Supplementary Materials - RSPB-2022-0548

Long-distance vocalizations of spotted hyenas contain individual, but not group, signatures

Kenna D. S. Lehmann[1], Frants H. Jensen[2,3], Andrew S. Gersick[4], Ariana Strandburg-Peshkin[5,6,7], Kay E. Holekamp[8,9]

[1] School of Biological Sciences, University of Nebraska—Lincoln, 1101 T Street, Lincoln, NE 68588 USA
kdslehmann@gmail.com
ORCID: 0000-0003-2690-7332

[2] Department of Biology, Syracuse University, 107 College Place, Syracuse, NY 13244
[3] Biology Department, Woods Hole Oceanographic Institution, Woods Hole, MA 02543 USA
frants.jensen@gmail.com
ORCID: 0000-0001-8776-3606

[4] Dept of Ecology and Evolutionary Biology, Princeton University, 106A Guyot Hall, Princeton, NJ 08544 USA
agersick@princeton.edu

[5] Biology Department, University of Konstanz, Universitätsstrasse 10, 78464 Konstanz, Germany
[6] Department for the Ecology of Animal Societies, Max Planck Institute of Animal Behaviour, Bücklestrasse 5a, 78467 Konstanz, Germany
[7] Centre for the Advanced Study of Collective Behaviour, University of Konstanz, Universitätsstrasse 10, 78464 Konstanz, Germany
astrandburg@ab.mpg.de
ORCID: 0000-0003-2985-6788

[8] Department of Integrative Biology, Michigan State University, 288 Farm Lane, East Lansing, MI 48824 USA
[9] Ecology, Evolution, and Behavior Program, Michigan State University, 293 Farm Lane, East Lansing, MI 48824 USA
holekamp@msu.edu
ORCID: 0000-0001-5471-1076

Supplementary Materials

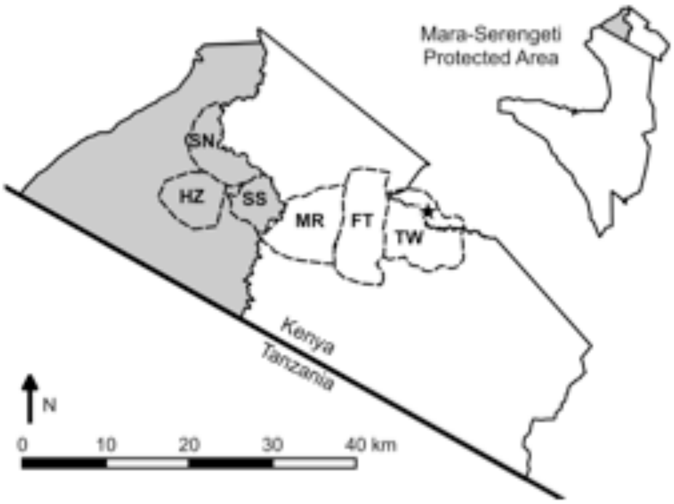

Figure S1: Map of the Mara Hyena Project study clans in the Maasai Mara, Kenya. The approximate clan boundaries are indicated by dashed lines. The Talek West (TW) territory lies on the eastern side of the Reserve, approximately 25 km from the remaining three clans which occupy adjacent territories on the western side of the Reserve: Happy Zebra (HZ), Serena South (SS), and Serena North (SN). Reproduced from Green 2015.

Figure S2: Acoustic recordings were obtained from wild spotted hyenas in the field using either (A) handheld shotgun microphone and recording setup deployed from offroad vehicles, or (B) custom-made acoustic and movement recording collars sampling sound directly from the tagged animal.

