.199
	K9	36	Mean	0.154	3390.278	6907.381	3517.078	5782.869	5500.539
			Std	0.019	440.197	216.596	467.597	1131.483	627.099
	K2	17	Mean	0.152	3475.706	6571.429	3095.706	4869.035	4752.512
			Std	0.014	280.192	680.646	747.662	919.237	568.465
	g8	43	Mean	0.124	3351.153	6532.072	3180.895	5214.040	5089.760
			Std	0.019	393.094	648.550	850.519	1037.987	668.322
L	L	183	Mean	0.107	3786.066	6403.016	2616.929	5002.287	4891.206
			Std	0.023	471.495	668.493	640.169	887.551	536.229
	L1	122	Mean	0.135	3734.057	6402.778	2668.701	4721.063	4696.350
			Std	0.018	436.124	495.852	684.714	631.053	375.160
	L2	17	Mean	0.120	3541.576	6500.494	2958.929	4559.965	4717.047
			Std	0.020	417.686	696.071	936.532	578.524	504.422
	g7	31	Mean	0.099	3220.255	6243.248	3022.974	4026.003	4076.013
			Std	0.015	411.433	516.276	702.933	514.469	388.529
	L23	3	Mean	0.098	3761.100	6287.733	2526.567	4048.233	4450.200
			Std	0.010	40.588	243.622	202.987	70.341	177.000
N	N	7	Mean	0.044	5192.571	7370.514	2177.929	6349.229	6423.057
			Std	0.009	378.857	263.929	387.145	854.801	526.661
	g13	12	Mean	0.072	3703.700	7120.333	3416.600	6158.500	5440.717
			Std	0.006	787.080	610.401	812.063	1211.233	889.455
S	S	65	Mean	0.144	3675.875	6599.109	2923.205	4982.092	4865.832
			Std	0.019	432.674	371.216	493.029	1080.528	682.936
	S1	21	Mean	0.137	3621.667	6521.500	2899.805	5471.486	5098.243
			Std	0.011	337.772	432.009	584.386	944.155	523.329
T	T	8	Mean	0.125	4220.500	6083.125	1862.638	4941.863	4920.325
			Std	0.015	357.730	298.200	372.815	301.264	299.714
	g6	4	Mean	0.097	3165.375	5641.675	2476.300	4285.075	4177.450
			Std	0.015	281.575	563.156	496.202	153.789	187.719
Y	Y	202	Mean	0.082	3948.453	6753.758	2805.282	5795.207	5553.005
			Std	0.021	439.651	520.512	625.921	773.800	453.526
	g17	6	Mean	0.074	3560.150	6230.283	2670.100	5354.600	5412.017
			Std	0.017	821.127	169.853	655.968	255.604	274.265
U	U	7	Mean	0.048	2743.943	5377.157	2633.186	4441.971	4380.457
			Std	0.005	391.832	165.091	367.900	808.877	468.230
	g14	9	Mean	0.080	2966.778	5139.256	2172.489	3990.811	4067.367
			Std	0.009	358.869	329.853	280.631	617.111	423.493
g3	g3	30	Mean	0.105	4028.130	6916.473	2888.310	5208.160	5337.357
			Std	0.016	570.339	442.642	530.825	957.528	767.021
	g15	13	Mean	0.143	3723.577	6618.977	2895.377	6234.700	5797.392
			Std	0.018	300.569	150.498	359.964	421.350	304.783
Tr	Tr1	327	Mean	0.060	3407.635	6521.866	3114.210	5319.427	5020.723
			Std	0.011	570.436	559.023	724.948	915.671	649.916
	Tr3	934	Mean	0.055	3189.949	6646.159	3456.186	4493.840	4454.830
			Std	0.009	463.849	571.557	743.684	923.202	458.555
	Tr4	1148	Mean	0.053	3553.195	5959.448	2406.246	5068.854	4873.629
			Std	0.011	539.116	542.101	543.391	761.755	564.695
	Tr5	18	Mean	0.052	3153.411	6105.856	2952.433	5115.344	4823.428
			Std	0.013	684.339	402.863	463.655	1138.761	838.057
	Tr6	61	Mean	0.059	2578.338	5679.121	3100.775	3784.190	3719.233
			Std	0.013	483.188	662.956	821.423	1000.941	673.442
	Tr7	365	Mean	0.069	3522.702	6271.415	2748.695	4947.558	4837.828
			Std	0.013	387.650	512.257	535.810	716.854	474.582
	Tr8	251	Mean	0.067	3517.021	6808.962	3291.911	5295.968	5174.487
			Std	0.013	455.608	545.361	691.089	901.685	509.008
	Tr9	92	Mean	0.062	3460.282	6309.235	2848.932	4506.051	4540.687
			Std	0.011	336.140	649.383	737.691	529.733	379.783
	Tr10	268	Mean	0.053	3535.289	6598.485	3063.171	5890.458	5541.108
			Std	0.014	734.741	831.839	699.778	1026.663	897.739
	Tr11	79	Mean	0.061	3323.192	6934.246	3611.033	5145.071	5026.223
			Std	0.009	387.291	419.257	522.357	886.660	447.887

Table 3.2: Abundance, mean and std. values of various parameters of the morphs of note types in non-breeding season

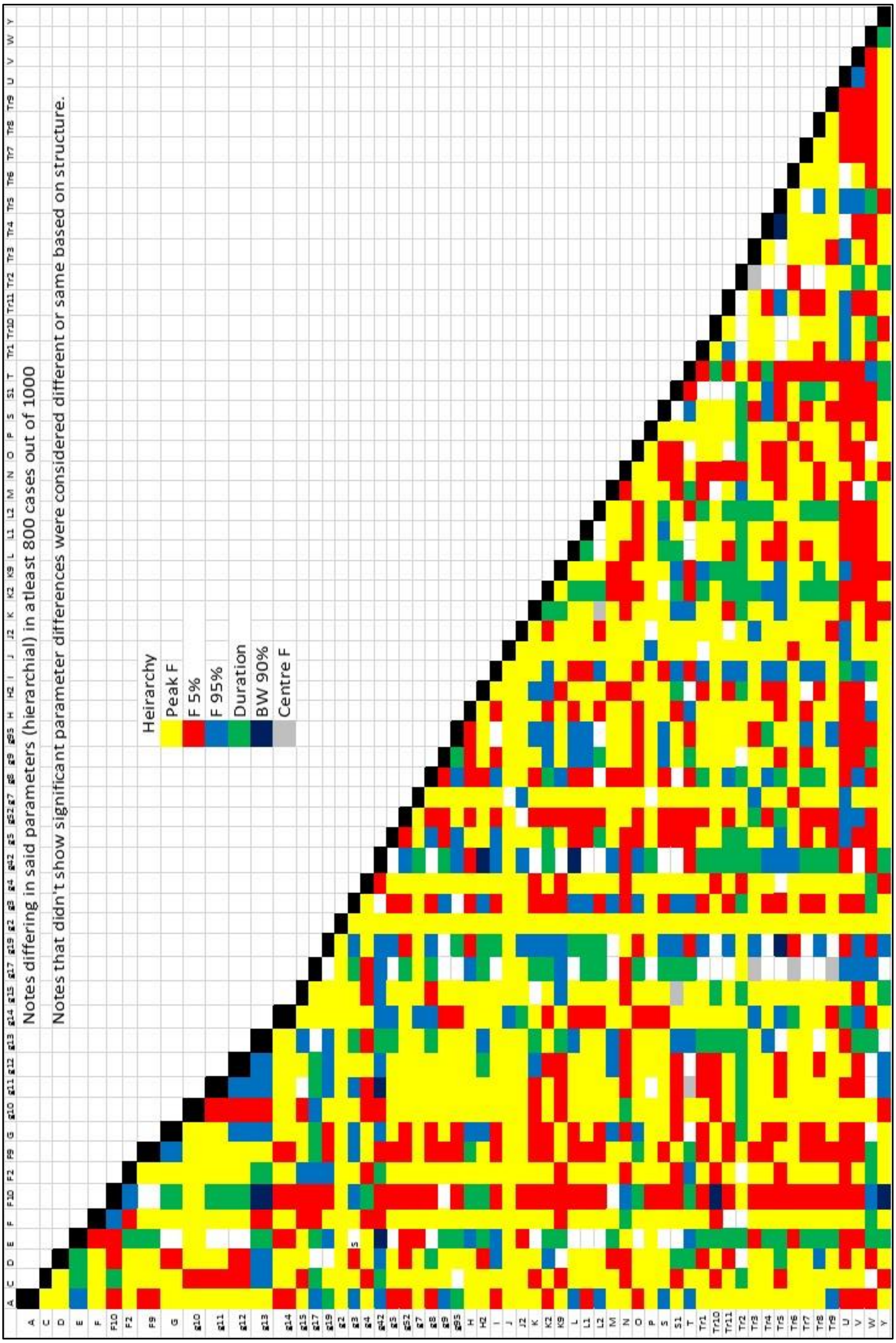


Fig 3.2: Hierarchical classification of notes showing significant result for MWU-i test. (Order of hierarchy is represented in figure) in non-breeding season

A total of 327 different types of phrases were found in the song of the Purple sunbird in non-breeding season, out of which single-noted phrases (phrases with a only one distinct note, either with one or multiple repetitions) are the most abundant. The abundance plot (Fig 3.3, Table A 1.4) showed that “A” is the most common phrase, followed by “M”. There are multiple phrases with just one occurrence. Table 3.3 shows the mean values of various parameters for common phrases. There is a significant difference ($p<0.05$) between the inter-phrase duration and intra-phrase duration, but there is good overlap between the two populations (small effect size) (Fig 3.4, Table A 2.4). This tells us that the difference is possibly not biologically relevant. Hence, it points to a continuous vocalisation. “M” as a prefix is present in around 18% of the total phrases and appears as a single-noted phrase with a frequency of 10% (Fig 3.5). Trill parts are seen in around 26% of phrases (Fig 3.6), with 10% of total starting with a trill, and around 9% phrases are single noted “Tr” phrases (Fig 3.7). Suffix and pre-suffix presence in structured phrases are almost negligible (Fig 4.9). Amongst the structured phrases, prefix lies the farthest away. The inter-note duration (Fig 3.8, Table 2.5) of body is significantly different from the pre-suffix and suffix, but the effect size is small. Hence, there is enough overlap. No significant difference is found between the inter-note duration of pre-suffix and suffix, whereas the effect size is large. This indicates that the sample sizes are small. But considering their low abundance (amongst structured phrases) in non-breeding season, it might not be possible to get a large enough sample size.

S. No.	Phrase		Temporal Characters				Spectral Characters				
			Note Number	Note Duration (s)	Internote duration (s)	Phrase Duration (s)	Freq 5% (Hz)	Freq 95%(Hz)	BW 90%(Hz)	Peak Freq (Hz)	Centre Freq (Hz)
1	M	Mean	1.4	0.070	0.104	0.147	4541.697	6376.050	1834.360	5664.203	5555.285
		Std	3.7	0.028	0.138	0.462	1138.251	821.033	617.100	1100.655	1022.576
2	MA	Mean	2.6	0.121	0.508	1.095	4288.061	5833.386	1545.333	5171.347	5146.010
		Std	0.7	0.065	0.192	0.412	514.630	604.278	328.281	544.206	525.967
3	MC	Mean	2.5	0.120	0.215	0.606	4399.144	6287.704	1888.544	5691.148	5589.056
		Std	0.5	0.059	0.148	0.263	425.167	471.773	620.196	372.816	334.281
4	MCA	Mean	4.4	0.145	0.146	1.136	4243.995	5994.073	1750.068	5281.509	5222.791
		Std	0.8	0.043	0.116	0.224	351.493	485.623	410.938	564.443	484.843
5	MCH	Mean	5.7	0.118	0.088	1.076	3815.165	5933.040	2117.853	4924.771	4945.029
		Std	2.4	0.044	0.071	0.085	598.033	446.944	694.128	721.390	498.804
6	MD	Mean	7.0	0.063	0.042	0.694	3701.943	6350.984	2649.014	5521.296	5199.606
		Std	2.3	0.012	0.059	0.241	507.482	325.911	477.670	629.168	382.317
7	MH	Mean	3.3	0.124	0.181	0.809	3909.092	5611.885	1702.792	4949.315	4816.792
		Std	0.8	0.063	0.115	0.231	353.590	384.977	418.103	267.326	387.358
8	MTr	Mean	6.1	0.059	0.063	0.676	3359.173	6094.881	2735.699	5106.328	4835.283
		Std	3.1	0.014	0.079	0.269	684.302	684.301	757.819	896.648	748.301
9	MTrC	Mean	9.3	0.078	0.053	1.172	3612.952	6287.700	2674.737	5137.209	5043.375
		Std	6.3	0.047	0.049	0.513	612.186	630.427	612.600	813.469	635.237
10	MTrK	Mean	10.3	0.092	0.048	1.401	3773.155	6593.335	2820.155	5518.065	5343.013
		Std	0.5	0.033	0.033	0.132	344.122	548.191	715.293	845.338	481.055
11	MTrV	Mean	18.4	0.071	0.033	1.885	3312.829	6465.115	3152.270	5027.998	4809.858
		Std	3.7	0.038	0.042	0.313	551.067	647.193	905.106	1038.836	615.066
12	MTrVJFL	Mean	25.7	0.072	0.022	2.411	3388.260	6741.852	3353.583	5179.152	4957.668
		Std	2.9	0.032	0.014	0.308	582.128	673.027	870.041	851.808	600.367
13	MYV	Mean	7.3	0.080	0.056	1.305	3982.619	6747.086	2764.457	5766.810	5459.176
		Std	0.6	0.027	0.048	0.714	674.313	456.039	1048.879	629.706	506.279
14	Tr	Mean	4.7	0.058	0.045	0.441	3489.724	6326.705	2836.964	5300.508	5077.316
		Std	4.0	0.014	0.041	0.374	597.540	732.313	713.495	1059.346	847.385
15	TrA	Mean	12.5	0.069	0.037	1.276	3524.548	6253.244	2728.688	5433.252	5140.408
		Std	0.5	0.033	0.015	0.007	604.115	558.198	892.358	830.070	620.028
16	TrC	Mean	2.8	0.096	0.142	0.536	3785.181	6019.984	2234.805	5284.362	5163.300
		Std	1.1	0.052	0.073	0.190	1020.892	782.994	735.759	853.431	896.679
17	TrF[5]	Mean	21.0	0.052	0.026	1.620	3829.486	6662.313	2832.810	5055.849	5009.370
		Std	0.8	0.020	0.014	0.117	412.025	720.834	872.608	619.345	409.279
18	TrV	Mean	20.5	0.728	0.032	2.112	3572.609	6449.042	2876.412	4924.693	4874.698
		Std	13.3	0.040	0.022	1.665	829.596	742.861	922.292	1099.392	823.427
19	TrVK	Mean	20.6	0.080	0.032	2.276	3447.391	6484.632	3037.223	5014.516	4833.887
		Std	2.3	0.046	0.020	0.393	490.076	649.684	784.143	1076.161	698.050
20	Y	Mean	1.8	0.081	0.065	0.203	4197.009	6590.467	2393.448	5794.391	5556.867
		Std	1.9	0.020	0.049	0.264	604.700	453.358	623.906	496.510	395.066
21	YA	Mean	4.3	0.104	0.080	0.717	3935.600	6188.323	2252.708	5592.015	5280.600
		Std	3.3	0.083	0.107	0.136	407.360	478.791	662.754	620.624	308.506
22	TrG	Mean	14.0	0.075	0.034	1.495	3651.404	6413.825	2762.404	4994.164	4804.979
		Std	4.3	0.039	0.018	0.292	417.135	595.182	633.326	735.474	435.471

Table 3.3: Mean and std. values of various parameters for common phrases in non-breeding season

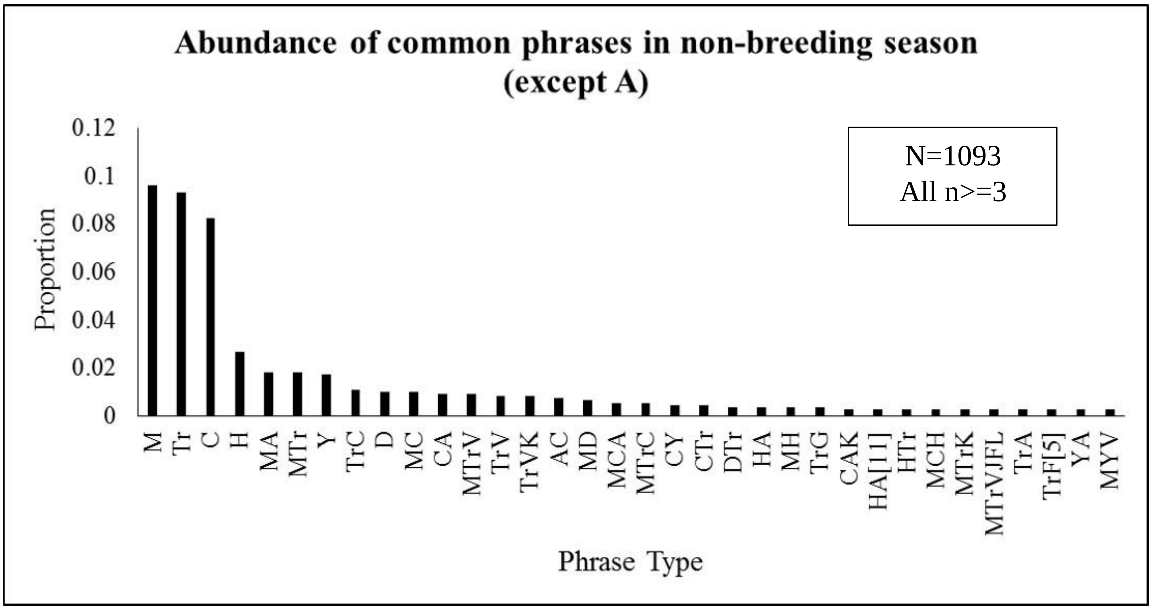


Fig 3.3: Graph depicting abundance of various common phrases (n>=3) observed in non-breeding season

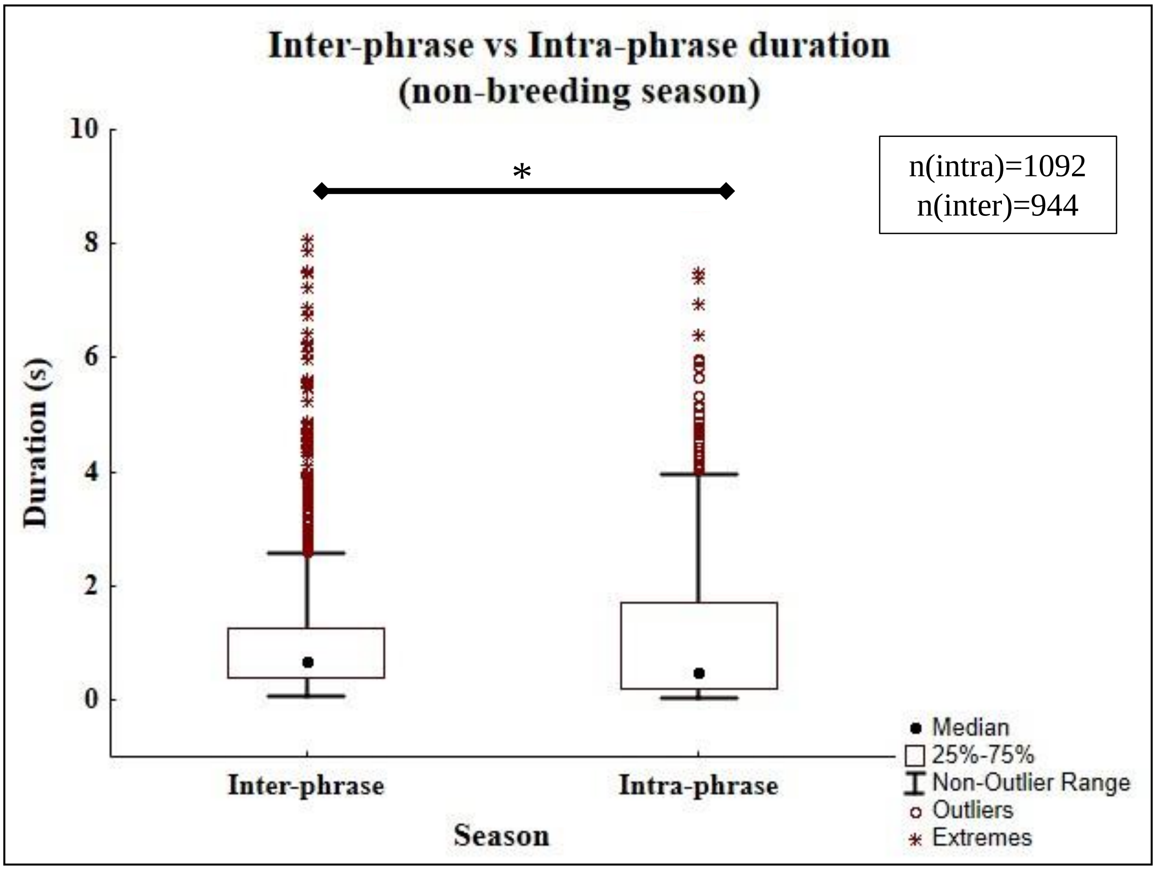


Fig 3.4: Graph depicting intra-phrase and inter-phrase duration during non-breeding season. Mann-Whitney U test showed significant difference between them ($p<0.05$) (Table A 2.4). * represent significant difference. Extreme outliers may be omitted.

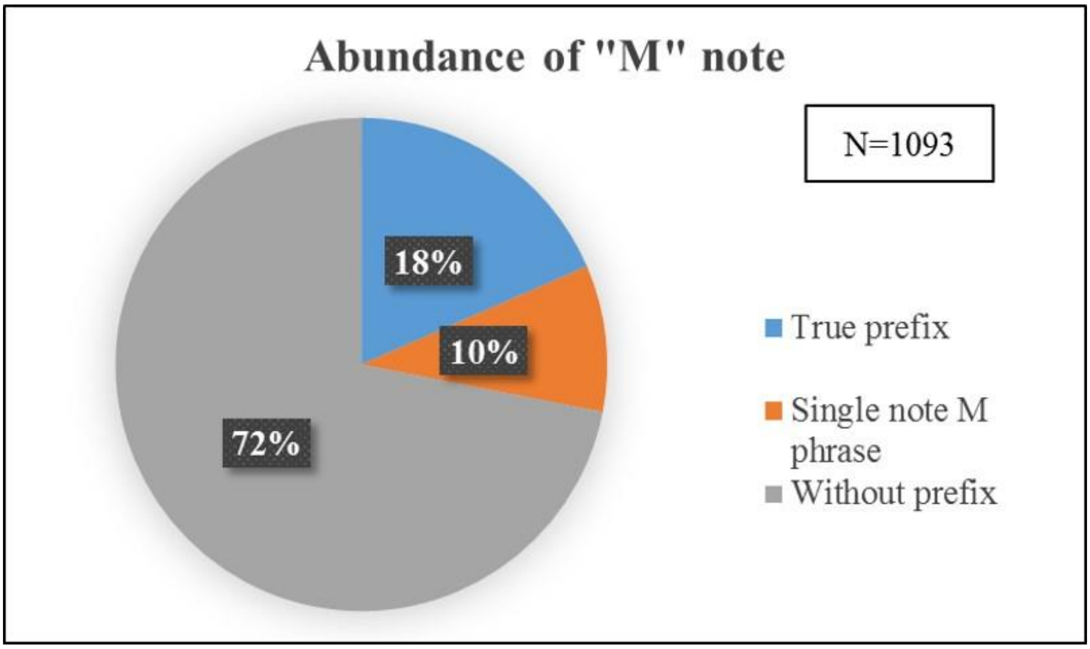


Fig 3.5: Pie-chart depicting abundance of prefix in all phrases in non-breeding season

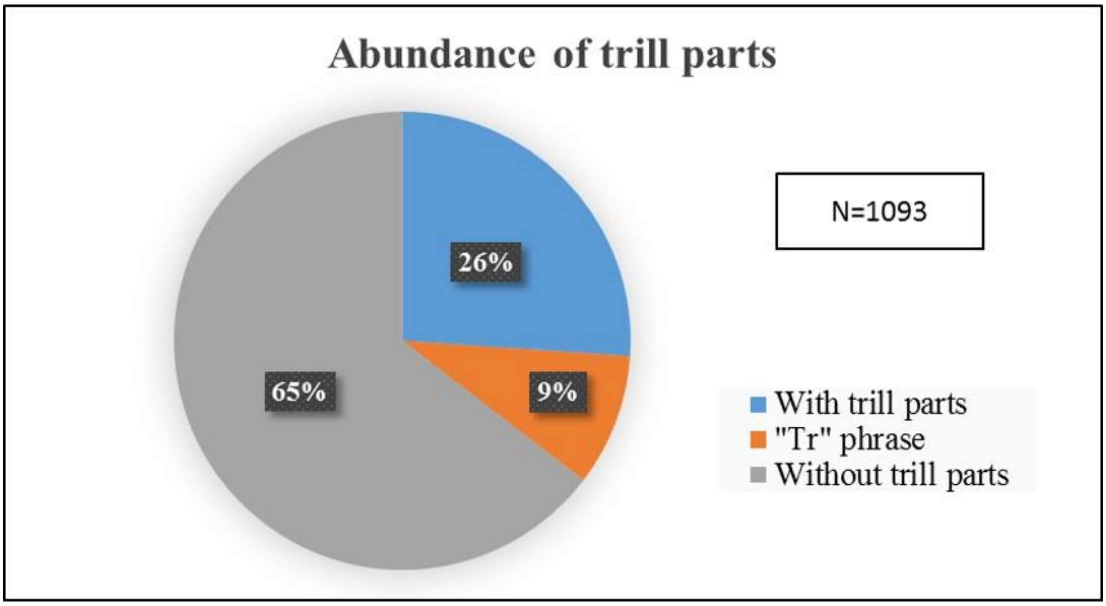


Fig 3.6: Pie-chart depicting abundance of trill parts in all phrases in non-breeding season