Recording methods – shotgun microphone

Observers deployed recording equipment once the vehicle was turned off and aimed the handheld directional microphone (ME-66/K6 and ME-67/K6, sensitivity: 50 mV/Pa, frequency response: 40 Hz–20 kHz; Sennheiser Electronic Corporation, Old Lyme) toward vocalizing animals within 50 meters of the car. For these recordings, observers used a Marantz PMD661 handheld solid-state recorder (Marantz America, Inc., Mahwah, NJ; Figure 8a) at sampling rates of 44.1, 48, or 96 kHz and 16 or 24-bit sampling depths. From April 2010 to January 2011 recordings were elicited via call-in playbacks (fully described in Gersick et al. 2015) and from July 2014 to April 2016 recordings were obtained opportunistically. In Table S1, whoop bouts obtained via call-in are italicized and those obtained opportunistically are in plain text.

Recording methods - collar

Five collars were deploiyed from January to March 2017 on five adult females from the Talek West clan. Collars consisted of a custom-built DTAG board capable of recording audio, accelerometer, and magnetometer data integrated with a GPS board (Gipsy 5; Technosmart, Italy) and mounted onto a Tellus Medium collar (Followit Sweden AB). Each collar consisted of a base Followit Wildlife (Followit AB, Lindesberg, Sweden) Medium Iridium collar with reinforced belting, integrated VHF antenna and a GPS and iridium module for transmitting location and battery state. Each collar was fitted with a secondary sound and movement module consisting of a modified digital acoustic tag (DTAG: Johnson and Tyack, 2003, Johnson et al. 2009) connected using a serial cable to a high sample rate Gipsy-5 GPS module (Technosmart Europe, Rome, Italy). This module was placed on the top of the collar and thus located on the back of the neck with the microphone facing forward and protected by an oleophobic acoustic vent (GAW325, 3.2mm ID, W. L. Gore and Associates, Elkton, MD, USA). Collars digitized sound using a sigma-delta ADC with an oversampling rate of x6, for a final 32 kHz sampling rate and 16-bit depth. In Table S1, whoop bouts obtained via collars are bolded.

Table S1. Summary of datasets used in random forest analyses. The clan signature hypothesis was tested with datasets composed of all whoop types (PAST Clan) and only A and S whoop types (AS Clan). The PAST Clan dataset was further divided into females only and males only datasets (see status and sex column). The individual signature hypothesis was tested with datasets composed of all whoop types (PAST Individual) and only A and S whoop types (AS Individual). The PAST Individual dataset was divided into recordings from females only, males only (see status and sex column), microphone only, and collar only. Bolded individuals' recordings were obtained from recording collars.

clan	**hyena**	**status & sex**	**whoops per bout in dataset**			
			PAST clan	**AS clan**	**PAST individual**	**AS individual**
HZ	JLYR	natal female	8	6		
	PIKE	*natal female*	*6*	*6*		
	SGL-	natal female	5,6	5,6	5,6	5,6
	SNAP	*natal female*	*8*	*6*		
	ANNR	imm. male	7,10,11	6,7,8	7,10,11	6,7,8
	ISTA	imm. male	7,6,4,10,13,9	6,5,4,9,10,7	7,6,4,10,13,9	6,5,4,9,10,7
	JAZZ	imm. male	11,7	10,7	11,7	10,7
	PGLG	imm. male	5			
	TEMP	imm. male	7	5		
HZ total	9		140	113	106	90
SN	*ANGI*	*natal female*	*8*	*8*		
	LOGC	natal female	9	9		
	RBC-	*natal female*	*12*	*11*		
	RMON	natal female	6	6		
	LGO-	*imm. male*	*8,5*	*7,4*	*8,5*	*7,4*
	RALI	imm. male	10	9		
SN total	6		58	54	13	11
SS	*BADG*	*natal female*	*7*	*6*		
	BBW-	*natal female*	*6*	*6*		
	BRPH	*natal female*	*7,8,9*	*6,6,7*	*7,8,9*	*6,6,7*
	GRIM	*natal female*	*6*	*6*		