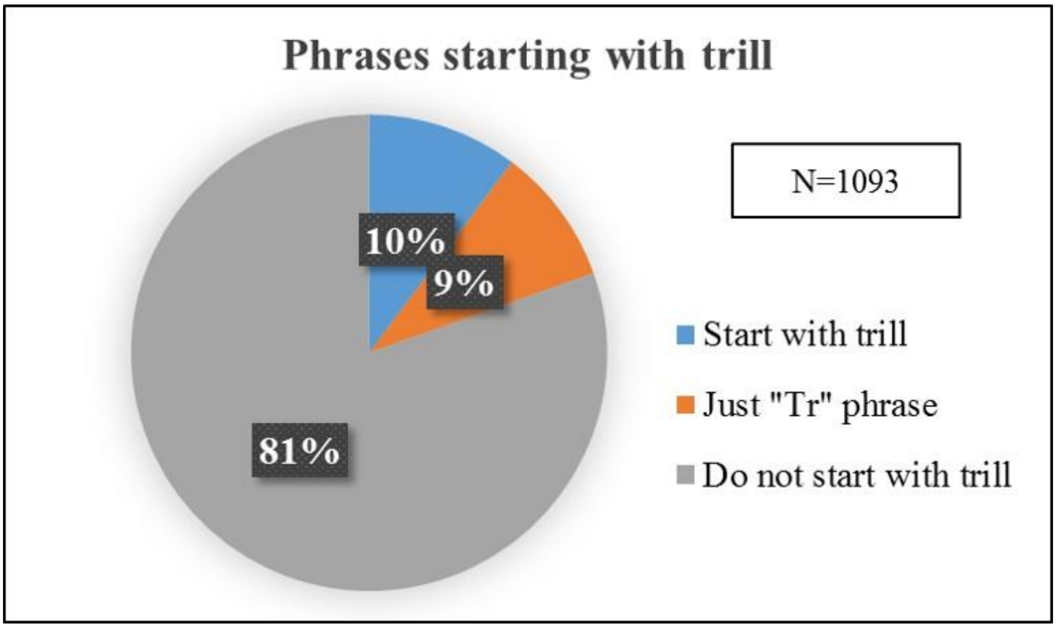


Fig 3.7: Pie-chart depicting abundance of phrases starting with trill in non-breeding season

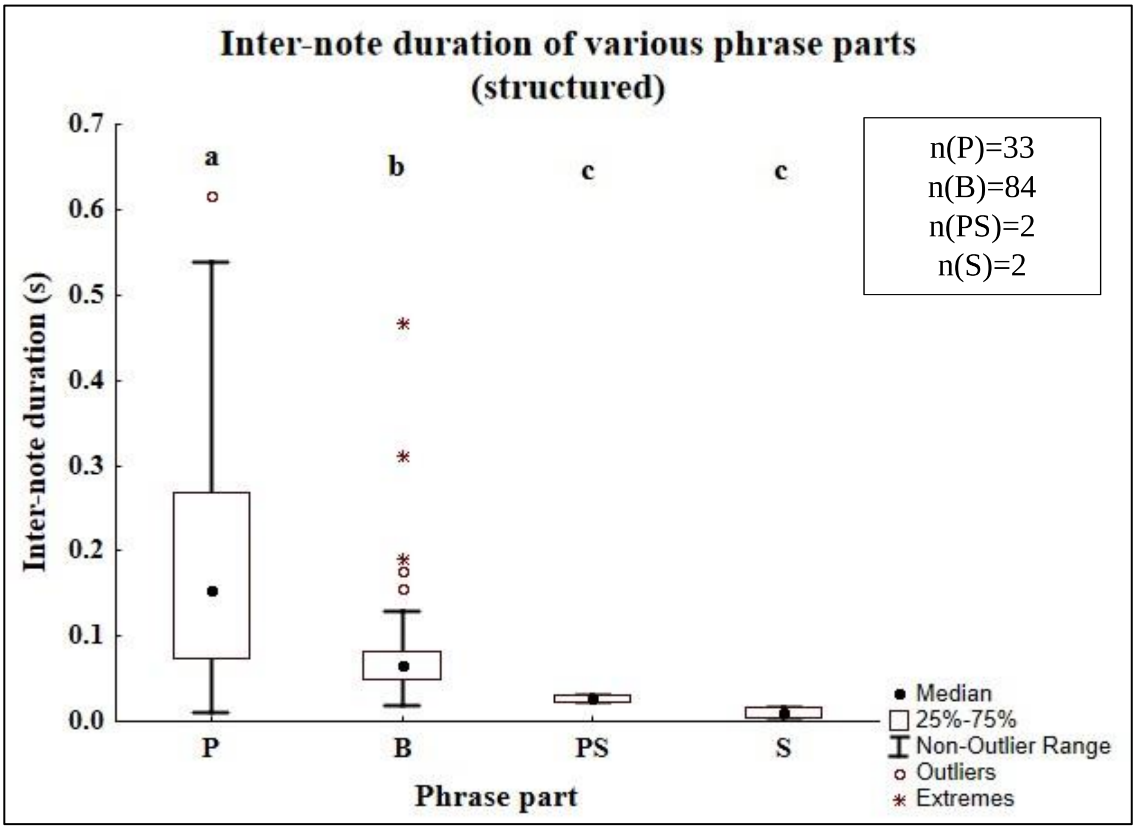


Fig 3.8: Graph depicting inter-note duration of various parts of phrases (structured phrases) in non-breeding season. Mann-Whitney U test showed significant difference between them ($p<0.05$) depicted by different letters (a,b,c). P: prefix; B: body; PS: pre-suffix; S: suffix. (Table A 2.5). Extreme outliers have been omitted.

Out of the 32 note types, trill notes are the most abundant. Notes have shown more distortion. Most common phrases are sing-noted. Inter-phrase and intra-phrase duration have a considerable overlap, pointing towards a continuous vocalisation. Prefix ‘M’ is present in low number of phrases. Trilling is present in a considerable number of phrases and a low proportion of phrases start with a trill. Prefix lies farthest away from the phrase. There is less difference between body with pre-suffix and suffix. Whereas, the same cannot be concluded for just pre-suffix and suffix since their abundance is low in non-breeding season. This considerable overlap between all parts points towards possibly less breath modulation and an overall ambiguity between various phrase parts.

Chapter 4

4.1 Objective

To compare song diversity of Purple Sunbird in breeding and non-breeding season by characterising note diversity variation and phrase diversity variation.

4.2 Methodology

The results of the structural study of the song in breeding (BS) and non-breeding season (NBS) are discussed in a comparative manner. To understand the organisation of notes into phrases, proportion vs number of distinct notes (in order) of each phrase is plotted. For this a dataset comprising of number of note repetition per phrase in BS was compared to its NBS counterpart. Test of normality showed that this data was not normal. Hence, Mann-Whitney U test (alpha=0.05) was performed.

4.3 Results

In BS, out of 1.3 hours of recordings, 5453 note repetitions and 445 phrase repetitions were obtained. This comprised of 29 distinct note types (Table 2.1), and 117 distinct phrases (Table A 1.1). In NBS, 40 minutes of recordings, 8831 note repetitions and 1093 phrase repetitions were obtained. This comprised of 32 distinct note types (Table 3.1), and 327 distinct phrases (Table A 1.4). The phrase duration and inter-phrase duration, during breeding season, show a significant difference with a large effect size (fig 2.6, Table A 2.1). In non-breeding season, the difference between the two parameters is significant but the effect size is small (Fig 3.4, A 2.4). These show that the song in non-breeding season is more continuous (example in Fig A 3.4). There is substantial difference between the note repertoires in the two seasons. 19 notes are mutual in the two seasons, but their abundance differs (Fig 4.1). 11 notes are unique to BS, whereas 13 notes are unique to NBS. In BS, 10 notes showed morphs (Table 2.2), while in NBS 13 notes showed morphs (Table 3.2). This could point to more distortion of notes in latter season (examples of structural variation in “K” and “L” notes in two seasons depicted in Fig A 3.3).

The phrase repertoire and their abundance are quite different in the two seasons. Considering classification of phrases based on “abundance”, in the BS, there are 35 common phrases (each n>=3), whereas in NBS, there are 21 common phrases. Out of these only 4 phrases are mutual to both seasons, but their abundance differs (Fig 4.2). 31 common phrases are unique to BS whereas 17 common phrases are unique to NBS. Considering classification of phrases based on “structure”, in the BS a larger proportion (85%) of phrases fall in the structured category compared to the NBS (60%) (Fig 4.3).

The number of notes per phrase (for all phrases) in BS lies in a more limited area but the data for NBS is quite spread out with multiple outliers (Fig 4.4, Table A 2.6). For common phrases, 5 is the highest number of distinct notes (per phrase) in BS, whereas 1 per phrase in NBS (Fig 4.5, Table A .6). Similar results can be seen for structured phrases (Fig 4.6, Table A 1.7). This points to the fact that even though some longer phrases exist in NBS, most common and structured are single noted.

A structured phrase is made of many parts like prefix, body, and suffix (pre-suffix and erratic parts introduced in Chapter 2). Comparing their abundance and identity across the seasons gives insight into their structural variation and their signalling aspects (if any). The presence of trill parts is much more in NBS phrases than in BS phrases (Fig 4.7). “M” as a prefix appears much more frequently in BS, than in NBS (Fig 4.8). In fact, in NBS around 10% phrases begin with a trill (Fig 3.7).

The abundance of suffix and also pre-suffix in structured phrases was checked. Both pre-suffix and suffix reduces greatly in the NBS (Fig 4.9). Thus, suffix and pre-suffix are proposed as to have a role in sexual selection. On comparing the inter-note durations, a significant difference is seen between prefix of BS and NBS, but the effect size is small (Fig 4.10, Table A 2.7). No differences were seen for body, pre-suffix, and suffix in the two seasons (Fig 4.11, Fig 4.12, Fig 4.13, Table A 2.7, Table A 2.8). But different parts showed significant difference in their inter-note duration with medium/large effect size in the BS (Fig 2.11, Table A 2.2). Whereas in NBS, either there was not a significant difference, or the effect size was small (Fig 3.8, Table A 2.5). This indicates that even though there is no difference between the same parts over season but overall, the parts in BS (over temporal scale) are more distinguishable from one another than in NBS.

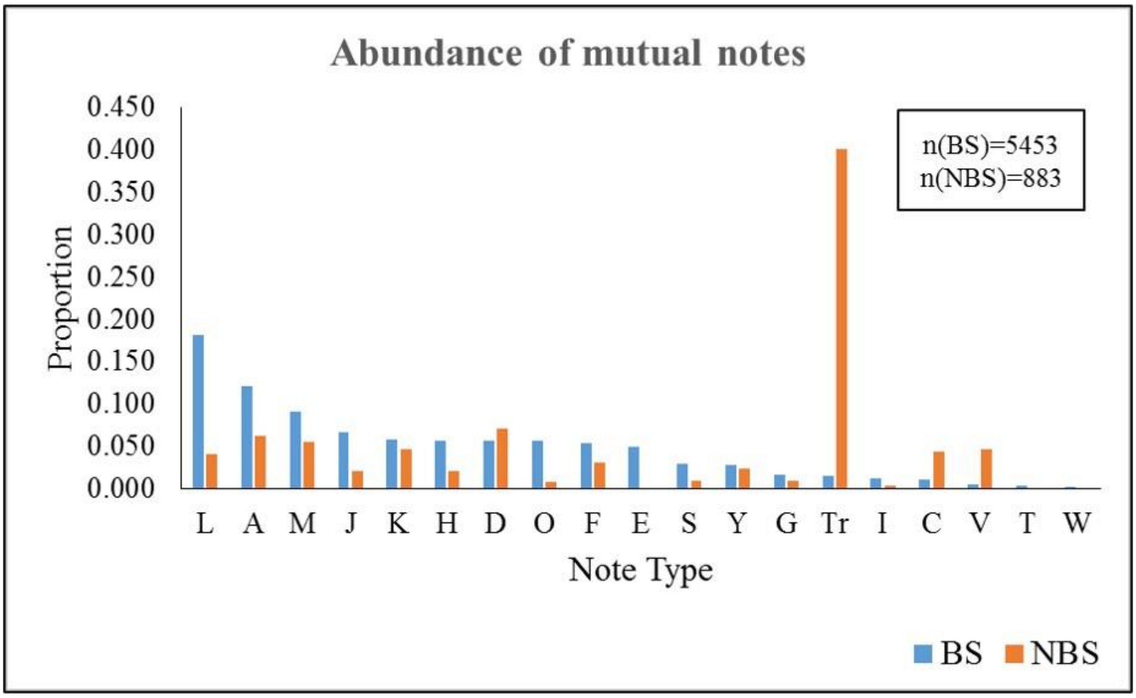


Fig 4.1: Graph depicting abundance of mutual notes in the two seasons

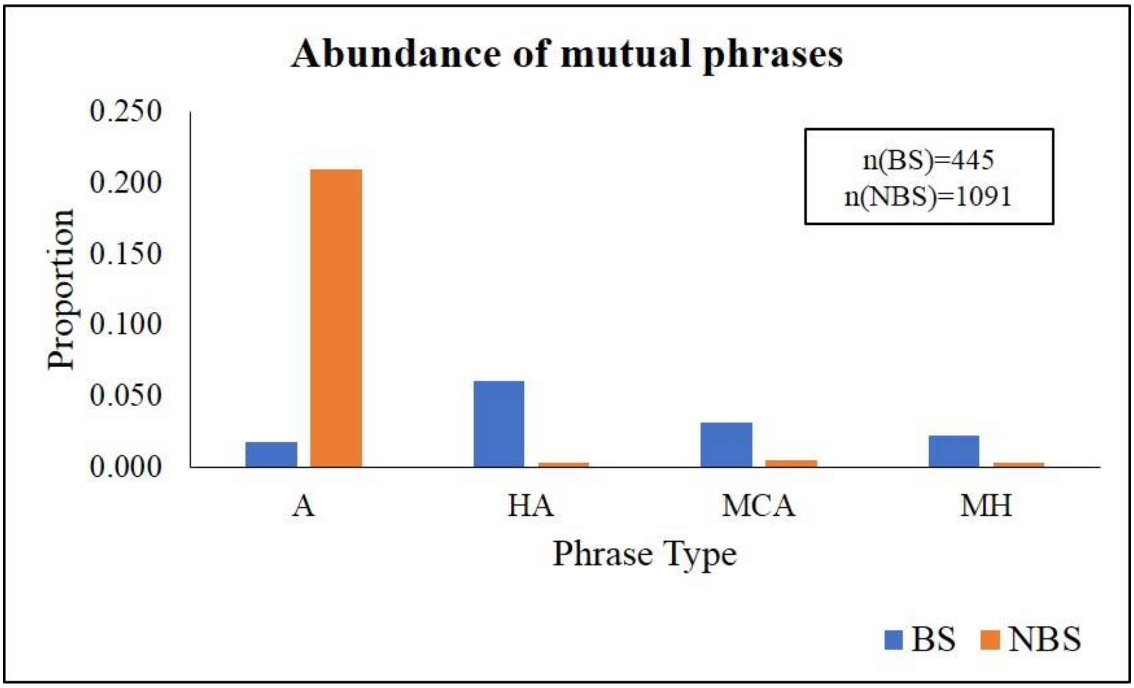


Fig 4.2: Graph depicting abundance of mutual phrases in the two seasons

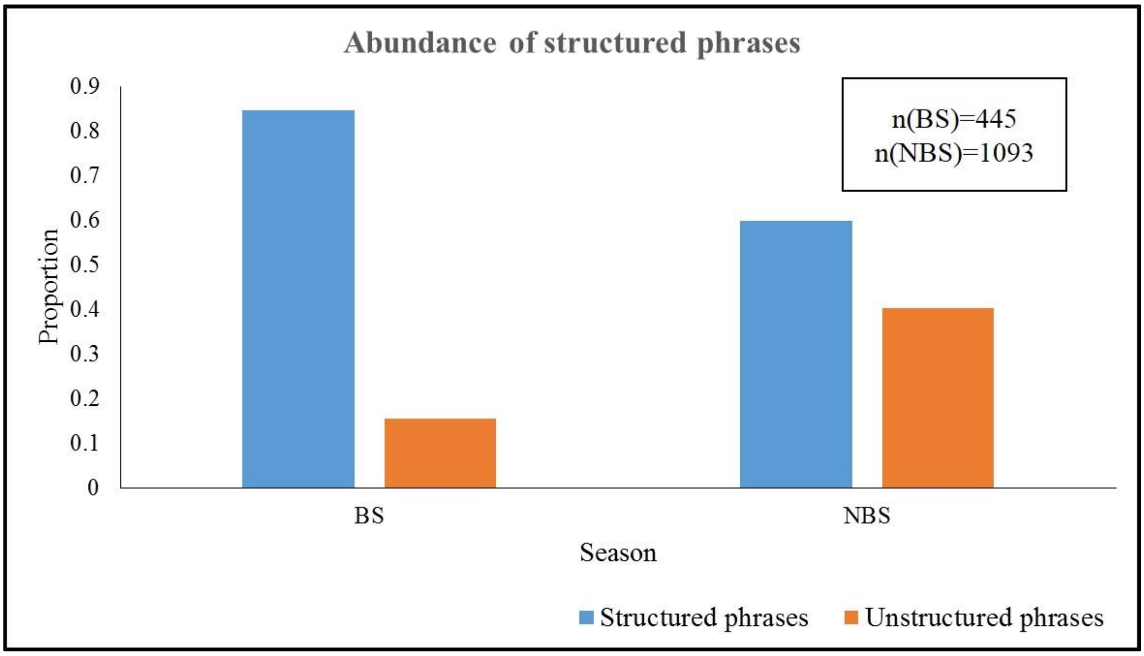


Fig 4.3: Graph depicting abundance of structured phrases in the two seasons

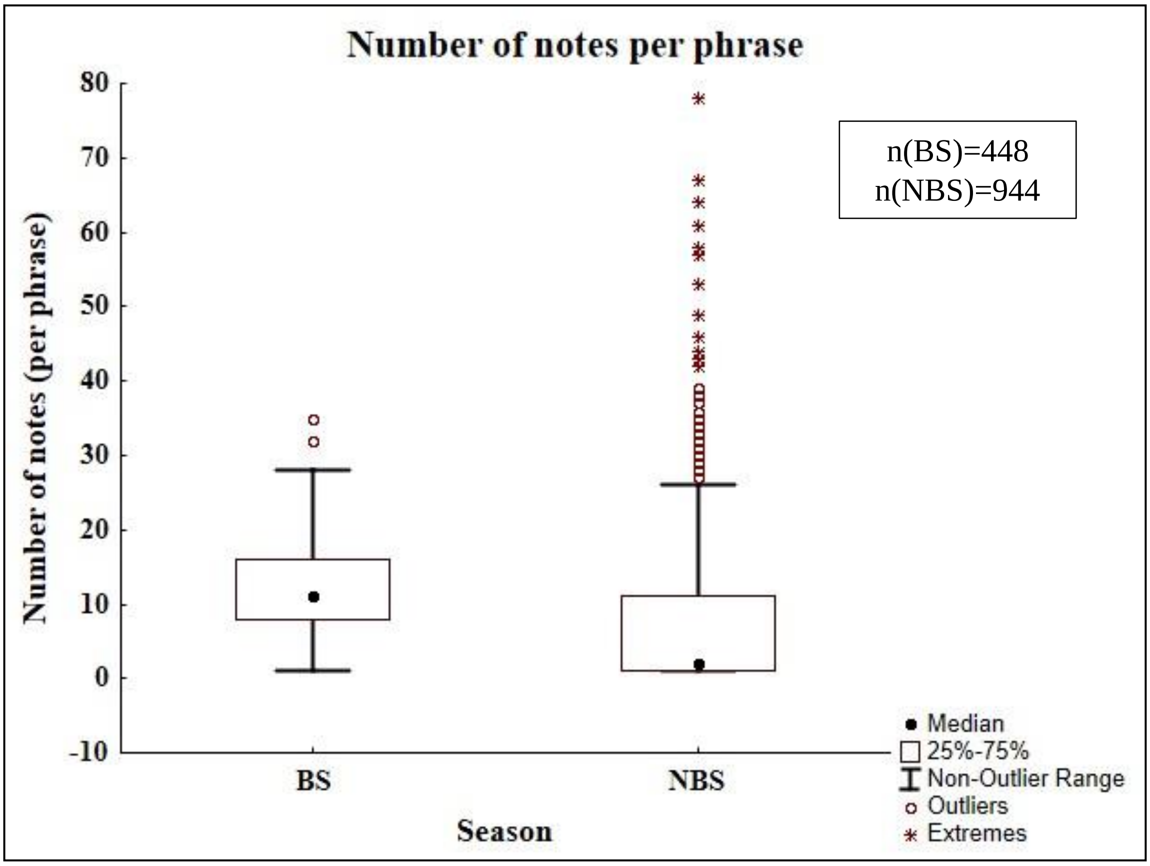


Fig 4.4: Graph depicting distribution of number of notes per phrase in the two seasons (Table A 2.6). * represents significant differences. Extreme outliers may be omitted.

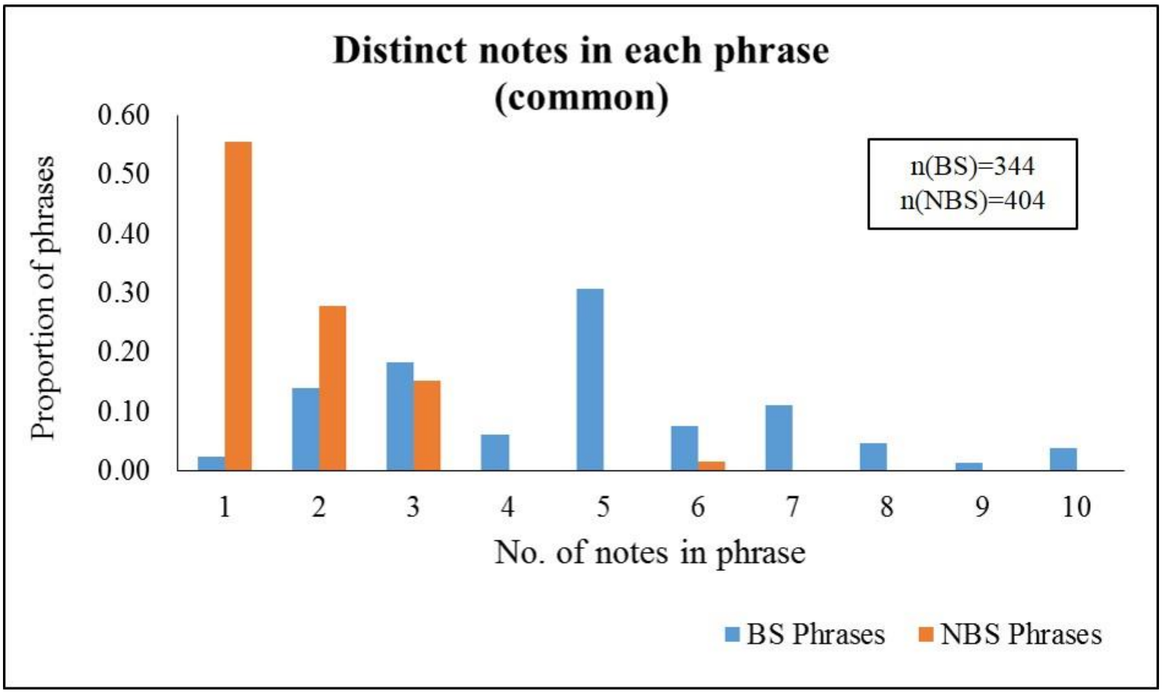


Fig 4.5: Graph depicting proportion of common phrases vs number of distinct notes (in order) in the two seasons (Table A 1.6)

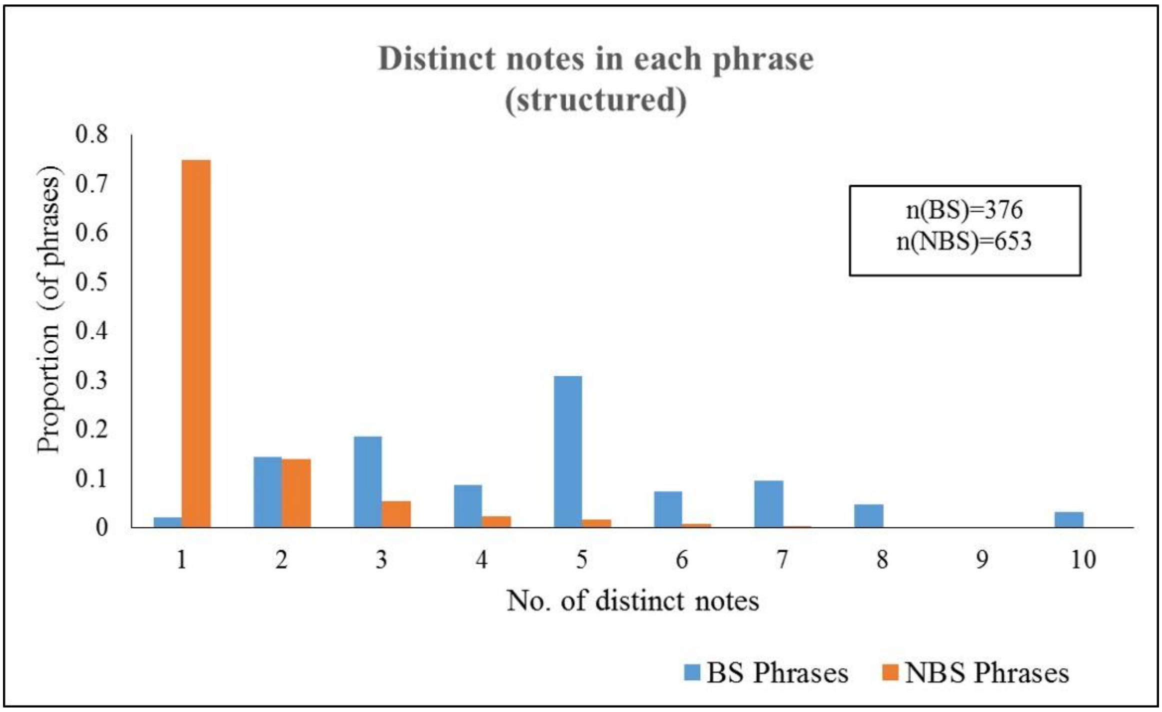


Fig 4.6: Graph depicting proportion of structured phrases vs number of distinct notes (in order) in the two seasons (Table A 1.7)

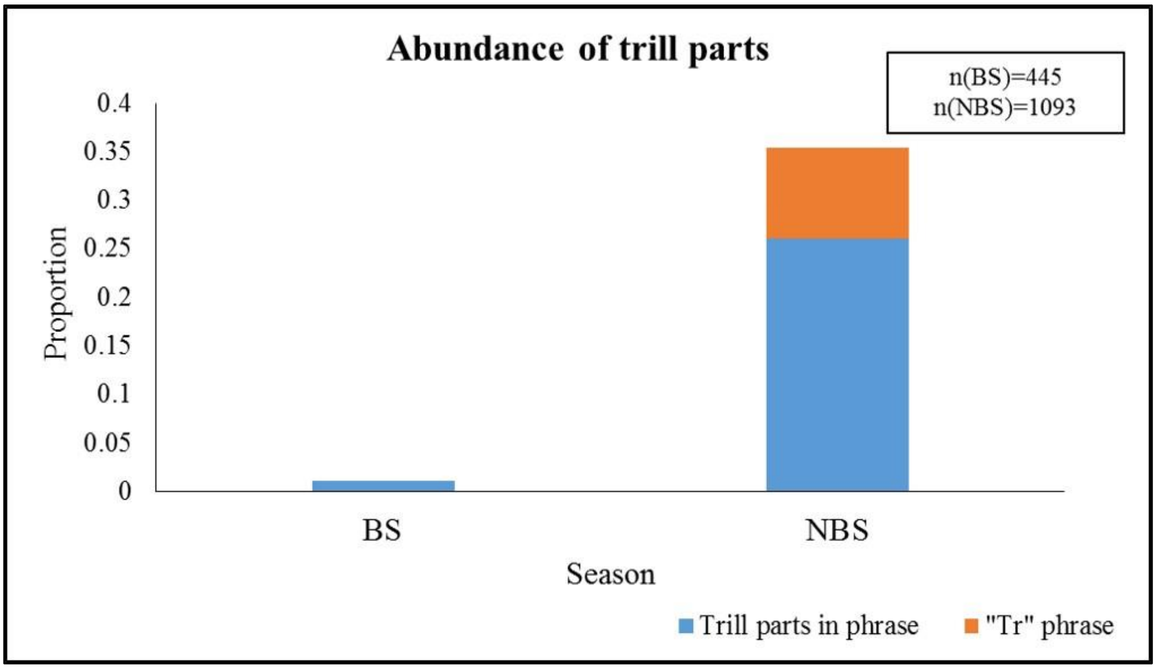


Fig 4.7: Graph depicting abundance of trill parts in the two seasons

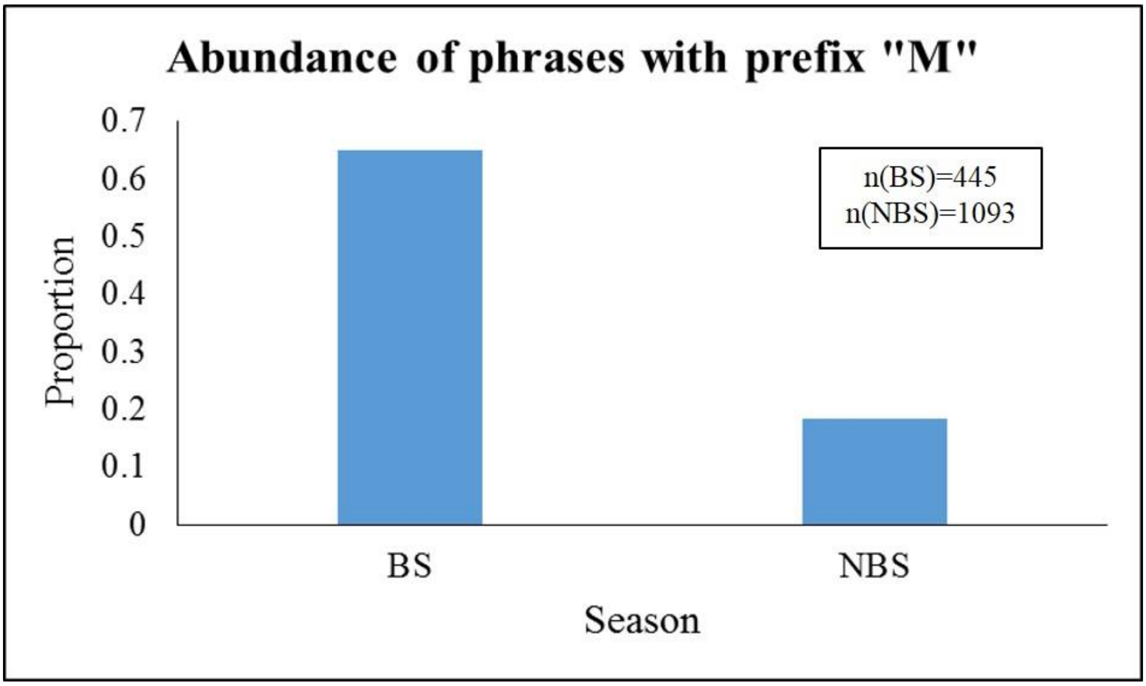


Fig 4.8: Graph depicting abundance of prefix in the two seasons

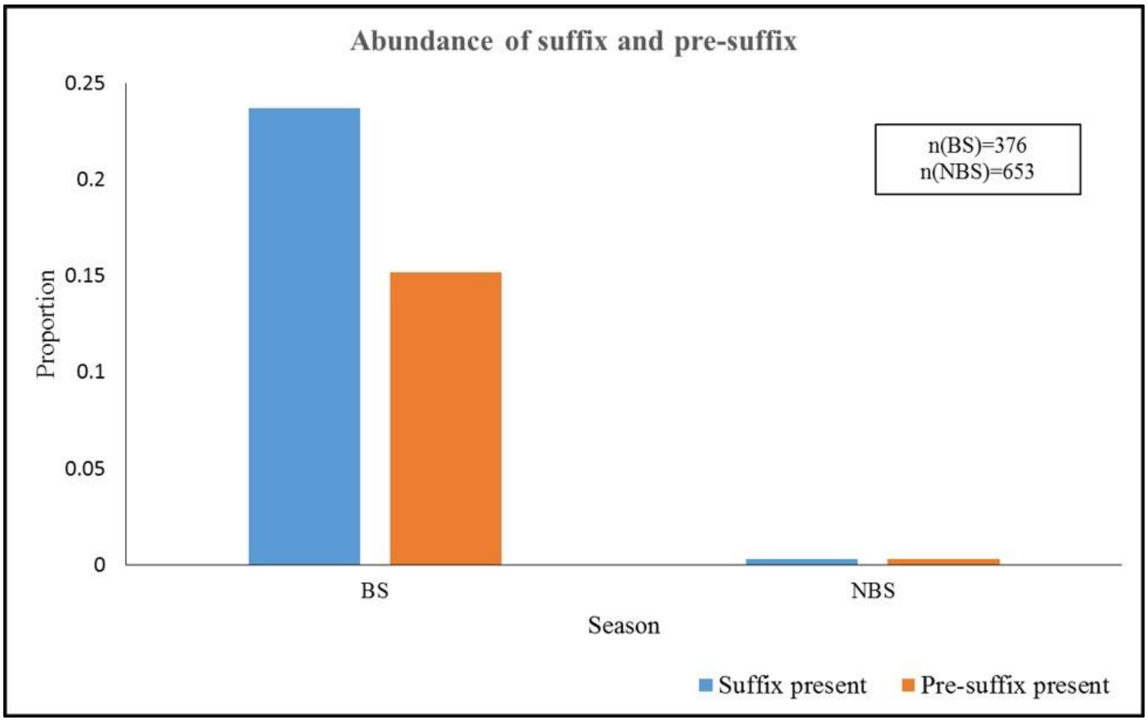


Fig 4.9: Graph depicting abundance of suffix and pre-suffix in the two seasons

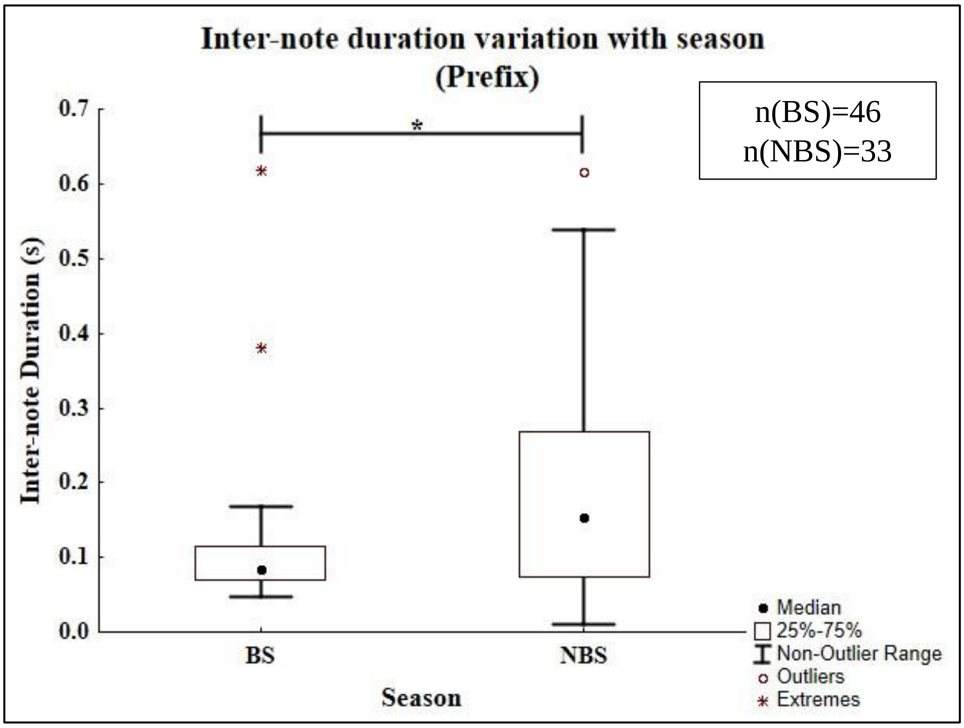


Fig 4.10: Graph depicting inter-note variation in prefix over two seasons. Mann-Whitney U test shows significant difference ($p<0.05$), with small effect size (Table A 2.7). * represents significant difference. Extreme outliers may be omitted.

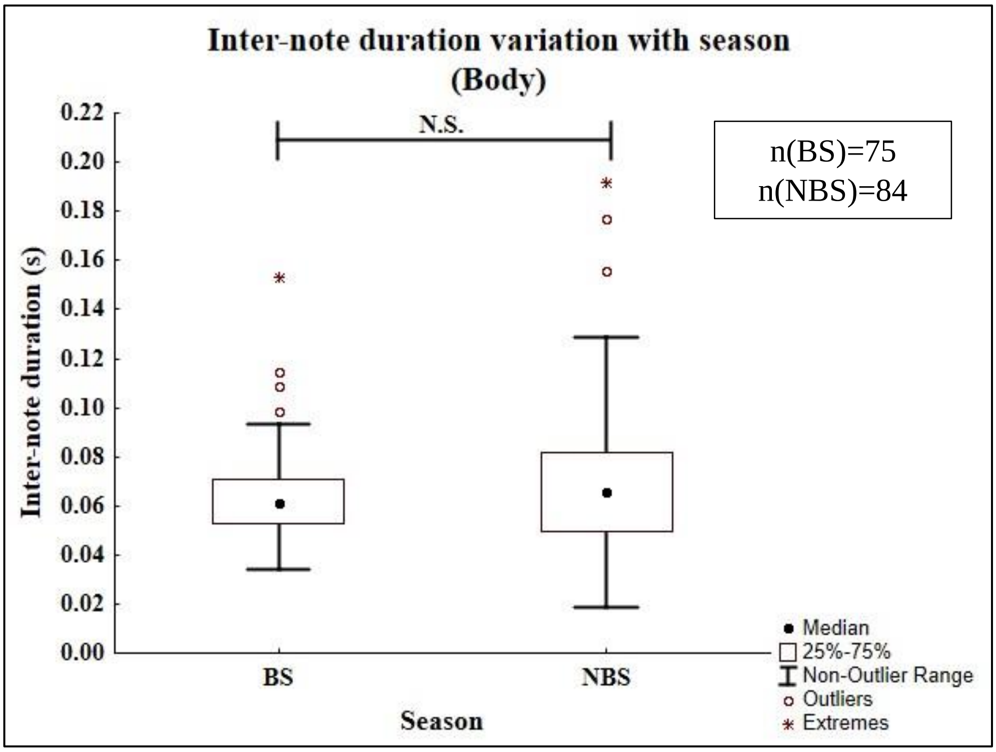


Fig 4.11: Graph depicting inter-note variation in body over two seasons. Mann-Whitney U test shows no significant difference ($p>0.05$) (Table A 2.7). N.S. represents non-significant difference. Extreme outliers may be omitted.

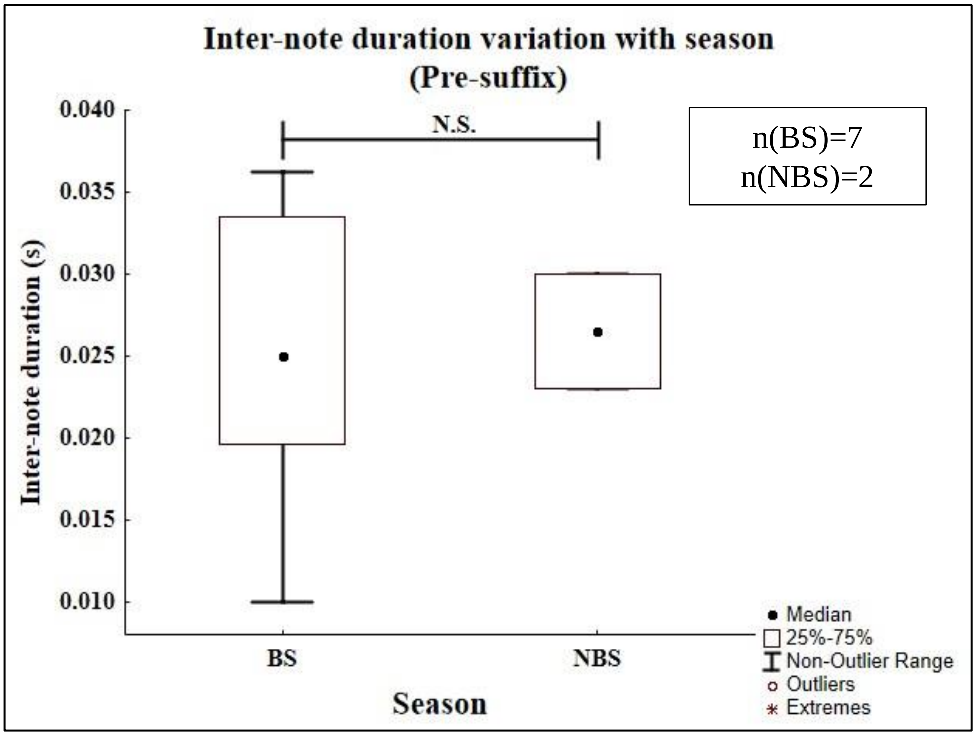


Fig 4.12: Graph depicting inter-note variation in pre-suffix over two seasons. Mann-Whitney U test shows no significant difference ($p>0.05$) (Table A 2.8). N.S. represents non-significant difference. Extreme outliers may be omitted.

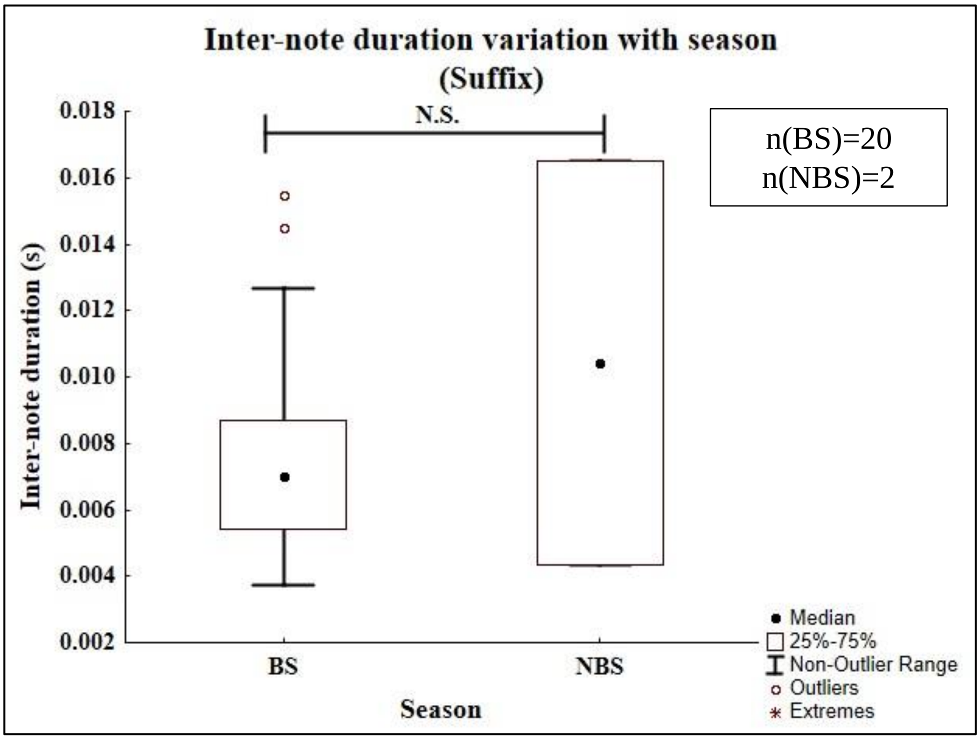


Fig 4.13: Graph depicting inter-note variation in suffix over two seasons. Mann-Whitney U test shows no significant difference (p>0.05) (Table A 2.7). N.S. represents non-significant difference. Extreme outliers may be omitted.

4.4 Conclusion

The song bout in breeding season is structured with spaced phrases, whereas in non-breeding season it is a continuous vocalisation without any set structure. Note repertoire changes, with some unique notes in each season. But, the change in phrase repertoire is much more pronounced. In breeding season, males produce medium length unique-noted phrases, whereas in non-breeding season, they are mostly isolated single-noted phrases. The proportion of both structured and common phrases reduces in non-breeding season, with an increase in distortion of notes. Trilling during song bout becomes a much more pronounced phenomena during the non-breeding season. Amongst the structured phrases, the abundance of suffix and pre-suffix falls immensely in the non-breeding season, providing further evidence into checking their role in sexual selection. The inter-note durations show that there is more difference between different parts in breeding season compared to non-breeding season, indicating more definite structure in the breeding season.

Chapter 5

5.1 Objective

To study temporal variation in various behaviour of Purple sunbird in non-breeding season

5.2 Methodology

5.2.1 Sampling location and behavioural recordings

Pre-liminary field observations and video recordings were used to construct the ethogram. This ethogram was then used to conduct the sampling on field. Focal animal sampling was employed with 1 min sample and 1 min rest in the IISER Mohali campus (30.6650° N, 76.7300° E, Punjab). All behaviours observed were noted down in the rest period. Date, time slot, location, sex of focal animal and behaviours observed were noted down. Sampling sessions were 75 minutes long and spread to cover each slot (between 6 am to 6 pm) twice in a week. Data was collected from two locations on campus for 33 days. In one week, while data was collected from one location, presence of individuals was ascertained at the other location.

5.2.2 Data Analyses

All data (presence/absence) was replicated in an excel file. Seven distinct behaviours were observed, namely: Vocalisation, Displacement, Foraging, Grooming, Antagonism, Body Movement and Stationary. Out of these, the first five behaviours are believed to utilise most energy, and hence used to study the time activity budget (TAB) and diel patterns. The frequency table of various behaviours portrayed during song bout was constructed. One set represents all singing data points and thus the proportion of different behaviours amongst those data points. The other set represents middle singing points, i.e the first and last samples of an entire song bout were removed. This is to ensure that behaviours that were exhibited before or after song bout are not mis-represented. On field observation suggests that the focal male is perching at one location during the song bout. It usually shows grooming activities and other body movements during this time. Hence, “Body Movement” and “Stationary” behaviours have been included in this analysis.

5.2.3 Statistical Analyses

A total of 802 samples of 1 minute each were obtained. These accounted for 13 hours and 37 minutes of recording. Statistical tests were run in Statistica version 10. The sample set of data points for each behaviour was constructed by taking the proportions in each sampling duration for the specific timeslot (Table A 1.8).

5.2.3.1 Time-Activity Budget (TAB)

Test for normality (Kolmogorov-Smirnov and Lilliefors test, Shapiro-Wilk test) showed that data was not normal for all behaviours and hence non-parametric tests were employed. Kruskal-Wallis ANOVA showed significant ($p<0.05$) difference between the proportion of all behaviours throughout the day. Hence, a post-hoc Mann-Whitney U test was employed (alpha=0.05).

5.2.3.2 Diel Pattern of behaviours

Test for normality (Kolmogorov-Smirnov and Lilliefors test, Shapiro-Wilk test) showed that data was normal for ‘FORAGING’ and not normal for other behaviours. Hence, for ‘FORAGING’, one-way ANOVA was performed (alpha=0.05). The difference between different time slots was not significant. For other behaviours, Kruskal-Wallis ANOVA (alpha=0.05) was conducted.

5.2.3.3 Behaviours associated with song

Continuous song bout samples (more than 3) coming from single individuals were separated to perform statistical analysis. Proportion for each behaviour for each individual was calculated which gave the sample set ($n=11$ for each behaviour) to run the analysis. Test for normality (Kolmogorov-Smirnov and Lilliefors test, Shapiro-Wilk test) showed that data was not normal for all behaviours and hence non-parametric tests were employed.

Kruskal-Wallis ANOVA showed significant ($p<0.05$) difference. Hence, a post-hoc Mann-Whitney U test was employed (alpha=0.05).

5.3 Result

The ethogram of all behaviours with their definitions is given in Table 4.1. All seven behaviours were recorded through the sampling. The TAB (Fig 5.1) shows that "Displacement" is the most common behaviour (and is significantly different from others, MWU, $p<0.05$) which agrees with the dynamic nature of this bird. This is followed by "Vocalisation" (significantly different from others, MWU, $p<0.05$), and then "Foraging" and "Grooming", which do not show a significant difference (MWU, $p>0.05$). "Antagonism" is the least abundant behaviour (and significantly different from others, MWU, $p<0.05$) in non-breeding season. The frequency of each behaviour during each time slot is given in Fig 5.2 (Table A 2.9). None of the behaviours showed a diel pattern (MWU, $p>0.05$) (Fig 5.3, Table A 2.11). During the song bout, the male is mostly stationary and performs body movements at a place. This is portrayed by both the frequency table and the statistical test (Fig 5.4, Table A 2.10). The two most abundant behaviours namely stationary and body movement do not show a significant difference between them (MWU, $p>0.05$, Fig 5.5). This is followed by grooming and foraging behaviours (not significantly different from one another, MWU, $p>0.05$, Fig 5.5). And the least abundant is antagonism.

S. no.	Behaviour	Sub-category	Desription
1	Vocalisation	Singing	Producing continuous phrases made up of notes interspersed with short empty durations while sitting at one place.
2		Hop Phrase	The bird jumps/flies from one place to another singing phrases interspersed with other calls or foraging behaviour. Constant movment during phrase production. Could be at beginning or at the end of a song.
3		Call	Any other vocalisation except (1) and (2). Usually, a continious repetiotion of a single note.
4	Displacement	Long Flight	The bird moves itself via rapid flapping of the wings through a large distance. Mostly accompanied by call.
5		Short Flight	The bird moves itself via rapid flapping of the wings through a short distance (between branches on same plant, or between neighbouring plants).
6		Hopping (Smith and Wassmer 2016)	The bird moves from one place to another by propelling itself with its feet.
7		Flapping	Rapidly moving the wings at same position while bill insertion. Body seems stretched. Momentary stop mid air while rapidly moving wings.
8		Swooping	Recapturing the food particles with bill after it falls. Usually swift downward motion accompanied with wing movement.
9		Turning	Rotaing the body by changing the orientation of the feet at 180 degree angle at the same position
10		Jumping	Leaves grip on current branch and falls down. Or perfroms a back flip.
11		Walking	Moving short distances by alternatively forwarding each leg on surface
12		Fly twirl	Takes a 360 degree turn while flying and lands (upward or downward)
13	Foraging	Bill Insertion	Bird puts its beak in the flower from the front to consume nectar/ insect.
14		Picking	Bird pecks at the surface of petal attachment on the flower (floral axis). They do the same with leaves and branch as well.
15		Side Picking	Bird will insert the bill from the side (through adjacent petals) to reach the floral axis
16		Pulling	Using its beak to hold onto leaves/branches/petals it applies a backward force to try to detach the former from its base.
17		Flycatching	Flying after a nearby flying insect and catching it using the bill. Then perching at a branch.
18		Still catching	Perching on a branch and catching a within reach flying insect with the bill.
19		Food preparation	Beating the caught insect on the branch to remove wings and make it immobile.
20		Defecation	Releases droplet of waiste from under the tail, Usually acoompanied by a small dip in position

Table 5.1 (a): List of behaviours (ethogram) observed in non-breeding season

21	Grooming	Autopreening (adapted from Smith and Wassmer 2016)	Bird smooths and cleans with its beak its own wings, throat, vent, and area around the legs. The neck and abdomen are tended to by bending the neck backwards and approaching from above. The breast is groomed by bending the head downwards. The top of the wing is smooth and cleaned by sideways and approaching from above. The underwing is grromed by lifting the wing and approaching from underneath. It bends backwards at tends to the spread tail feathers. It uses its beak to groom its foot.
22		Foot Scratching	Birds brings the foot over the shoulder on the same side to scratch the head, neck area and beak. Also might use the foot to wipe the underside of the wing on the same side.
23		Scratching	Rubs a body part on the branch
24		Fluffing (Smith and Wassmer 2016)	Feathers are erected from the head downwards towards the vent then smoothed down rapidly.
25		Bill wiping (adapted from Smith and Wassmer 2016)	The individual rubs both sides of its bill on a branch.
26	Body Movement	Head movement	Tilting sideways or rotating the head about the neck joint
27		Tongue protusion	Sticking out its tongue
28		Partial turning	Body rotates with the head but feet in same position
29		Stretching	Elongates the body along one axis and appears thinner. Upward, downward, while side perching. To get hold of things.
30		Shaking	Rapidly moves its body for short duration. Toshoo fly as well
31		Wing opening	Partially or fully spreading the wings on the side but not for flying. Sometimes accompanied with speading tail feathers.
32		Mouth opening	The two bill parts are apart. Sometimes the tongue hangs out.
33		Bending Forward	The chest and head are lowered forward without the tail moving upwards.
34		Bending Backward	The chest and head are lowered backward without the tail moving upwards.
35	Antagonistic behaviour	Chasing	Active: One individual flies after another individual replacing the latter from its initial position. Mostly accompanied by trilling sound. Passive: The incoming of the focal may lead to moving away of another individual without the focal chasing it away actively.
36		Chased	The focal abruptly changes its position due to incoming of another individual.
37	Stationary	Perching	The tail makes an angle of almost 90 degree with respect to feet. Includes when bird perches on a vertical branch, hence sideways
38		Inverted Perching	The tail makes an angle greater than 90 degree with respect to feet. Tail is upward and head is downward in position.
39		Rest perching	The tail makes an angle much less than 90 degree with respect to feet.
40	Rare	Beaking	An individual pecks its beak on another individual. (One sighting when M beaks F)

Table 5.1 (b): List of behaviours (ethogram) observed in non-breeding season

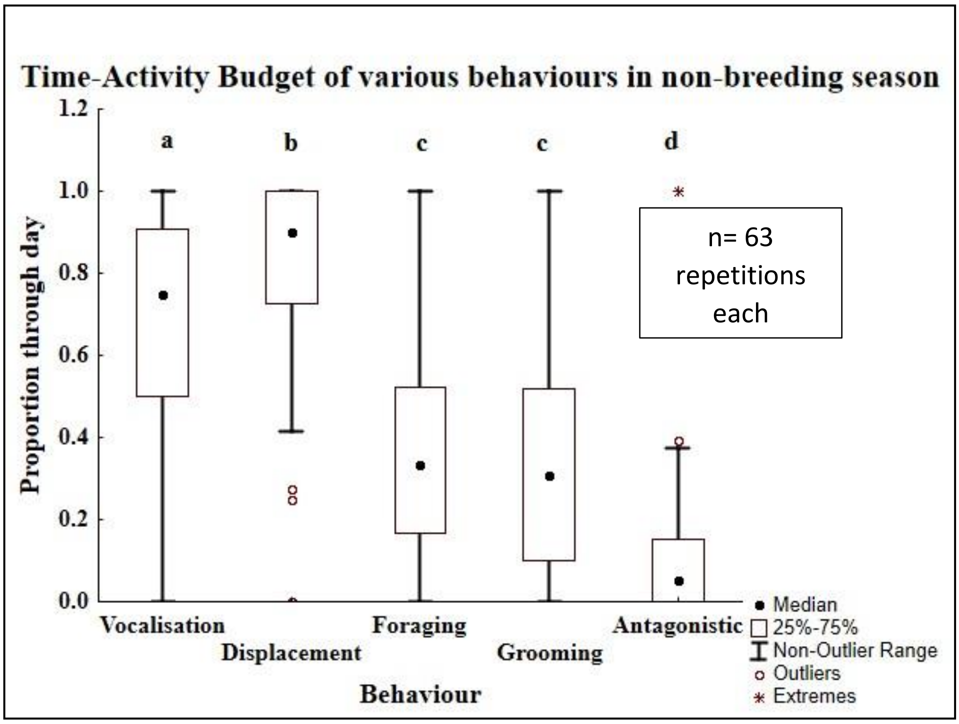


Fig 5.1: Graph representing time activity budget of different behaviours. Mann-Whitney U tests shows significant difference between most groups ($p<0.05$) (Table A 2.9). Different letters (a,b,c,d) represent significant differences. Extreme outliers may be omitted.

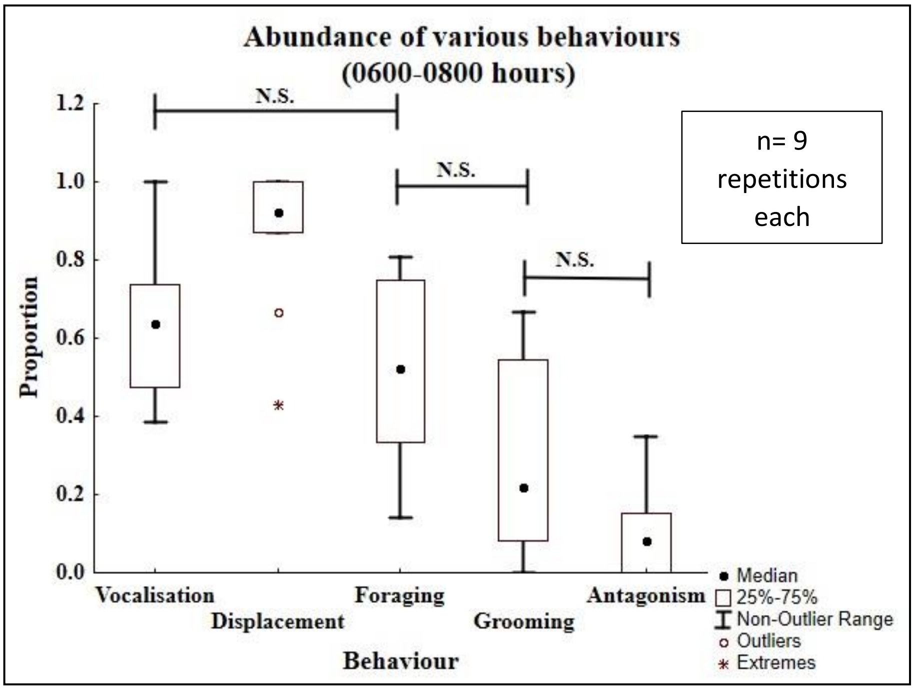


Fig 5.2 (a): Graph representing proportion of behaviours during 0600-0800 hours. Mann-Whitney U tests (alpha=0.05). NS: Non-significant. Rest are significant. (Table A 2.12). Extreme outliers may be omitted.

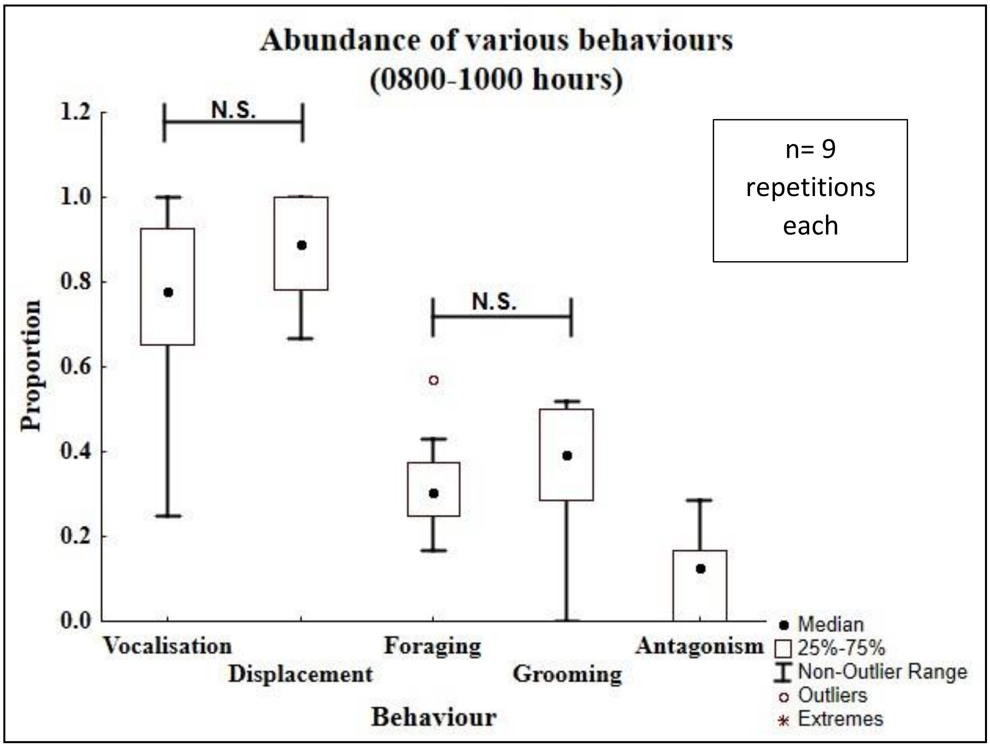


Fig 5.2 (b): Graph representing proportion of behaviours during 0800-1000 hours. Mann-Whitney U tests (alpha=0.05). NS: Non-significant. Rest are significant. (Table A 2.9). Extreme outliers may be omitted.

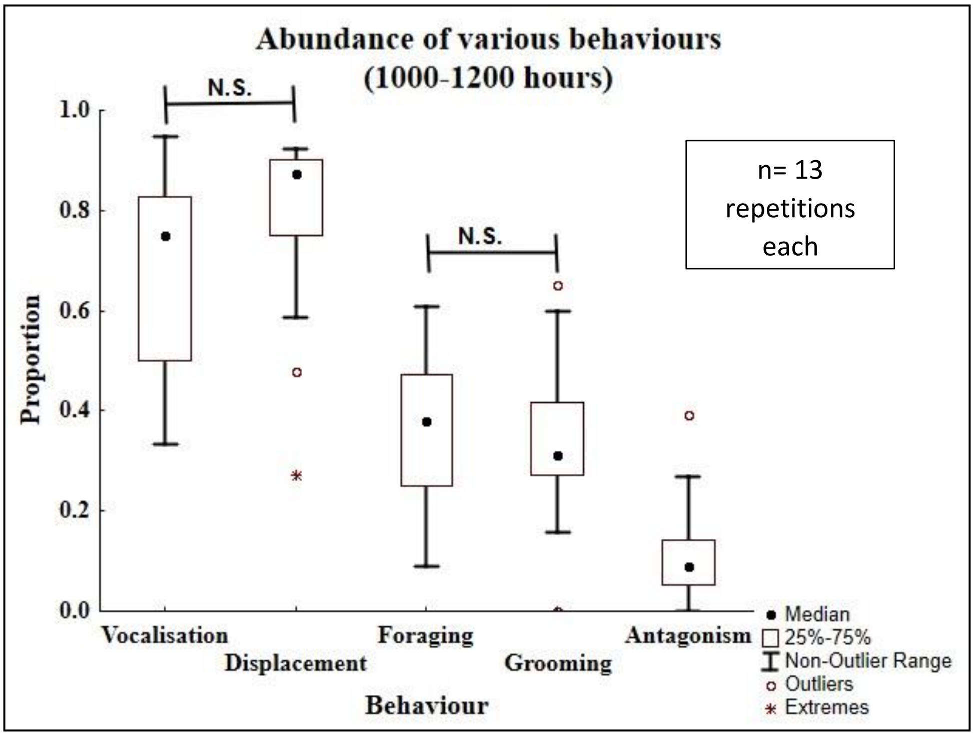


Fig 5.2 (c): Graph representing proportion of behaviours during 1000-1200 hours. Mann-Whitney U tests (alpha=0.05). NS: Non-significant. Rest are significant. (Table A 2.9). Extreme outliers may be omitted.

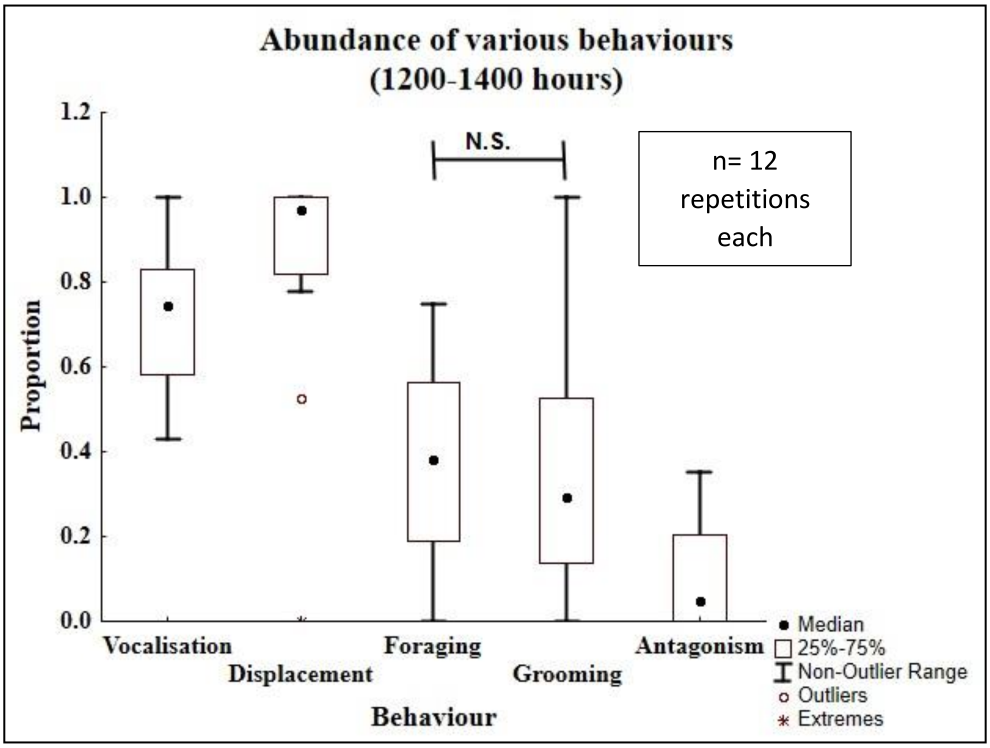


Fig 5.2 (d): Graph representing proportion of behaviours during 1200-1400 hours. Mann-Whitney U tests (alpha=0.05). NS: Non-significant. Rest are significant. (Table 2.9). Extreme outliers may be omitted.

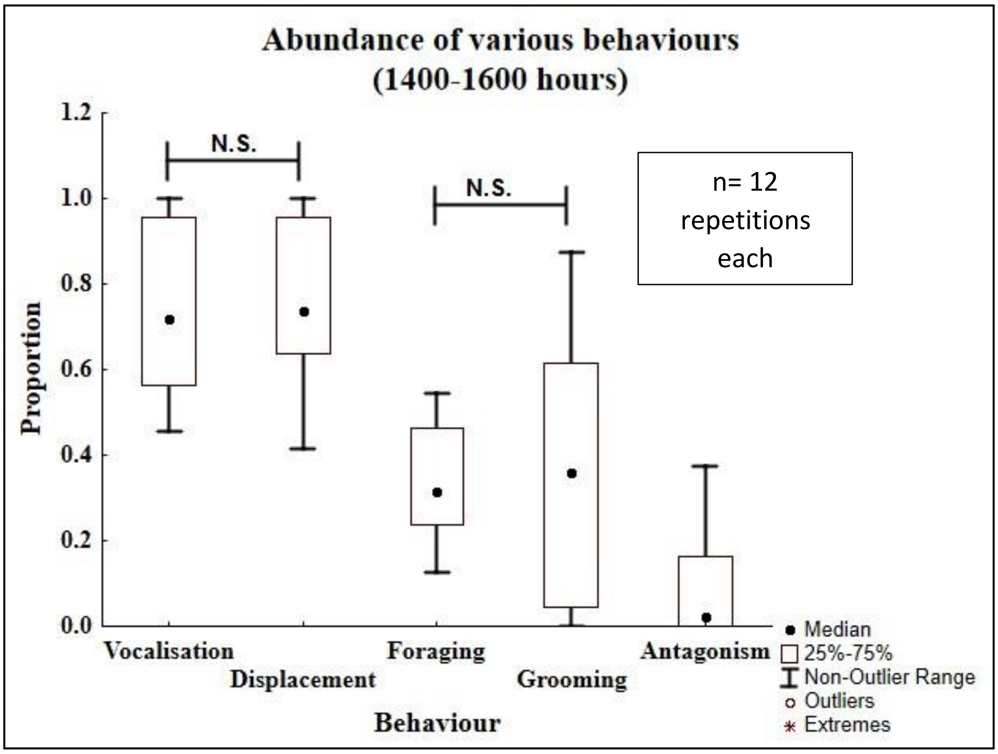


Fig 5.2 (e): Graph representing proportion of behaviours during 1400-1600 hours. Mann-Whitney U tests (alpha=0.05). NS: Non-significant. Rest are significant. (Table A 2.9). Extreme outliers may be omitted.

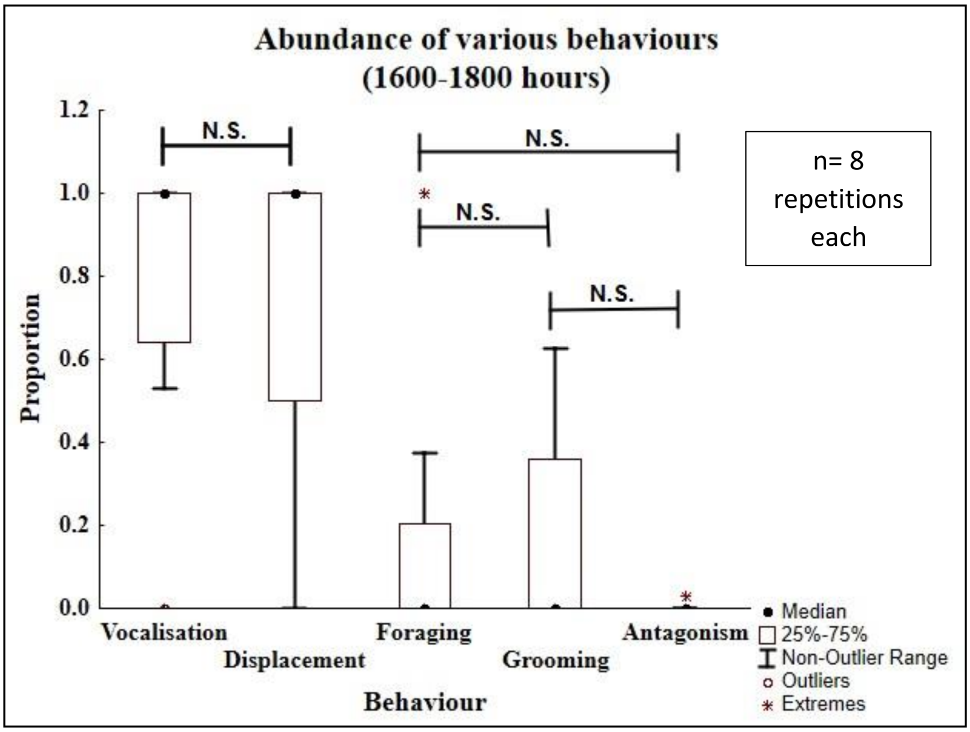


Fig 5.2 (f): Graph representing proportion of behaviours during 1600-1800 hours. Mann-Whitney U tests (alpha=0.05). NS: Non-significant. Rest are significant. (Table A 2.9). Extreme outliers may be omitted.

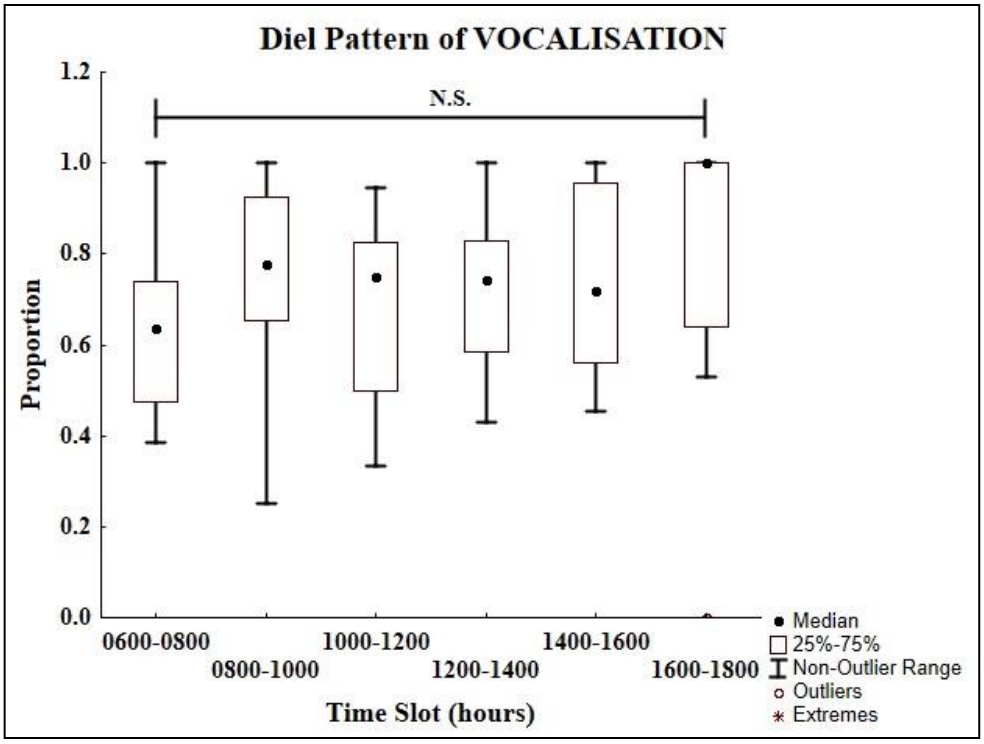


Fig 5.3 (a): Graph depicting diel pattern of Vocalisation during non-breeding season. Mann-Whitney U test (alpha=0.05) showed non-significant (NS) differences. (Table A 2.11). Extreme outliers may be omitted.

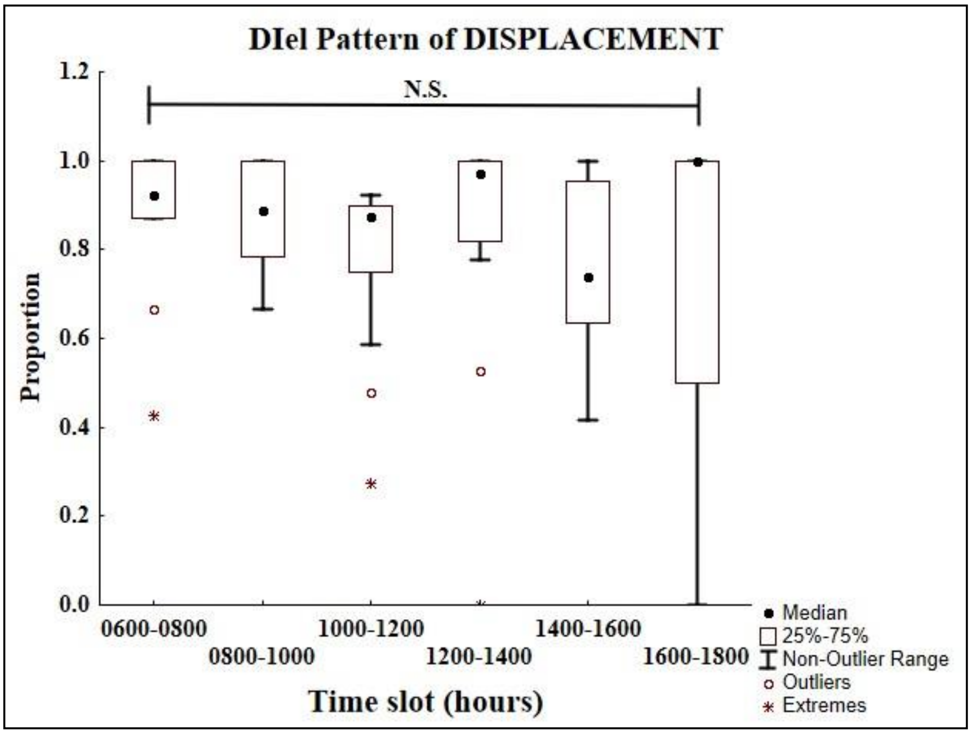


Fig 5.3 (b): Graph depicting diel pattern of Displacement during non-breeding season. Mann-Whitney U test (alpha=0.05) showed non-significant (NS) differences. (Table A 2.11). Extreme outliers may be omitted.

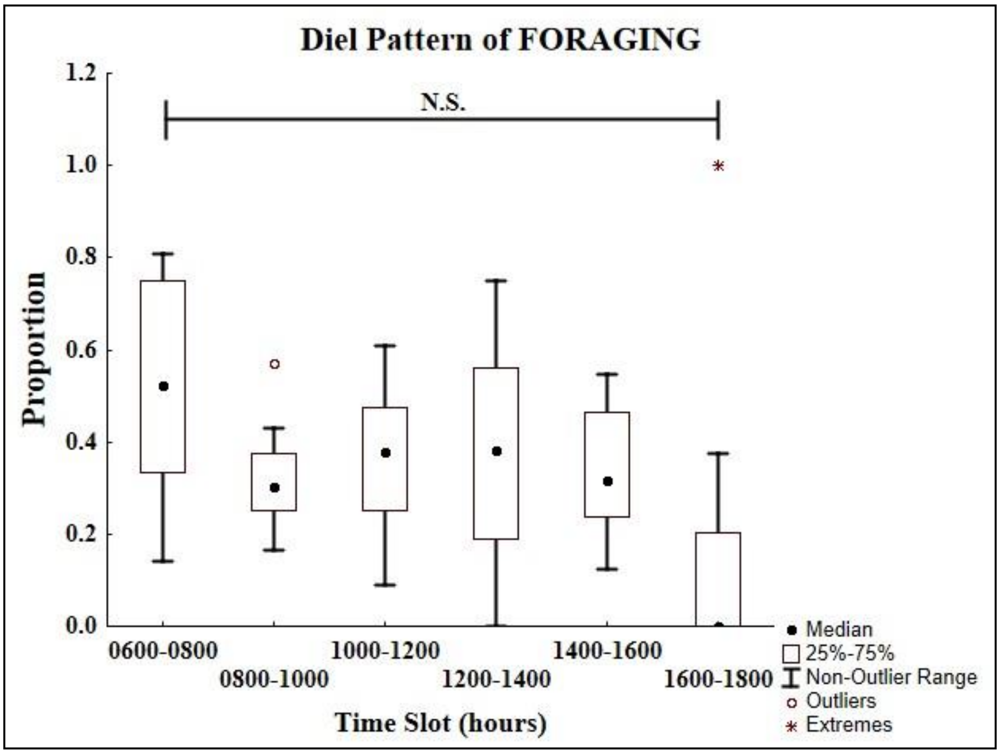


Fig 5.3 (c): Graph depicting diel pattern of Foraging during non-breeding season. One-way ANOVA (alpha=0.05) showed non-significant (NS) differences. (Table A 2.11). Extreme outliers may be omitted.

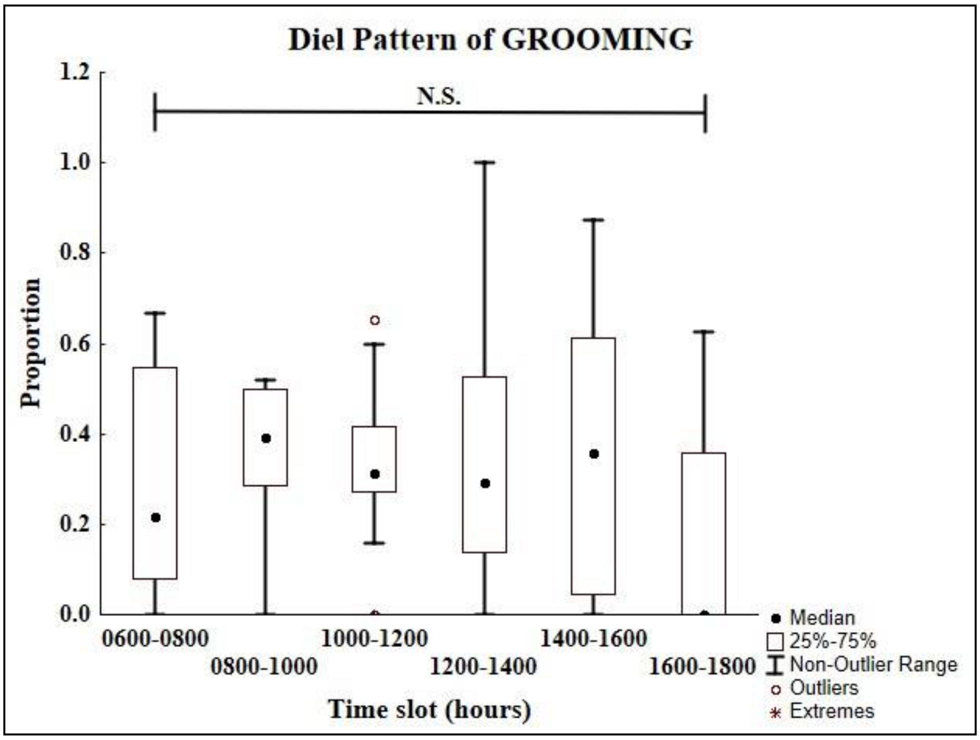


Fig 5.3 (d): Graph depicting diel pattern of Grooming during non-breeding season. Mann-Whitney U test (alpha=0.05) showed non-significant (NS) differences. (Table A 2.11). Extreme outliers may be omitted.

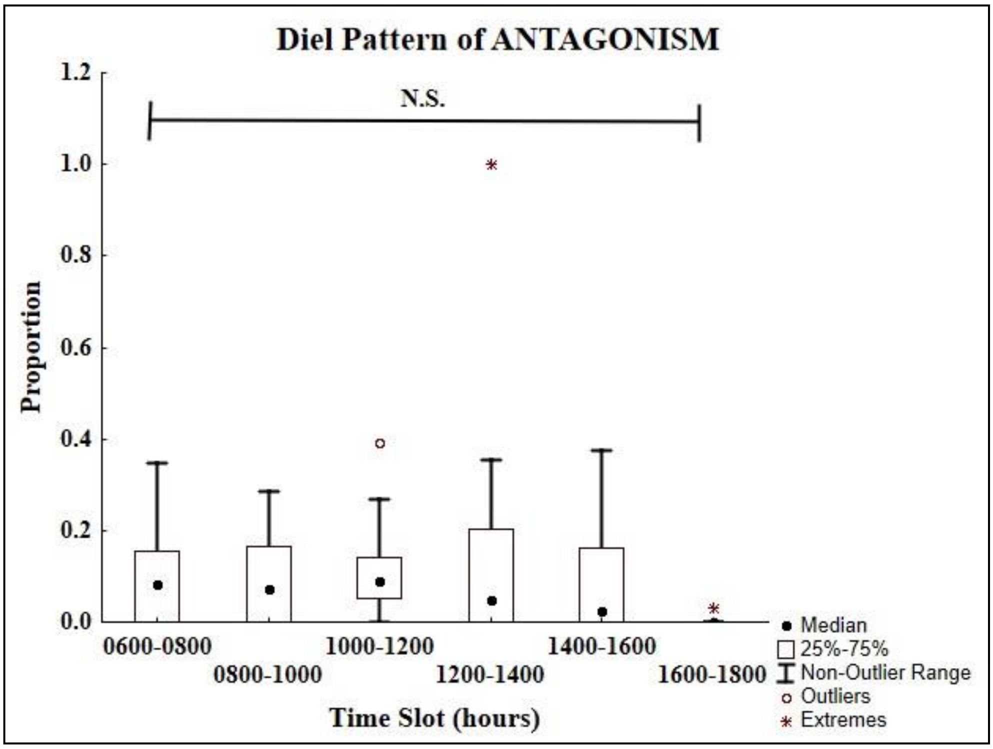


Fig 5.3 (e): Graph depicting diel pattern of Antagonism during non-breeding season. Mann-Whitney U test (alpha=0.05) showed non-significant (NS) differences. (Table A 2.11). Extreme outliers may be omitted.

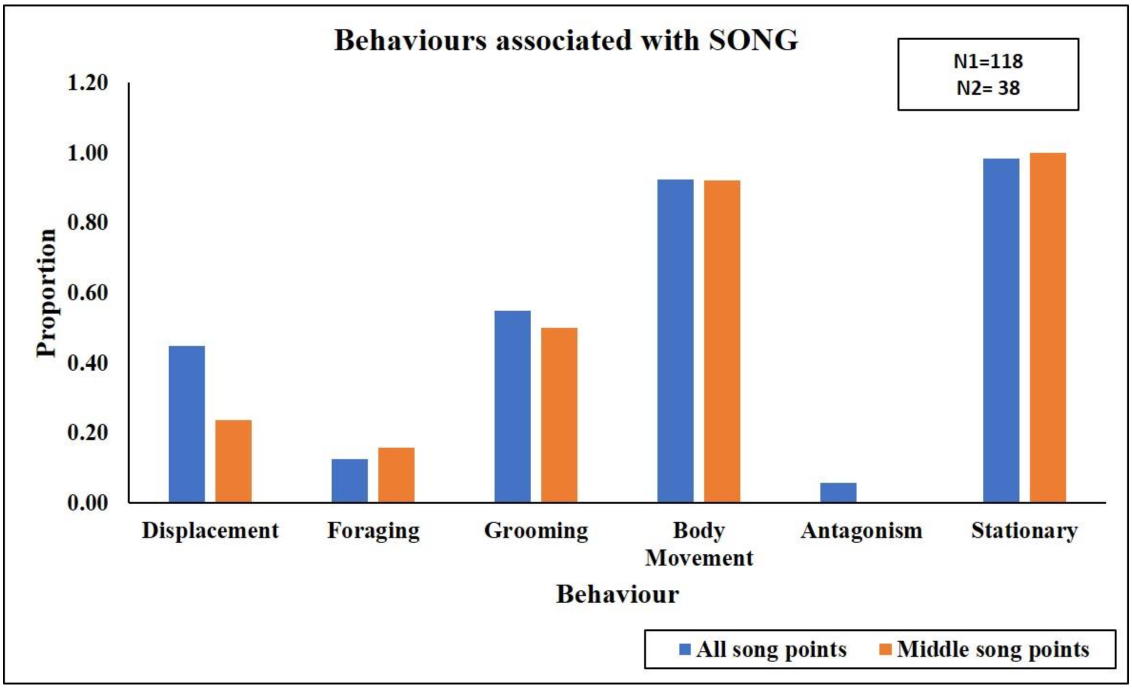


Fig 5.4: Graph depicting proportion of other behaviours whilst Singing. N1: All song points sample size; N2: Middle song points sample size

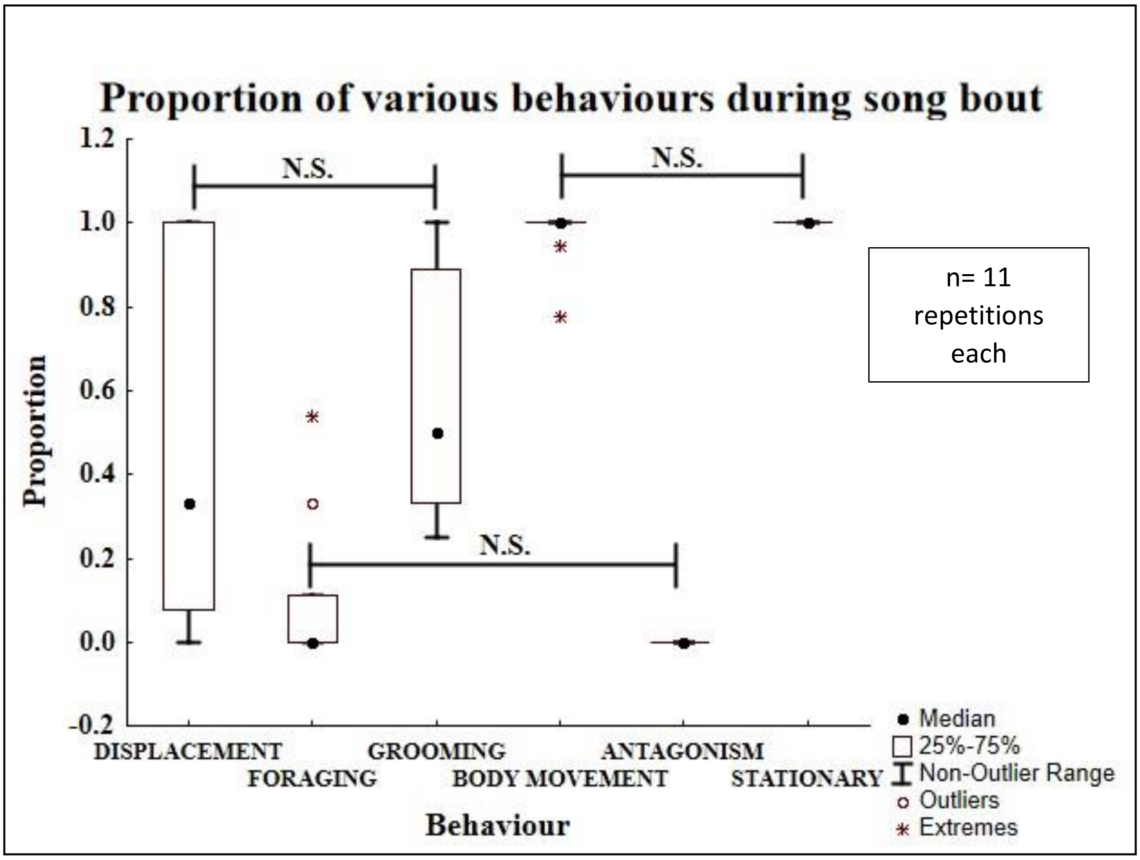


Fig 5.5: Graph depicting proportion of other behaviours whilst Singing from 11 individuals. Mann-Whitney U test (alpha=0.05) was performed. NS: Non-significant. Rest are significant. (Table A 2.10). Extreme outliers may be omitted.

5.4 Conclusion

The time-activity budget showed that “Displacement” is the most common behaviour throughout the day during the non-breeding season. Also, “Antagonism” is the least common. No diel variation in behaviour was observed. While the males sing, they are mostly “Stationary” and show “Body Movement” at one position. Also, foraging and antagonism during the song bout are the least.

Chapter 6: Discussion

This thesis provides evidence that there is structural variation in the song of the Purple sunbird (*Cinnyris asiaticus*) over breeding and non-breeding seasons. No diel pattern is observed in the behaviours in non-breeding season. The males are mostly found to be stationary and perform body movements at the same position while in a song bout during the non-breeding season. A similar behavioural study in the breeding season, can possibly highlight any visual sexual display by comparing the frequencies of behaviours in the two seasons. This can also help quantify the response of conspecifics to a male song which can further provide a basis to run various playback experiments. Song output (C. K. Catchpole, 1973) and structure (Hennin et al., 2009) is also documented to change through the breeding season. A similar output study can help understand the functionality of the song and its role in sexual selection. A study focussing on structural variation in song over the breeding season can help understand the development of song in the early fledglings (born in earlier months of breeding season) and the late fledglings. This done with tagged fledglings can help ascertain any differences between their songs, as early fledglings are able to hear more song bouts (through the rest of the breeding season) compared to the late fledglings. Since a strong variation was found in the abundance of suffix and pre-suffix between the two seasons, its role in sexual selection can be tested through playback experiments. The inter-note results of phrases in breeding season highlights that the time interval falls gradually from prefix to body to pre-suffix to suffix or can be sudden from body to suffix. This modulation of time interval and thus breath would be an interesting aspect to investigate. Some studies suggest that trilling is expensive, produced more in the breeding season, possibly being an indicator of better quality (Hill, Amiot, Ludbrook, & Ji, 2015). In this study, the opposite is observed with trilling increasing during the non-breeding season. To decode this, the definitions and characteristics (like trill rate, frequency range, trill duration, trill note duration and others) used in the two studies would have to be compared foremost.

If the idea is similar, then there could be physiological reasons behind this variation, studying which could yield some interesting behavioural aspects in the model species Testosterone dependent changes in song trills have been reported before (Black redstart: Apfelbeck, Kiefer, Mortega, Goymann, & Kipper, 2012; White-crowned sparrow: Whaling, Nelson, & Marler, 1995). It was noted during field observations that the males prefer a certain range of sunlight (local temperature/warmth) to begin a song bout. This can possibly be tested by measuring the lux levels at the perching position during a song bout. Anecdotal field observation also suggests that song output showed a cyclic pattern over the year, with high intensity during the breeding season, falling gradually through the months of September and October, and very low in December and January and rising up gradually through February and March and into the next breeding season. Similar anecdotes were observed for amplitude of the song bout which is much higher in breeding season compared to the non-breeding season. Hence, a study designed to quantify variation in both these characters would yield more insight into its song acoustics. At the level of individual, variation has been reported in song repertoires (Osiejuk, Ratyńska, Cygan, & Dale, 2003) and element/syllable repertoire (Harris & Lemon, 1972) and thus, can be studied. Studies can be done on a larger geographical area, with varying environmental factors. This can help understand the repertoire variation with vegetation, climate, anthropogenic effects (Red-winged blackbirds: Hanna, Blouin-Demers, Wilson, & Mennill, 2011; Purple sunbird: Singh et al., 2019) and other geographical factors. Since this bird is widespread across India, attempting a dialect study in various regions would be interesting. Dialect has been reported in the song of Song sparrows (Bell, Slabbekoorn, & Jesse, 2003; Harris & Lemon, 1972). Many sister sunbird species are present in India. These occur in allopatric regions (like olive-backed sunbird; Andaman and Nicobar Islands, India) and sympatric regions (purple rumped sunbirds; southern India (Grimmett, Inskipp, & Inskipp, 2011b). Thus, comparing the presence and structural similarity of song amongst all these species can give insight into the evolution of song.

This study opens avenues to study different levels of variation in the song structure. There are multiple questions that can be asked on variation in individual, group, species, space, and time themes.

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APPENDIX 1: Data tables

A 1.1: Table of all phrases in breeding season highlighting their abundance and classification

S. No.	Phrase	Repetition	Proportion	Classification	
1	MBEQL	71	0.160	Structured	COMMON
2	HA	27	0.061	Structured	
3	MDOKL	20	0.045	Structured	
4	MDOKLJZ	17	0.038	Structured	
5	HAKLJFL	17	0.038	Structured	
6	MCA	14	0.031	Structured	
7	MHA	14	0.031	Structured	
8	HA[50]	10	0.022	Structured	
9	MH	10	0.022	Structured	
10	M[4]OKLI	9	0.020	Structured	
11	MBE	9	0.020	Structured	
12	MHSKL	9	0.020	Structured	
13	A	8	0.018	Structured	
14	MCASLJFL	8	0.018	Structured	
15	MHSJFL	8	0.018	Structured	
16	M[4]OKLILJFL	7	0.016	Structured	
17	YA[1]LJFL	6	0.013		
18	DEL	6	0.013	Structured	
19	HA[50]K	6	0.013	Structured	
20	HYJFL	6	0.013	Structured	
21	DOKL	5	0.011	Structured	
22	HAKL	5	0.011	Structured	
23	MDOK	5	0.011	Structured	
24	MDG	5	0.011	Structured	
25	MHS	5	0.011	Structured	
26	MHSKLJFL	5	0.011	Structured	
27	MHSKLTJFL	5	0.011		
28	DELJFL	4	0.009	Structured	
29	YA	4	0.009	Structured	
30	CT	4	0.009	Structured	
31	M[4]	3	0.007	Structured	
32	MBDOKLJZ	3	0.007		
33	MDOKLILJFL	3	0.007	Structured	
34	MDWTJFL	3	0.007		
35	MDGJFLKJFL	3	0.007		
36	HY	2	0.004	Structured	RARE
37	AJFL	2	0.004	Structured	
38	AGJFL	2	0.004		
39	YAKLJFL	2	0.004	Structured	
40	YJFL	2	0.004		
41	HA[50]KJFL	2	0.004	Structured	
42	HA[1]LJFL	2	0.004		
43	HSKLJFL	2	0.004		
44	MA	2	0.004	Structured	
45	MBEQL-MBEQL	2	0.004	Structured	
46	MDGQLJFL	2	0.004	Structured	
47	MDGQLJFLK	2	0.004		
48	MDHA	2	0.004	Structured	
49	MDHGL	2	0.004	Structured	
50	MHAK[1]LI	2	0.004		
51	MHAJFL	2	0.004	Structured	
52	M[4]OKL	2	0.004	Structured	
53	M[4]OK	2	0.004	Structured	
54	DELJFJFLJF	2	0.004		
55	[51]R[42]LIT	1	0.002		
56	AO	1	0.002	Structured	
57	AJFL[42][39]	1	0.002		
58	AGJFLG	1	0.002		

S. No.	Phrase	Repetition	Proportion	Classification	
59	ATrV[39]LA	1	0.002		RARE
60	ATr	1	0.002		
61	YAKL	1	0.002	Structured	
62	YLJFL	1	0.002		
63	DOKLJZ	1	0.002	Structured	
64	DSELJFL	1	0.002		
65	DELJF	1	0.002		
66	DGJFL	1	0.002		
67	HAJFL	1	0.002	Structured	
68	HAK[1]	1	0.002	Structured	
69	HAKLI	1	0.002	Structured	
70	HAKLIK[1]	1	0.002		
71	HAKL[1]LI	1	0.002		
72	HATrV[39]L	1	0.002		
73	HYLJFL	1	0.002		
74	HBEQL	1	0.002	Structured	
75	HM[4]O	1	0.002	Structured	
76	HR	1	0.002	Structured	
77	HSK	1	0.002	Structured	
78	HVS	1	0.002	Structured	
79	M[4]OKLILF	1	0.002		
80	M[4]OKILJFL	1	0.002	Structured	
81	M[4]OKJFL	1	0.002	Structured	
82	M[4]OKJFLV	1	0.002		
83	M[51]R	1	0.002	Structured	
84	MBH	1	0.002	Structured	
85	MCASL	1	0.002	Structured	
86	MD[4]OKLI	1	0.002		
87	MDA[50]K	1	0.002	Structured	
88	MDLDOKLILJFL	1	0.002		
89	MDOSJFL	1	0.002		
90	MDHO	1	0.002	Structured	
91	MDGQL	1	0.002	Structured	
92	MDGQKQL	1	0.002	Structured	
93	MDHGLJFL	1	0.002	Structured	
94	MDHOHGLG	1	0.002	Structured	
95	MDWTJL	1	0.002		
96	MHAIL	1	0.002	Structured	
97	MHAKLIAK	1	0.002		
98	MHAKLI	1	0.002		
99	MHAKLG	1	0.002	Structured	
100	MHAKL[42]	1	0.002	Structured	
101	MHA[1]LJFL	1	0.002		
102	MHAS	1	0.002	Structured	
103	MHASLJFL	1	0.002		
104	MHEAO	1	0.002	Structured	
105	MHG	1	0.002	Structured	
106	MHSKLG	1	0.002	Structured	
107	MHSKLGUN	1	0.002	Structured	
108	MGJFL	1	0.002		
109	MGQLJFL	1	0.002		
110	MWGJFL[42][39]	1	0.002		
111	MTr[52]LJFL[42]	1	0.002		
112	OKLIJFL	1	0.002		
113	TrVHO[42]	1	0.002		
114	QHS	1	0.002	Structured	
115	QL	1	0.002	Structured	
116	H2LGJFL	1	0.002		
117	MDOKLI	1	0.002	Structured	
	Total	**445**	**1.000**		

A 1.2: Table of all structured phrases with suffix and their counterparts in breeding season

With suffix	Without suffix counterparts
AJFL	A
YAKLJFL	YAKL
DELJFL	DEL
DOKLJZ	DOKL
HAJFL	HA
HAKLJFL	HAKL
HYJFL	HY
M[4]OKLILJFL	M[4]OKLI
MCASLJFL	MCASL
MDGQLJFL	MDGQL
MDHGLJFL	MDHGL
MDOKLJZ	MDOKL
MDOKLILJFL	MDOKLI
MHAJFL	MHA
MHSJFL	MHS
MHSKLJFL	MHSKL
HA[50]KJFL	HA[50]K
MHSKLGUN	MHSKLG
M[4]OKJFL	M[4]OK

A 1.3: Table of all structured phrases with pre-suffix and their counterparts in breeding season

With pre-suffix	Without pre-suffix counterpart
M[4]OKLILJFL	M[4]OKL
M[4]OKLI	M[4]OK
M[4]OKILJFL	MDOKL
MDOKLI	MDOKLJZ
MDOKLILJFL	MHA
MHAIL	MHAJFL

A 1.4: Table of all unstructured and rare phrases having erratic parts in breeding season. (Highlighted phrase has two types of erratic parts)

Trill parts		Extended body		Incomplete suffix		
Phrase	Repetition	Phrase	Repetition	Phrase	Repetition	
ATr	1	[51]R[42]LIT	1	DELJF	1	
ATrV[39]LA	1	AJFL[42][39]	1	DELJFJFLJF	2	
HATrV[39]L	1	AGJFLG	1	M[4]OKLILF	1	
MTr[52]LJFL[42]	1	HAKLIK[1]	1	MDWTJL	1	
TrVHO[42]	1	M[4]OKJFLV	1			
		MHAKLIAK	1			
		MWGJFL[42][39]	1			
		MTr[52]LJFL[42]	1			
		MDGQLJFLK	2			
		MDGJFLKJFL	3			
Total	5		13		5	23

A 1.5: Table of all phrases in non-breeding season highlighting their abundance and classification

S. No.	Phrase	Repetition	Proportion	Classification	
1	A	229	0.209	Structured	COMMON
2	M	105	0.096	Structured	
3	Tr	102	0.093		
4	C	90	0.082	Structured	
5	H	29	0.027	Structured	
6	MA	20	0.018	Structured	
7	MTr	20	0.018		
8	Y	19	0.017	Structured	
9	TrC	12	0.011		
10	D	11	0.010	Structured	
11	MC	11	0.010	Structured	
12	CA	10	0.009	Structured	
13	MTrV	10	0.009		
14	TrV	9	0.008		
15	TrVK	9	0.008		
16	AC	8	0.007	Structured	
17	MD	7	0.006	Structured	
18	MCA	6	0.005	Structured	
19	MTrC	6	0.005		
20	CY	5	0.005	Structured	
21	CTr	5	0.005		
22	DTr	4	0.004		
23	HA	4	0.004	Structured	
24	MH	4	0.004	Structured	
25	TrG	4	0.004		
26	CAK	3	0.003	Structured	
27	HA[11]	3	0.003	Structured	
28	HTr	3	0.003		
29	MCH	3	0.003	Structured	
30	MTrK	3	0.003		
31	MTrVJFL	3	0.003		
32	MYV	3	0.003	Structured	
33	TrA	3	0.003		
34	TrF[5]	3	0.003		
35	YA	3	0.003	Structured	
36	Atr	2	0.002		RARE
37	CAKLJFL[5]	2	0.002		
38	CYAKLJFL	2	0.002		
39	D[3]	2	0.002	Structured	
40	DTrGAKTr	2	0.002		
41	DTrV	2	0.002		
42	HAK	2	0.002	Structured	
43	K	2	0.002	Structured	
44	M[4]	2	0.002	Structured	
45	MCAK	2	0.002	Structured	
46	MCHS	2	0.002	Structured	
47	MCY	2	0.002	Structured	
48	MD[5]	2	0.002	Structured	
49	MHA	2	0.002	Structured	
50	MATr	2	0.002		
51	MCDTr	2	0.002		
52	MCTr	2	0.002		
53	MD[11]F[5]	2	0.001		
54	MDTr[95]	2	0.002		
55	MDTrF[5]	2	0.002		
56	MDTrF[5]	2	0.002		
57	MTrF[5]	2	0.002		
58	MTrVJFLTr[2]	2	0.002		
59	MTrVK	2	0.002		
60	Tr[5]	2	0.002		

S. No.	Phrase	Repetition	Proportion	Classification	
61	Tr[5][52]JFLK	2	0.002		
62	Tr[5][52]LJFL	2	0.002		
63	TrH	2	0.002		
64	TrV[2]	2	0.002		
65	TrVJFLTr[2]	2	0.002		
66	V	2	0.002	Structured	
67	YVKIL	2	0.002		
68	[11]	1	0.001	Structured	
69	[12]	1	0.001	Structured	
70	[12]KILVK	1	0.001		
71	[2]H	1	0.001	Structured	
72	[95][3]K[5]AK	1	0.001	Structured	
73	A[11]	1	0.001	Structured	
74	A[5][3]L	1	0.001	Structured	
75	ACFLKJFKA	1	0.001		
76	ACFLKL	1	0.001		
77	ACFLYL[3]JFL	1	0.001		
78	ACGLFK	1	0.001		
79	ACLFSVGFL	1	0.001		
80	ACLKFL	1	0.001		
81	ACNOKJFLA	1	0.001		
82	ACO	1	0.001	Structured	
83	ACOJF	1	0.001		
84	ACSJFLSLF	1	0.001		
85	ACV	1	0.001	Structured	
86	AD[3]LKJFL	1	0.001		
87	AHKLKDH	1	0.001	Structured	
88	AHLJFLK	1	0.001		
89	AK	1	0.001	Structured	RARE
90	AKGJFLVIL	1	0.001		
91	A[12]KTr[12]F[11]JF	1	0.001		
92	ACFLSVDTr[2]VJFL	1	0.001		
93	ACKIL[5]Ytr	1	0.001		
94	ADWLVTr[2]V	1	0.001		
95	AHLJFLDTrVH	1	0.001		
96	AJFLVKLILTr	1	0.001		
97	AMTrK	1	0.001		
98	AMTrYHSKL[95]JFL	1	0.001		
99	ATrVJF[5]Tr[2]V	1	0.001		
100	ATrVTr[2]	1	0.001		
101	CA[5]K	1	0.001	Structured	
102	CAFLVD[3]	1	0.001		
103	CAHLK	1	0.001	Structured	
104	CAJFLK	1	0.001		
105	CAKILV	1	0.001		
106	CAKILVK	1	0.001		
107	CAKLJFL[52]	1	0.001		
108	CHF[5]	1	0.001		
109	CHS	1	0.001	Structured	
110	CHS[5]V	1	0.001	Structured	
111	CHYAKIL	1	0.001		
112	CK	1	0.001	Structured	
113	CKLJFL	1	0.001		
114	CO	1	0.001	Structured	
115	COAK	1	0.001	Structured	
116	C[5]TrC	1	0.001		
117	CAUGUNTr[5]Tr[2]HA	1	0.001		

S. No.	Phrase	Repetition	Proportion	Classification	
118	CKTr[11]	1	0.001		RARE
119	CL[F]STrSL	1	0.001		
120	CTr[12]	1	0.001		
121	CTrCA	1	0.001		
122	CTrGO[12]FLV	1	0.001		
123	CTrVKF[12][11]	1	0.001		
124	CTrVYC	1	0.001		
125	D[11]	1	0.001	Structured	
126	D[11]PJFLV	1	0.001		
127	DA	1	0.001	Structured	
128	DLGFLS	1	0.001		
129	DOK	1	0.001	Structured	
130	DT	1	0.001	Structured	
131	DV	1	0.001	Structured	
132	DWLJFLV	1	0.001		
133	DTr[3]LK	1	0.001		
134	DTr[5]KLJFL	1	0.001		
135	DTr[F][5]	1	0.001		
136	DTrHSK[5]KLJFLD	1	0.001		
137	DTrKPK[2]	1	0.001		
138	DTrVF[5]S	1	0.001		
139	DTrVJFL	1	0.001		
140	F[5]MDTrVS[95]	1	0.001		
141	GKIO	1	0.001	Structured	
142	GL	1	0.001	Structured	
143	GOKLTrVKL	1	0.001		
144	HAF[3]	1	0.001	Structured	
145	HAF[5]	1	0.001		
146	HAJFKL	1	0.001		
147	HAJFL[3]	1	0.001		
148	HAJFLKL	1	0.001		
149	HAK[19]	1	0.001	Structured	
150	HAKJFL	1	0.001	Structured	
151	HAKS	1	0.001	Structured	
152	HAKVK	1	0.001	Structured	
153	HAYJFL	1	0.001		
154	HC	1	0.001	Structured	
155	HCAJFILVK	1	0.001		
156	HCAVFJFL	1	0.001		
157	HCK	1	0.001	Structured	
158	HCO	1	0.001	Structured	
159	HK	1	0.001	Structured	
160	HY	1	0.001	Structured	
161	HYALK[3]	1	0.001		
162	HAF[5]LTrD	1	0.001		
163	HAJFLKLTr	1	0.001		
164	HCAJFLTr[2]	1	0.001		
165	HDAKTr[2]	1	0.001		
166	HGOAKLTrVKP	1	0.001		
167	HGV[5]OKLTrVGLA	1	0.001		
168	HKGTrA	1	0.001		
169	HMTrV	1	0.001		
170	HTr[11]PFUNLVTr[11]F[11]PTr[2]	1	0.001		
171	HTr[12]KGTrV[11]	1	0.001		
172	HTrCTrPJFL[11]PV	1	0.001		
173	HTrG	1	0.001		
174	KHSTrV[5][3]	1	0.001		
175	LGJFL	1	0.001		
176	LKTrD	1	0.001		

S. No.	Phrase	Repetition	Proportion	Classification	
177	M[4]KLJFL[42]	1	0.001		
178	M[4]O	1	0.001	Structured	
179	M[4]O[42]JFL	1	0.001		
180	M[4]OKFL	1	0.001		
181	M[4]OKIV	1	0.001	Structured	
182	M[4]OL	1	0.001	Structured	
183	M[4]OLIL	1	0.001	Structured	
184	MACK	1	0.001	Structured	
185	MADKL	1	0.001	Structured	
186	MAJFL	1	0.001	Structured	
187	MAY[5]KJFL	1	0.001		
188	MCAD[3]	1	0.001		
189	MCAKIL	1	0.001	Structured	
190	MCALFKL[3]	1	0.001		
191	MCAOK	1	0.001	Structured	
192	MCAVKJFL	1	0.001		
193	MCC	1	0.001	Structured	
194	MCEKE	1	0.001	Structured	
195	MCHSD	1	0.001	Structured	
196	MCHSLJFLMTr[5]	1	0.001		
197	MCOK	1	0.001	Structured	
198	MCYCAOK	1	0.001	Structured	
199	MDCA	1	0.001	Structured	
200	MDHKLJFL	1	0.001		
201	MDLJFL[95]	1	0.001		
202	MHA[11]F[5]	1	0.001		
203	MHAKLJFL[42]	1	0.001		
204	MHAUNTSYUNC	1	0.001		
205	MHKC[5][3]K[5]L	1	0.001	Structured	RARE
206	MHS	1	0.001	Structured	
207	MHSK[5][3]	1	0.001	Structured	
208	MHSKL	1	0.001	Structured	
209	ML[4]OKJFL	1	0.001		
210	MY	1	0.001	Structured	
211	MYSJFLV	1	0.001		
212	MACOKGUNHTr	1	0.001		
213	MASDTrVTr[2]A	1	0.001		
214	MCFLKLSTrSLFLTF	1	0.001		
215	MCTrSJFL[52]LJFL	1	0.001		
216	MDTr	1	0.001		
217	MDTrCD	1	0.001		
218	MDTrHLJFLK	1	0.001		
219	MDTrVF[5]JFLTrV	1	0.001		
220	MDTrVKL	1	0.001		
221	MGJFLVTrDV	1	0.001		
222	MDHALJFLKDTrVTr[2]A	1	0.001		
223	MHA[11]F[5]TrV	1	0.001		
224	MHAJFLVKLTr[2]	1	0.001		
225	MHAKJFL[5]Tr[5]VTr[2]	1	0.001		
226	MHSKL[95]JFLTrDJF	1	0.001		
227	MHSKLJFLTrV	1	0.001		
228	MTr[5]KJFL	1	0.001		
229	MTrAC	1	0.001		
230	MTrCD	1	0.001		
231	MTrCHS	1	0.001		
232	MTrDHLJFL	1	0.001		
233	MTrDLGF	1	0.001		
234	MTrG	1	0.001		

S. No.	Phrase	Repetition	Proportion	Classification	
235	MTrH[12]IKTrCTr[12]	1	0.001		
236	MTrHCAOK	1	0.001		
237	MTrKFL	1	0.001		
238	MTrKL[19]	1	0.001		
239	MTrV[5][11]Tr[2]	1	0.001		
240	MTrVAJFL	1	0.001		
241	MTrVAK	1	0.001		
242	MTrVH	1	0.001		
243	MTrVHJFL	1	0.001		
244	MTrVJFLKTr[2]H	1	0.001		
245	MTrVKIL	1	0.001		
246	MTrVKLILJFLTr[2]	1	0.001		
247	MTrVTr[2]	1	0.001		
248	MTrYHSKL	1	0.001		
249	MTrYJFL	1	0.001		
250	MYTr	1	0.001		
251	O	1	0.001	Structured	
252	Tr[11]	1	0.001		
253	Tr[12]F	1	0.001		
254	Tr[5][52]LJF[2]	1	0.001		
255	Tr[5][F][11]	1	0.001		
256	Tr[5]K	1	0.001		
257	Tr[5]L	1	0.001		
258	Tr[5]LJFLTr[2]	1	0.001		
259	Tr[5]V[5][3]	1	0.001		
260	Tr[52][5][11]VS	1	0.001		
261	Tr[52]LJFL	1	0.001		
262	TrACVJFLCA[12]PJFLTrV	1	0.001		
263	TrAKJFL	1	0.001		
264	TrC[2]	1	0.001		RARE
265	TrCAFLKSDTrVTr[2]	1	0.001		
266	TrCAJFL	1	0.001		
267	TrCDP[12]JFL	1	0.001		
268	TrCDTrKO	1	0.001		
269	TrCGOAKLTrVKOTr[2][5]Tr	1	0.001		
270	TrCH	1	0.001		
271	TrCTrK	1	0.001		
272	TrCTrVJFL[11]	1	0.001		
273	TrCVK	1	0.001		
274	TrD	1	0.001		
275	TrDG	1	0.001		
276	TrDGL	1	0.001		
277	TrDGLJFG[5]LFKL	1	0.001		
278	TrDTrVK	1	0.001		
279	TrDTrVKL[3]	1	0.001		
280	TrDTrVTr[2]S	1	0.001		
281	TrDWEOSLKJFL	1	0.001		
282	TrFCHTrVK	1	0.001		
283	TrGOKV	1	0.001		
284	TrHGTrVGL	1	0.001		
285	TrIK[12]	1	0.001		
286	TrJFL[52]Tr[2]	1	0.001		
287	TrK[5]MC	1	0.001		
288	TrKL	1	0.001		
289	TrKLJFLK[19]	1	0.001		
290	TrKMCTrVLAP[12]JFLVTrYC	1	0.001		
291	TrMCAVTr	1	0.001		
292	TrMTrV	1	0.001		
293	TrP[12][5]JFAVTrVGLTr	1	0.001		

S. No.	Phrase	Repetition	Proportion	Classification	
294	TrVAC	1	0.001		
295	TrVF[5]	1	0.001		
296	TrVG	1	0.001		
297	TrVGLF[5]	1	0.001		
298	TrVIKLJFLTr[5]	1	0.001		
299	TrVJFL	1	0.001		
300	TrVKIL	1	0.001		
301	TrVKILUN	1	0.001		
302	TrVKL[12]	1	0.001		
303	TrVKLILTr[2]	1	0.001		
304	TrVKPJFL	1	0.001		
305	TrVLKTr[2]	1	0.001		
306	TrVLTr[2]	1	0.001		
307	TrVTr[2][5]Tr[2]	1	0.001		
308	TrVTr[2]HS	1	0.001		RARE
309	TrYAKTrAK	1	0.001		
310	TrYCJFL	1	0.001		
311	TrYKJF	1	0.001		
312	VKLTr	1	0.001		
313	YAK	1	0.001	Structured	
314	YC	1	0.001	Structured	
315	YCAP[12]JFL	1	0.001		
316	YCAV	1	0.001	Structured	
317	YCAVC	1	0.001	Structured	
318	YHAKJFL	1	0.001		
319	YLKILJFL[42]KV	1	0.001		
320	YOKIL	1	0.001		
321	YA[3]LDTr[3]L	1	0.001		
322	YCATrKDYC	1	0.001		
323	YCTrVYCAQVGJFLA	1	0.001		
324	YDC[2]TrDTrV	1	0.001		
325	YMTrKA	1	0.001		
326	YTrVA	1	0.001		
327	YTrVK[5][2]	1	0.001		
	Total	**1093**	**1.000**		

A 1.6: Table of number of distinct notes (in order) per phrase and their proportions amongst common phrases in the two seasons

No. of distinct notes (in order)	BS Phrases	BS Phrases	NBS Phrases	NBS Phrases
1	8	0.02	226	0.56
2	48	0.14	113	0.28
3	63	0.18	62	0.15
4	21	0.06	0	0.00
5	106	0.31	0	0.00
6	26	0.08	6	0.01
7	38	0.11	0	0.00
8	16	0.05	0	0.00
9	5	0.01	0	0.00
10	13	0.04	0	0.00
Total	**344**	**1**	**407**	**1**

A 1.7: Table of number of distinct notes (in order) per phrase and their proportions amongst structured phrases in the two seasons

No. of distinct notes (in order)	BS Phrases	BS Phrases	NBS Phrases	NBS Phrases
1	8	0.021277	490	0.750383
2	55	0.146277	91	0.139357
3	68	0.180851	36	0.05513
4	33	0.087766	16	0.024502
5	118	0.31383	11	0.016845
6	28	0.074468	6	0.009188
7	35	0.093085	2	0.003063
8	18	0.047872	0	0
9	1	0.00266	1	0.001531
10	12	0.031915	0	0
Total	376	1	653	1

A 1.8: Table of all merged behavioural samples (1 min each) taken during the same slot (time and day), to obtain proportions of each behaviour during non-breeding season

Merged sample #	Time slot (in hours)	Proportion of each behaviour in sampling time slot					n for each time-slot
		Vocalisation	Displacement	Foraging	Grooming	Antagonism	
1	0600-0800	0.38	0.96	0.81	0.08	0.08	
2	0600-0800	0.40	1.00	0.76	0.08	0.24	
3	0600-0800	0.74	0.87	0.52	0.22	0.35	
4	0600-0800	0.54	0.92	0.38	0.54	0.15	
5	0600-0800	0.75	1.00	0.75	0.00	0.08	9
6	0600-0800	0.64	0.91	0.27	0.55	0.09	
7	0600-0800	0.47	1.00	0.68	0.21	0.00	
8	0600-0800	1.00	0.43	0.14	0.57	0.00	
9	0600-0800	0.67	0.67	0.33	0.67	0.00	
10	0800-1000	0.65	0.78	0.30	0.39	0.04	
11	0800-1000	0.93	0.67	0.19	0.52	0.00	
12	0800-1000	0.75	0.75	0.38	0.50	0.13	
13	0800-1000	0.43	0.86	0.43	0.50	0.07	
14	0800-1000	0.78	0.89	0.17	0.50	0.22	9
15	0800-1000	0.86	0.93	0.57	0.29	0.29	
16	0800-1000	1.00	1.00	0.25	0.00	0.00	
17	0800-1000	0.25	1.00	0.25	0.25	0.00	
18	0800-1000	1.00	1.00	0.33	0.33	0.17	
19	1000-1200	0.69	0.75	0.56	0.31	0.06	
20	1000-1200	0.79	0.59	0.38	0.34	0.00	
21	1000-1200	0.91	0.83	0.61	0.39	0.39	
22	1000-1200	0.95	0.89	0.58	0.26	0.00	
23	1000-1200	0.75	0.82	0.43	0.43	0.14	
24	1000-1200	0.83	0.48	0.35	0.65	0.13	
25	1000-1200	0.38	0.92	0.46	0.31	0.08	13
26	1000-1200	0.50	0.92	0.27	0.31	0.27	
27	1000-1200	0.75	0.88	0.25	0.00	0.00	
28	1000-1200	0.84	0.89	0.47	0.16	0.05	
29	1000-1200	0.33	0.92	0.17	0.42	0.25	
30	1000-1200	0.60	0.90	0.15	0.60	0.10	
31	1000-1200	0.45	0.27	0.09	0.27	0.09	
32	1200-1400	0.87	1.00	0.47	0.13	0.00	
33	1200-1400	0.50	1.00	0.17	0.33	0.17	
34	1200-1400	0.75	1.00	0.75	0.25	0.00	
35	1200-1400	0.43	0.86	0.43	0.43	0.14	
36	1200-1400	0.86	0.90	0.52	0.14	0.24	
37	1200-1400	0.80	1.00	0.60	0.10	0.10	12
38	1200-1400	0.67	1.00	0.67	0.00	0.00	
39	1200-1400	0.71	0.94	0.29	0.53	0.35	
40	1200-1400	0.50	1.00	0.00	1.00	1.00	
41	1200-1400	0.78	0.78	0.33	0.22	0.00	
42	1200-1400	1.00	0.00	0.00	1.00	0.00	
43	1200-1400	0.74	0.53	0.21	0.53	0.00	
44	1400-1600	0.47	0.67	0.33	0.47	0.00	
45	1400-1600	0.82	1.00	0.55	0.00	0.00	
46	1400-1600	1.00	1.00	0.43	0.29	0.14	
47	1400-1600	0.50	0.42	0.17	0.42	0.00	
48	1400-1600	0.91	0.91	0.36	0.09	0.18	
49	1400-1600	0.64	0.73	0.55	0.00	0.00	12
50	1400-1600	0.45	0.64	0.27	0.68	0.05	
51	1400-1600	0.80	0.90	0.30	0.70	0.30	
52	1400-1600	0.64	0.64	0.27	0.55	0.09	
53	1400-1600	0.63	0.75	0.13	0.88	0.38	
54	1400-1600	1.00	0.50	0.20	0.30	0.00	
55	1400-1600	1.00	1.00	0.50	0.00	0.00	
56	1600-1800	1.00	1.00	0.00	0.00	0.00	
57	1600-1800	0.75	0.25	0.38	0.63	0.00	
58	1600-1800	1.00	1.00	1.00	0.00	0.00	
59	1600-1800	0.53	0.75	0.03	0.22	0.03	8
60	1600-1800	1.00	1.00	0.00	0.50	0.00	
61	1600-1800	1.00	1.00	0.00	0.00	0.00	
62	1600-1800	0.00	0.00	0.00	0.00	0.00	
63	1600-1800	1.00	1.00	0.00	0.00	0.00	

APPENDIX 2: Statistical tables

A 2.1: Statistical test table on inter-phrase and intra-phrase duration in breeding season

Sample set 1	Sample set 2	N1	N2	Statistic				Effect size	
				Test	U value	Z value	p-value	r	Interpretation
Inter-phrase	Intra-phrase	216	245	MWU	848	-17.943	p<0.05	0.835689	large

A 2.2: Statistical test table on inter-note duration in different phrase parts (structured) in breeding season

Sample set 1	Sample set 2	N1	N2	Statistic				Effect size	
				Test	U value	Z value	p-value	r	Interpretation
Prefix	Body	46	75	MWU	700	5.470	p<0.05	0.497302	medium
Prefix	Pre-suffix	46	7	MWU	0	4.216	p<0.05	0.579166	large
Prefix	Suffix	46	20	MWU	0	6.411	p<0.05	0.789174	large
Body	Pre-suffix	75	7	MWU	1	4.331	p<0.05	0.478306	medium
Body	Suffix	75	20	MWU	0	6.842	p<0.05	0.701971	large
Pre-suffix	Suffix	7	20	MWU	3	3.679	p<0.05	0.708088	large

A 2.3: Statistical test table on inter-note duration in different phrase parts (unstructured) in breeding season

Sample set 1	Sample set 2	N1	N2	Statistic				Effect size	
				Test	U value	Z value	p-value	r	Interpretation
Prefix	Body	67	118	MWU	1730.5	6.348	p<0.05	0.466714	medium
Prefix	Pre-suffix	67	14	MWU	0	5.852	p<0.05	0.650222	large
Prefix	Suffix	67	36	MWU	0	8.338	p<0.05	0.821568	large
Prefix	Erratic	67	13	MWU	32	5.256	p<0.05	0.587639	large
Body	Pre-suffix	118	14	MWU	9	6.034	p<0.05	0.525192	large
Body	Suffix	118	36	MWU	0	9.065	p<0.05	0.730479	large
Body	Erratic	118	13	MWU	211	4.276	p<0.05	0.373596	medium
Pre-suffix	Suffix	14	36	MWU	5	5.326	p<0.05	0.75321	large
Pre-suffix	Erratic	14	13	MWU	20	-3.421	p<0.05	0.658372	large
Suffix	Erratic	36	13	MWU	0	-5.288	p<0.05	0.755429	large

A 2.4: Statistical test table on inter-phrase and intra-phrase duration in non-breeding season

Sample set 1	Sample set 2	N1	N2	Statistic				Effect size	
				Test	U value	Z value	p-value	r	Interpretation
Inter-phrase	Intra-phrase	944	1092	MWU	421089.5	7.131256	p<0.05	0.158044	small

*Green highlight indicates that that even though test shows non-significant results, the effect size is large. This means that sample size of the two groups is not large enough. Hence, the test needs to be repeated with a larger sample size (if possible). [r= IzI/sqrt (N), where N is cumulative sample size. 0.1=<r<0.3, small; 0.3=<r<0.5, medium; 0.5=<r, large)

A 2.5: Statistical test table on inter-note duration in different phrase parts (structured) in non-breeding season

Sample set 1	Sample set 2	N1	N2	Statistic				Effect size	
				Test	U value	Z value	p-value	r	Interpretation
Prefix	Body	33	84	MWU	645	4.485	p<0.05	0.414653	medium
Prefix	Pre-suffix	33	2	MWU	2	2.168	p<0.05	0.366381	medium
Prefix	Suffix	33	2	MWU	1	2.239	p<0.05	0.378394	medium
Body	Pre-suffix	84	2	MWU	9	2.135	p<0.05	0.230188	small
Body	Suffix	84	2	MWU	0	2.393	p<0.05	0.257996	small
Pre-suffix	Suffix	2	2	MWU	0	1.162	0.245279	0.580948	large

A 2.6: Statistical test table on number of notes in each phrase in the breeding and non-breeding season

Sample set 1	Sample set 2	N1	N2	Statistic				Effect size	
				Test	U value	Z value	p-value	r	Interpretation
BS	NBS	448	944	MWU	105788.5	15.08098	p<0.05	0.404213	medium

A 2.7: Statistical test table on inter-note duration variation between different parts (prefix, body, suffix) in breeding and non-breeding season

Sample set 1	Sample set 2	N1	N2	Statistic				Effect size	
				Test	U value	Z value	p-value	r	Interpretation
Prefix-BS	Prefix-NBS	46	33	MWU	512	-2.450	p<0.05	0.275685	small
Body-BS	Body-NBS	75	84	MWU	2830	-1.102	0.270297	0.087424	small
Suffix-BS	Suffix-NBS	20	2	MWU	17	-0.286	0.775246	0.060873	small

A 2.8: Statistical test table on inter-note duration variation between different parts (pre-suffix) in breeding and non-breeding season (t-test)

Properties	Sample set 1	Sample set 2	Statistic			Effect size	
			t-value	df	p-value	Cohen's d	Interpretation
Groups	Pre-suffix - BS	Pre-suffix - NBS	-0.20801	7	0.841142	0.19521	small
Mean	0.025108	0.0265					
Sample size	7	2					
Stdev.	0.008786	0.00495					

*Green highlight indicates that that even though test shows non-significant results, the effect size is large. This means that sample size of the two groups is not large enough. Hence, the test needs to be repeated with a larger sample size (if possible). [r= IzI/sqrt (N), where N is cumulative sample size. 0.1=<r<0.3, small; 0.3=<r<0.5, medium; 0.5=<r, large)

A 2.9: Statistical test table on time activity budget for various behaviours in the non-breeding season

Sample set 1	Sample set 2	N1	N2	Statistic				Effect size	
				Test	U-value	Z-value	p-value	r	Interpretation
Vocalisation	Displacement	63	63	MWU	1406	-2.82	p<0.05	0.251226	small
Vocalisation	Foraging	63	63	MWU	547.5	7.009	p<0.05	0.624411	large
Vocalisation	Grooming	63	63	MWU	566.5	6.916	p<0.05	0.616126	large
Vocalisation	Antagonism	63	63	MWU	118.5	9.102	p<0.05	0.810871	large
Displacement	Foraging	63	63	MWU	392	7.768	p<0.05	0.692028	large
Displacement	Grooming	63	63	MWU	416	7.651	p<0.05	0.681605	large
Displacement	Antagonism	63	63	MWU	162.5	8.887	p<0.05	0.791717	large
Foraging	Grooming	63	63	MWU	1872.5	0.544	0.545	0.048463	small
Foraging	Antagonism	63	63	MWU	678.5	6.37	p<0.05	0.567485	large
Grooming	Antagonism	63	63	MWU	896	5.309	p<0.05	0.472963	medium

A 2.10: Statistical test table on proportion of various other behaviours performed by males during the song bout in non-breeding season

Sample set 1	Sample set 2	N1	N2	Statistic				Effect size	
				Test	U-value	Z-value	p-value	r	Interpretation
Displacement	Foraging	11	11	MWU	29	2.036	p<0.05	0.434077	medium
Displacement	Grooming	11	11	MWU	45	-0.952	0.341	0.202967	small
Displacement	Body Movement	11	11	MWU	19.5	-2.66	p<0.05	0.567114	large
Displacement	Antagonism	11	11	MWU	11	3.218	p<0.05	0.68608	large
Displacement	Stationary	11	11	MWU	16.5	-2.856	p<0.05	0.608901	large
Foraging	Grooming	11	11	MWU	8.5	-3.382	p<0.05	0.721045	large
Foraging	Body Movement	11	11	MWU	0	-3.94	p<0.05	0.840011	large
Foraging	Antagonism	11	11	MWU	33	1.773	0.076	0.378005	medium
Foraging	Stationary	11	11	MWU	0	-3.94	p<0.05	0.840011	large
Grooming	Body Movement	11	11	MWU	14	-3.021	p<0.05	0.644079	large
Grooming	Antagonism	11	11	MWU	0	3.94	p<0.05	0.840011	large
Grooming	Stationary	11	11	MWU	11	-3.218	p<0.05	0.68608	large
Body Movement	Antagonism	11	11	MWU	0	3.94	p<0.05	0.840011	large
Body Movement	Stationary	11	11	MWU	49.5	-0.67	0.491	0.142844	small
Antagonism	Stationary	11	11	MWU	0	-3.94	p<0.05	0.840011	large

A 2.11: Statistical test table on diel variation in different behaviours during the non-breeding season

Behaviour	Test	p-value
Vocalisation	KW ANOVA	0.3612
Displacement	KW ANOVA	0.3372
Grooming	KW ANOVA	0.4422
Foraging	One-way ANOVA	0.0745
Antagonism	KW ANOVA	0.1428

*Green highlight indicates that that even though test shows non-significant results, the effect size is large. This means that sample size of the two groups is not large enough. Hence, the test needs to be repeated with a larger sample size (if possible). [r= IzI/sqrt (N), where N is cumulative sample size. 0.1=<r<0.3, small; 0.3=<r<0.5, medium; 0.5=<r, large)

A 2.12: Statistical test table on proportion of various behaviours during different timeslots of the day in the non-breeding season

Sample set 1	Sample set 2	Timeslot	N1	N2	Statistic				Effect size	
					Test	U-value	Z-	p-value	r	Interpretation
Vocalisation	Foraging	0600-0800	9	9	MWU	33.00	0.62	0.54	0.145691	small
Vocalisation	Foraging	0800-1000	9	9	MWU	7.50	2.87	p<0.05	0.676423	large
Vocalisation	Foraging	1000-1200	13	13	MWU	23.00	3.13	p<0.05	0.613491	large
Vocalisation	Foraging	1200-1400	12	12	MWU	17.50	3.12	p<0.05	0.636396	large
Vocalisation	Foraging	1400-1600	12	12	MWU	8.50	3.64	p<0.05	0.742462	large
Vocalisation	Foraging	1600-1800	8	8	MWU	10.00	2.26	p<0.05	0.564488	large
Vocalisation	Grooming	0600-0800	9	9	MWU	17.00	2.03	p<0.05	0.478699	medium
Vocalisation	Grooming	0800-1000	9	9	MWU	11.50	2.52	p<0.05	0.593171	large
Vocalisation	Grooming	1000-1200	13	13	MWU	16.50	3.46	p<0.05	0.678864	large
Vocalisation	Grooming	1200-1400	12	12	MWU	29.50	2.42	p<0.05	0.494975	medium
Vocalisation	Grooming	1400-1600	12	12	MWU	24.50	2.71	p<0.05	0.5539	large
Vocalisation	Grooming	1600-1800	8	8	MWU	6.50	2.63	p<0.05	0.656381	large
Vocalisation	Antagonism	0600-0800	9	9	MWU	0.00	3.53	p<0.05	0.832521	large
Vocalisation	Antagonism	0800-1000	9	9	MWU	1.00	3.44	p<0.05	0.811708	large
Vocalisation	Antagonism	1000-1200	13	13	MWU	2.00	4.21	p<0.05	0.824693	large
Vocalisation	Antagonism	1200-1400	12	12	MWU	11.50	3.46	p<0.05	0.707107	large
Vocalisation	Antagonism	1400-1600	12	12	MWU	0.00	4.13	p<0.05	0.842636	large
Vocalisation	Antagonism	1600-1800	8	8	MWU	4.50	2.84	p<0.05	0.708892	large
Displacement	Foraging	0600-0800	9	9	MWU	9.00	2.74	p<0.05	0.645204	large
Displacement	Foraging	0800-1000	9	9	MWU	0.00	3.53	p<0.05	0.832521	large
Displacement	Foraging	1000-1200	13	13	MWU	12.00	3.69	p<0.05	0.724121	large
Displacement	Foraging	1200-1400	12	12	MWU	14.00	3.32	p<0.05	0.677644	large
Displacement	Foraging	1400-1600	12	12	MWU	6.50	3.75	p<0.05	0.766032	large
Displacement	Foraging	1600-1800	8	8	MWU	11.00	2.15	p<0.05	0.538233	large
Displacement	Grooming	0600-0800	9	9	MWU	4.50	3.13	p<0.05	0.738862	large
Displacement	Grooming	0800-1000	9	9	MWU	0.00	3.53	p<0.05	0.832521	large
Displacement	Grooming	1000-1200	13	13	MWU	13.50	3.62	p<0.05	0.709035	large
Displacement	Grooming	1200-1400	12	12	MWU	29.00	2.45	p<0.05	0.500867	large
Displacement	Grooming	1400-1600	12	12	MWU	20.50	2.94	p<0.05	0.601041	large
Displacement	Grooming	1600-1800	8	8	MWU	7.50	2.52	p<0.05	0.630126	large
Displacement	Antagonism	0600-0800	9	9	MWU	0.00	3.53	p<0.05	0.832521	large
Displacement	Antagonism	0800-1000	9	9	MWU	0.00	3.53	p<0.05	0.832521	large
Displacement	Antagonism	1000-1200	13	13	MWU	1.00	4.26	p<0.05	0.834751	large
Displacement	Antagonism	1200-1400	12	12	MWU	17.00	3.15	p<0.05	0.642289	large
Displacement	Antagonism	1400-1600	12	12	MWU	0.00	4.13	p<0.05	0.842636	large
Displacement	Antagonism	1600-1800	8	8	MWU	4.50	2.84	p<0.05	0.708892	large
Foraging	Grooming	0600-0800	9	9	MWU	22.00	1.59	0.11	0.374634	medium
Foraging	Grooming	0800-1000	9	9	MWU	29.50	-0.93	0.35	0.218537	small
Foraging	Grooming	1000-1200	13	13	MWU	77.50	0.33	0.74	0.065372	small
Foraging	Grooming	1200-1400	12	12	MWU	69.00	0.14	0.89	0.029463	small
Foraging	Grooming	1400-1600	12	12	MWU	69.50	-0.12	0.91	0.02357	small
Foraging	Grooming	1600-1800	8	8	MWU	31.50	0.00	1.00	0	small
Foraging	Antagonism	0600-0800	9	9	MWU	5.00	3.09	p<0.05	0.728456	large
Foraging	Antagonism	0800-1000	9	9	MWU	7.00	2.91	p<0.05	0.68683	large
Foraging	Antagonism	1000-1200	13	13	MWU	18.50	3.36	p<0.05	0.658749	large
Foraging	Antagonism	1200-1400	12	12	MWU	34.50	2.14	p<0.05	0.436049	medium
Foraging	Antagonism	1400-1600	12	12	MWU	16.50	3.18	p<0.05	0.648181	large
Foraging	Antagonism	1600-1800	8	8	MWU	23.00	0.89	0.37	0.22317	small
Grooming	Antagonism	0600-0800	9	9	MWU	22.00	1.59	0.11	0.374634	medium
Grooming	Antagonism	0800-1000	9	9	MWU	9.00	2.74	p<0.05	0.645204	large
Grooming	Antagonism	1000-1200	13	13	MWU	22.00	3.18	p<0.05	0.623549	large
Grooming	Antagonism	1200-1400	12	12	MWU	35.00	2.11	p<0.05	0.430157	medium
Grooming	Antagonism	1400-1600	12	12	MWU	35.00	2.11	p<0.05	0.430157	medium
Grooming	Antagonism	1600-1800	8	8	MWU	22.50	0.95	0.34	0.236297	small
Vocalisation	Displacement	0600-0800	9	9	MWU	16.00	-2.12	p<0.05	0.499512	medium
Vocalisation	Displacement	0800-1000	9	9	MWU	27.00	-1.15	0.25	0.270569	small
Vocalisation	Displacement	1000-1200	13	13	MWU	56.50	-1.41	0.16	0.276574	small
Vocalisation	Displacement	1200-1400	12	12	MWU	33.00	-2.22	p<0.05	0.453727	medium
Vocalisation	Displacement	1400-1600	12	12	MWU	65.50	-0.35	0.73	0.070711	small
Vocalisation	Displacement	1600-1800	8	8	MWU	31.50	0.00	1.00	0	small

*Green highlight indicates that that even though test shows non-significant results, the effect size is large. This means that sample size of the two groups is not large enough. Hence, the test needs to be repeated with a larger sample size (if possible). [r= IzI/sqrt (N), where N is cumulative sample size. 0.1=<r<0.3, small; 0.3=<r<0.5, medium; 0.5=<r, large)

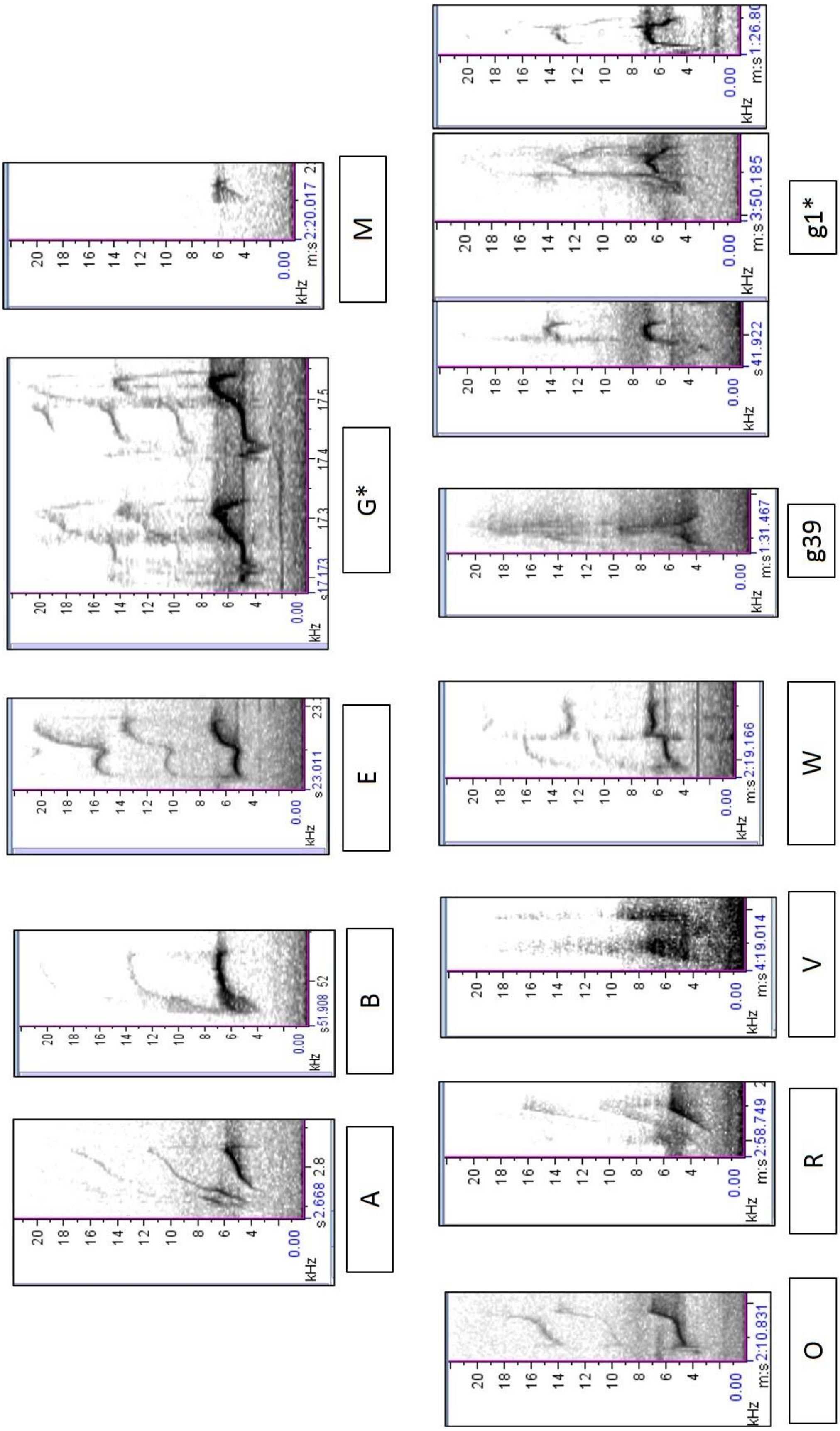
APPENDIX 3: Figures

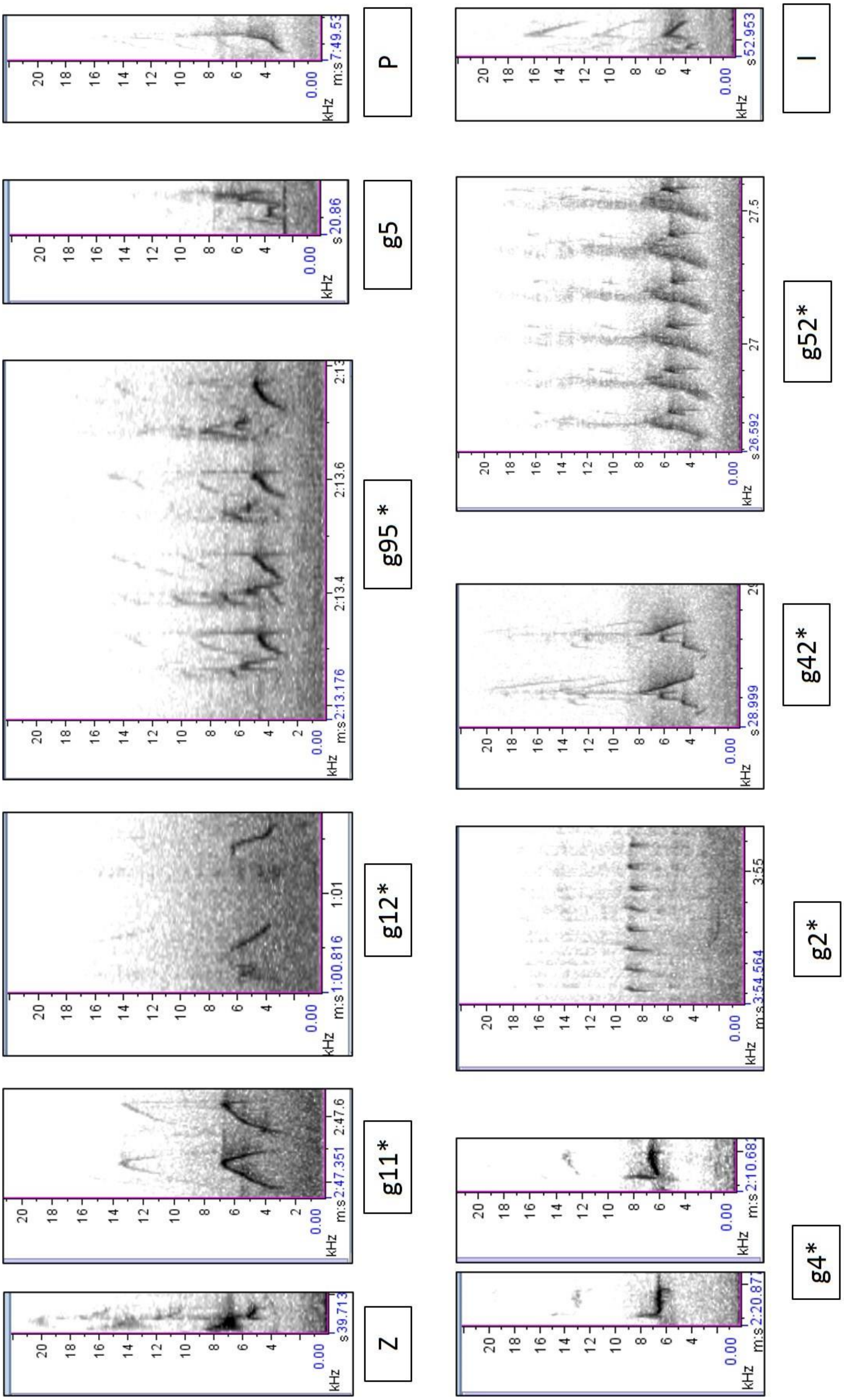
A 3.1: R-script for the Mann-Whitney U iteration (MWU-i) test

```
#import libraries required to read and write excel files
library(readxl)
library(xlsx)

#read excel file
notes=read_excel('………', sheet ='…………')

#define function to run wilcox test for given two groups and parameter
mwu_bs=function(group1,group2,par) {
  x=c() #x is list that stores values of group1
  y=c() #y is list that stores values of group2
  r=c(1:length(notes$`Note Type`))
  for(i in r){
    if(notes$`Note Type`[i]==group1){
      x=c(x,par[i])
    }else if(notes$`Note Type`[i]==group2){
      y=c(y,par[i])
    }
  }
  p=c() #p is list of p-values from the test from all iterations
  yes=c() # yes is a list 1's which represent significant p-values
  xl=length(x)
  yl=length(y)

  #following loops are for bootstrapping wilcox text for group1 and
group2
  if (min(xl,yl)>=5){
    if (xl>yl) {
      for(i in c(1:1000)){
        z=sample(x,yl,replace=F)
        w=wilcox.test(z,y)
        p=c(p,w$'p.value')
        if (w$'p.value'<0.05) {
          yes=c(yes,1)
        }
      }
    }else if(xl<yl){
      for(i in c(1:1000)){
        z=sample(y,xl,replace = F)
        w=wilcox.test(z,x)
        p=c(p,w$'p.value')
        if (w$'p.value'<0.05) {
          yes=c(yes,1)
        }
      }
    }else {
      p=c(p,wilcox.test(x,y)$'p.value')
      w=wilcox.test(y,x)
      if (w$'p.value'<0.05) {
        yes=1000
      }
    }
    sumyes=sum(yes)
    peryes=sumyes/1000
```

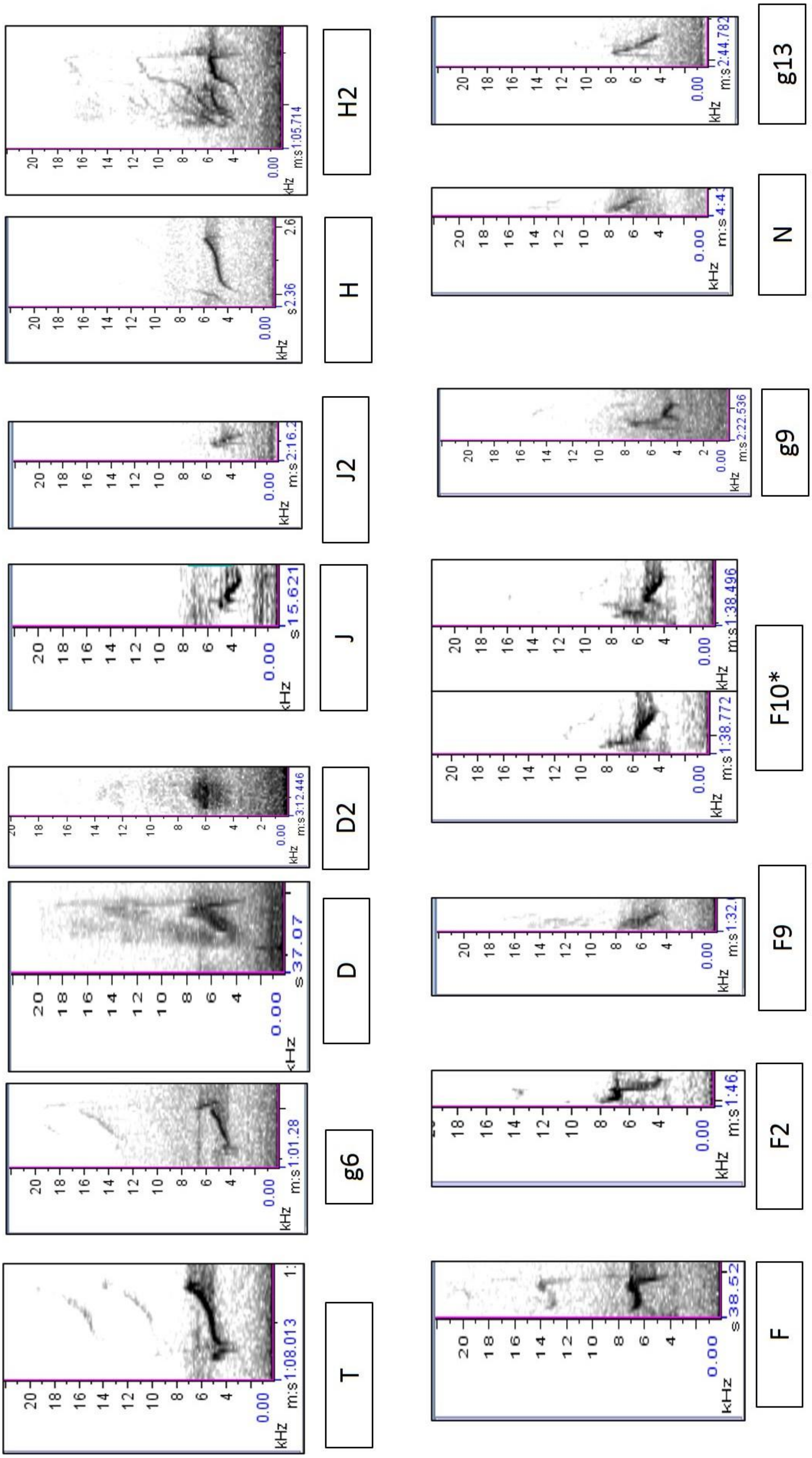
```
  } else{
    sumyes=-1000
    peryes=sumyes/1000
  }
  #sumyes is number of total significant results from the bootstraps
  #peryes is percentage of total significant results
  return(c(sumyes,peryes))
}

#define data.frame for values of all parameters
par_values = data.frame('Peak Freq. (Hz)'=notes$`Peak Freq. (Hz)`,
'Freq. 5% (Hz)'=notes$`Freq. 5% (Hz)`,'Freq. 95% (Hz)'=notes$`Freq. 95%
(Hz)`,'Duration (s)'=notes$`Duration (s)`,'Center
Freq.(Hz)'=notes$`Center Freq.(Hz)`,'BW 90% (Hz)'=notes$`BW 90% (Hz)`)

#define list of all parameter names
par_names=colnames(par_values)

#define list of all group names
grp_names=c()
lnote = notes$`Note Type`
for (i in seq(length(lnote))){
  if (i == 1){
    grp_names = c(grp_names,lnote[i])
  }else if (lnote[i] != lnote[i-1]){
    grp_names = c(grp_names,lnote[i])
  }
}

#define data.frame for the output for all combinations of groups and
paramters.
DF=data.frame(group1=rep(0,6*2500),group2=rep(0,6*2500),parameter=rep(0,
6*2500),sumyes=rep(0,6*2500), peryes=rep(0,6*2500))
rowcounter=1
for (i in seq(length(grp_names))){
  for (j in seq(length(grp_names))){
    if (i<j){
      parcounter = 1
      for (k in par_values) {
        print(c(grp_names[i],grp_names[j],par_names[parcounter]))
        out=mwu_bs(grp_names[i],grp_names[j],k)
        if (out[1] != -1000){

DF[rowcounter,]=c(grp_names[i],grp_names[j],par_names[parcounter],out[1]
,out[2])
          rowcounter = rowcounter + 1
          parcounter = parcounter + 1
        }
      }
    }
  }
}

#save the output data.frame containing peryes for each ombination of
groups and parameter
write.xlsx(DF, file='..............', sheetName = "..................", col.names = TRUE,
append = FALSE)s
```

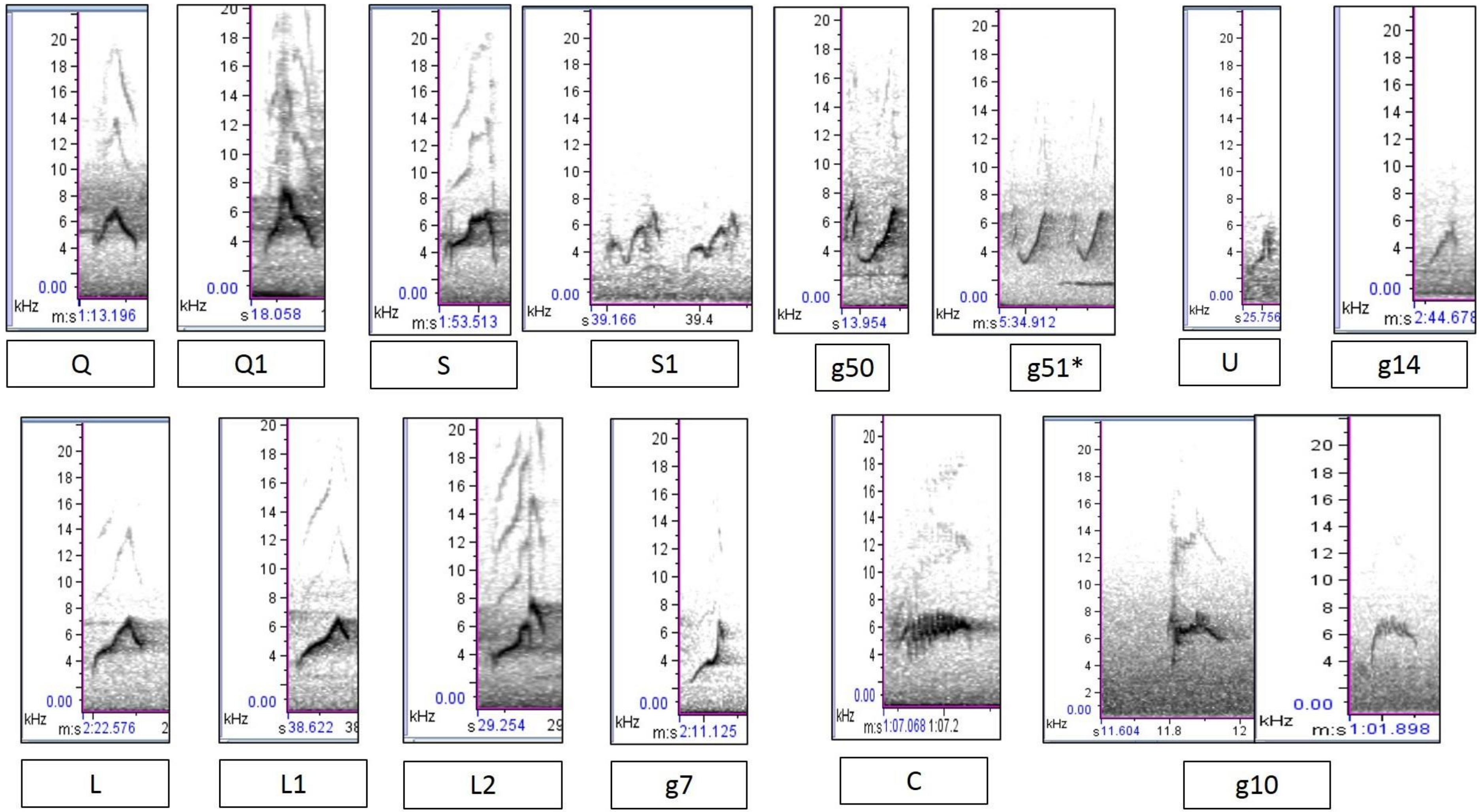
A 3.2: Spectrograms of all notes observed in male song (* repetitions of the same note)

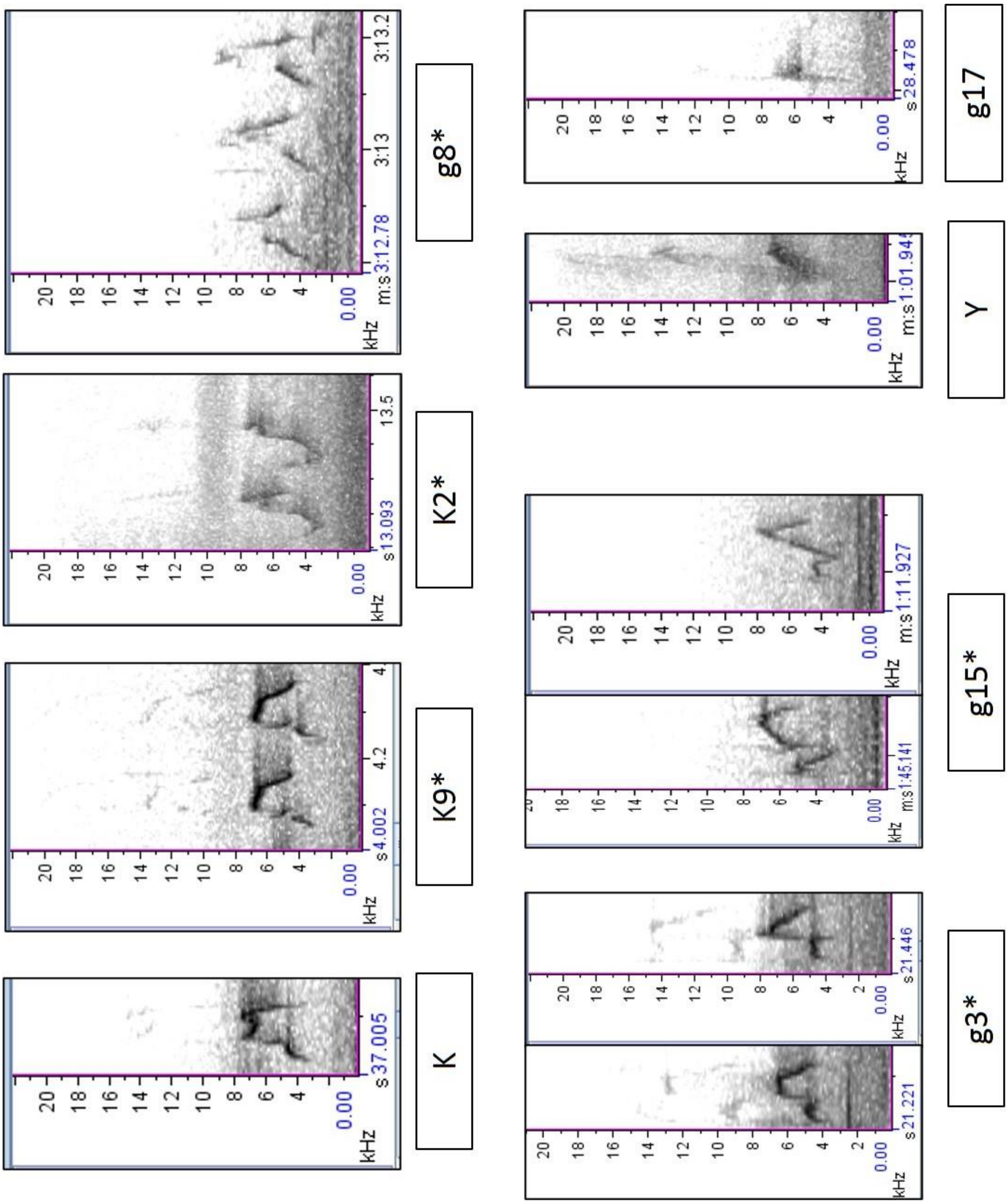


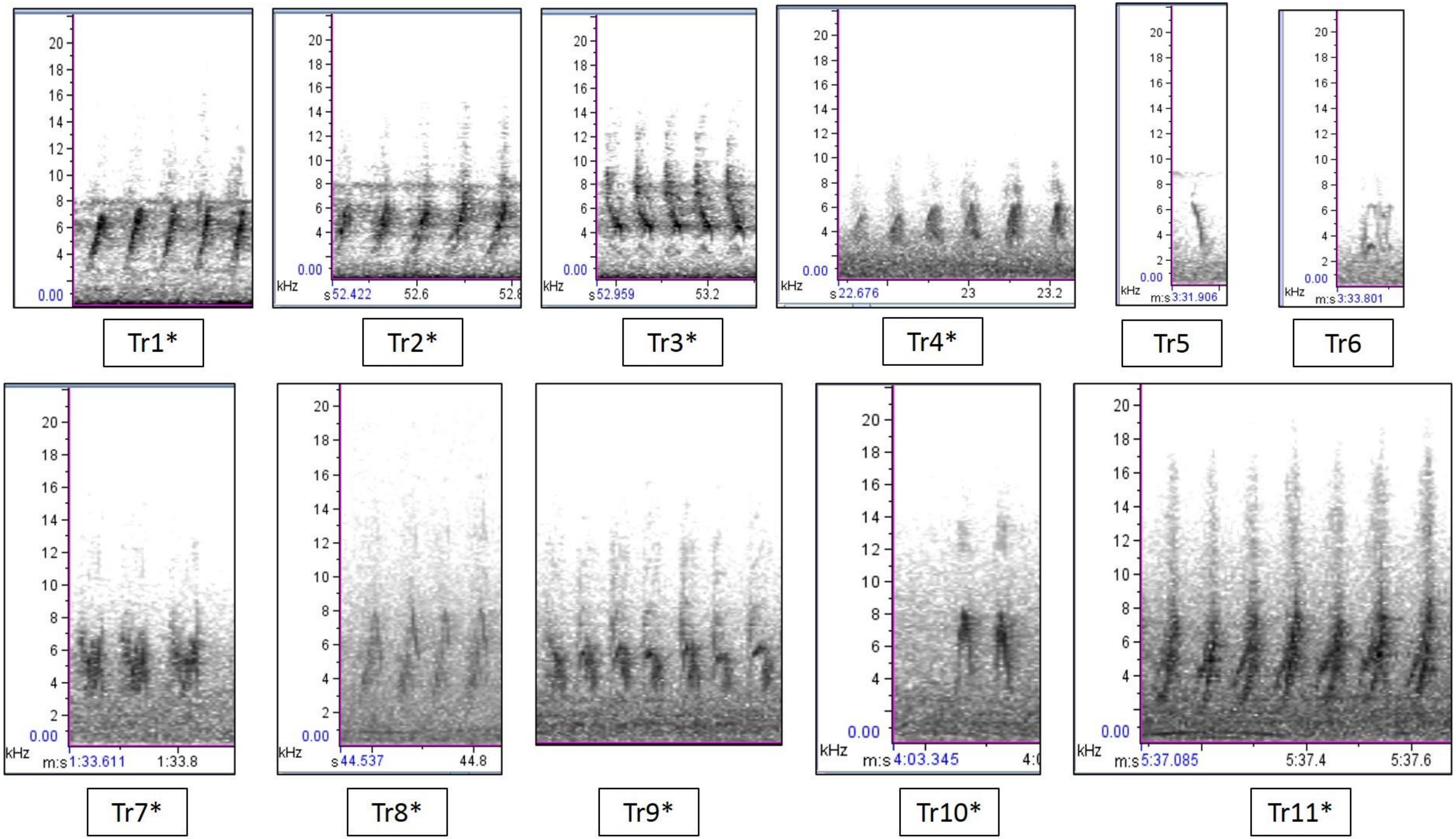


Z
g11*
g12*
g95 *
g5
P
g4*
g2*
g42*
g52*
I

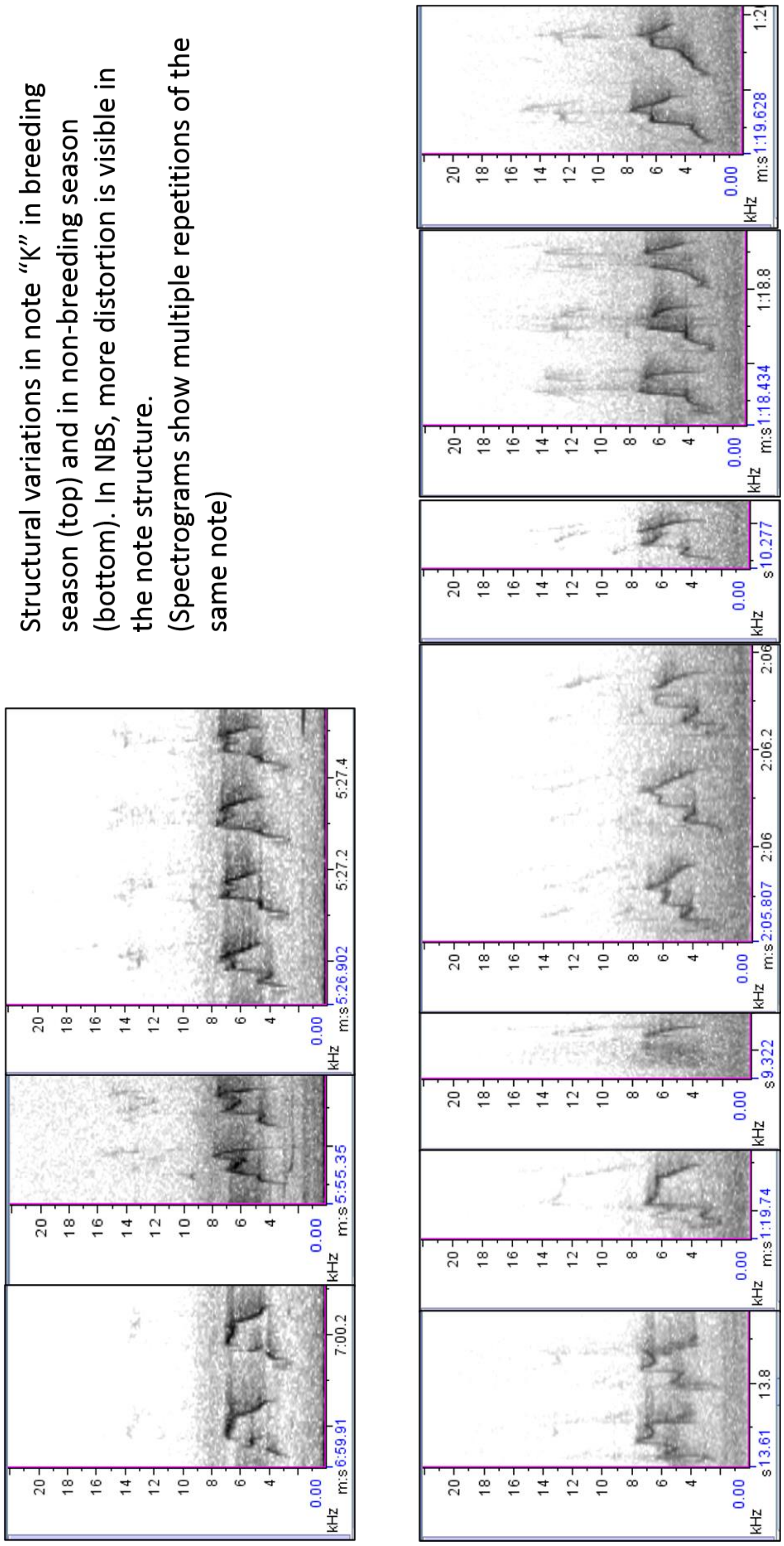

T
g6
D
D2
J
J2
H
H2
F
F2
F9
F10*
g9
N
g13


Q
Q1
S
S1
g50
g51*
U
g14
L
L1
L2
g7
C
g10

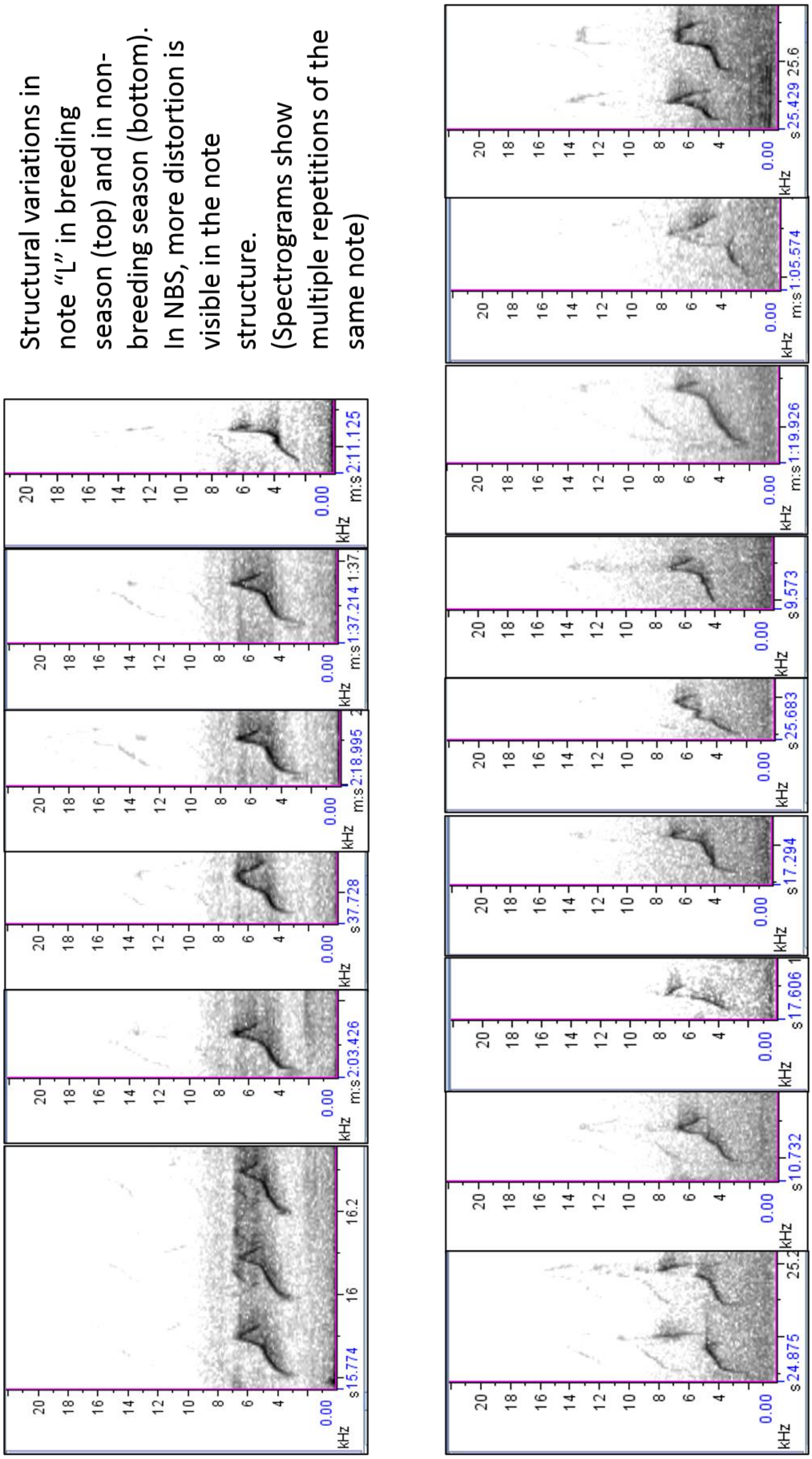

K
K9*
K2*
g8*
g3*
g15*
Y
g17


Tr1*
Tr2*
Tr3*
Tr4*
Tr5
Tr6
Tr7*
Tr8*
Tr9*
Tr10*
Tr11*

A 3.3(a): Structural variation in note "K" in the two seasons

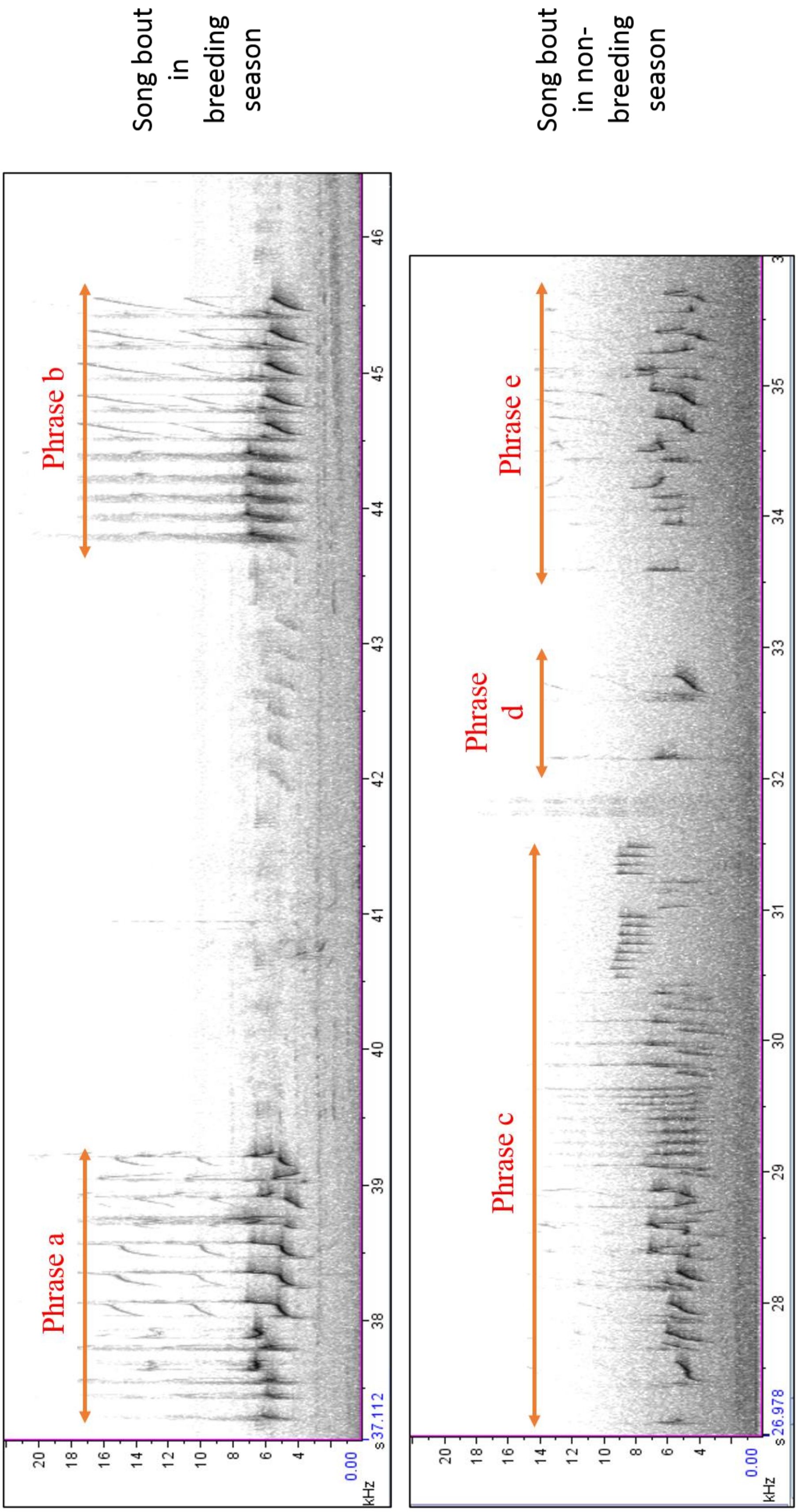


A 3.3(b): Structural variation in note "K" in the two seasons



Structural variations in note "L" in breeding season (top) and in non-breeding season (bottom). In NBS, more distortion is visible in the note structure. (Spectrograms show multiple repetitions of the same note)

A 3.4: Comparing inter-phrase durations in both seasons



The song bout in breeding season has consistently well separated phrases, whereas in non-breeding season the separation varies, thus giving a more continuous vocalisation. (Both spectrograms are at same magnification)