clan	hyena	status & sex	whoops per bout in dataset			
			PAST clan	AS clan	PAST individual	AS individual
SS	*JAVA*	*natal female*	*10*	*9*		
	KOMO	natal female	7	7		
	KS--	*natal female*	*5*	*5*		
	MTN-	*natal female*	*8*	*8*		
	PALA	natal female	6,3	5,3	6,3	5,3
	TAJ-	*natal female*	*6*	*6*		
	DEE-	imm. male	6	6		
	ONEK	imm. male	5			
	RSTR	*imm. male*	*11,13,11*	*10,12,10*	*11,13,11*	*10,12,10*
SS total	13		134	118	68	59
TW	**BORA**	**natal female**	**8,10**	**7,8**	**8,10**	**7,8**
	BYTE	**natal female**	**7,2,2**	**5**		
	FAY-	**natal female**	**2,7,4,1**	**1,7,1**	**7,4**	
	HRPY	natal female	5	5		
	MGTA	**natal female**	**4,2**	**3,2**		
	ROOS	natal female	12	11		
	TWST	natal female	7,12	6,9	7,12	6,9
	WRTH	**natal female**	**1,12,1,7,4,1,2**	**1,12,6,4,1,2**	**12,7,4**	**12,6,4**
	DDMA	imm. male	8	7		
	RSWL	imm. male	6,8,2,8,12,9,7,4	5,7,1,6,11,8,5,4	6,8,8,12,9,7,4	5,7,6,11,8,5,4
	ZITI	natal male	5	5		
TW total	11		182	150	125	98

Plain text indicate data that were obtained opportunistically from July 2014 to April 2016.

Italicized lines indicate data obtained from call-ins April 2010 to January 2011.

Bolded lines indicate data obtained from recording collars January to March 2017.

Acoustic processing methods and feature extraction

Recordings were resampled to a common sample rate of 32 kHz before being processed individually using custom-written software in Matlab 2019a to extract a range of acoustic parameters.

First, each signal was bandpass filtered using a 6-pole Butterworth filter (-3 dB cutoff points 100 Hz to 10,000 Hz) and the 99% energy duration of the signal was calculated after subtracting average noise energy. Within this time window, a power spectrum was calculated using Welch's method (FFT size of 8192, block size 40 ms, block overlap 35 ms, Hann window), and used to estimate the peak frequency (containing most signal energy) and the centroid frequency (separating the power spectrum into two halves with equal energy).

Next, a spectrogram was generated (FFT size of 8192, block size 40 ms, block overlap 35 ms, Hann window) and used to extract the fundamental frequency contour using a semi-supervised contour tracker. From the contour, 7 features were extracted: The minimum and maximum contour frequency were taken directly from the contour. The contour was segmented into an initial flat "constant-frequency" (CF) component (ending when contour frequency exceeded median frequency by more than 10% of the difference between median and maximum frequency) and an upsweep component (ending at the point of maximum frequency) and both the total duration and the relative time into call where each period ended were extracted, as well as the centroid frequency within the initial CF portion (see Figure 1b-d).

Some whoops contained portions with pronounced subharmonics. To find and quantify these events, the acoustic energy in the fundamental frequency, first harmonic and second harmonic (1 f0, 2 f0, 3 f0) was isolated and compared to energy in uneven harmonics (1.5 f0, 3.5 f0, 3.5 f0) using a variable-frequency filter (Madsen and Jensen 2012). For the fundamental frequency, -3 dB cutoff points for each time slice corresponded to the instantaneous fundamental frequency ± ¼ octave to get a filter width of 0.5 octave. For higher harmonics, the fundamental frequency was multiplied by harmonic number before calculating cutoff points. The total energy was summed across even harmonics and across uneven harmonics separately. Then, the ratio of energy within harmonics relative to energy within subharmonics was calculated and converted to deciBels (10 log10(Eharmonics/Esubharmonics) for both the entire call and for the initial constant-frequency component.

Finally, the signal was downsampled to 8 kHz. For each time slice (40 ms block size, 35 ms block overlap) within the 99% energy duration of the signal, we calculated the spectral entropy (Misra et al. 2004) and cepstral peak prominence (Heman-Ackah et al. 2014, Soltis et al. 2005) and finally we calculated the mean spectral entropy and cepstral peak prominence across the entire signal.

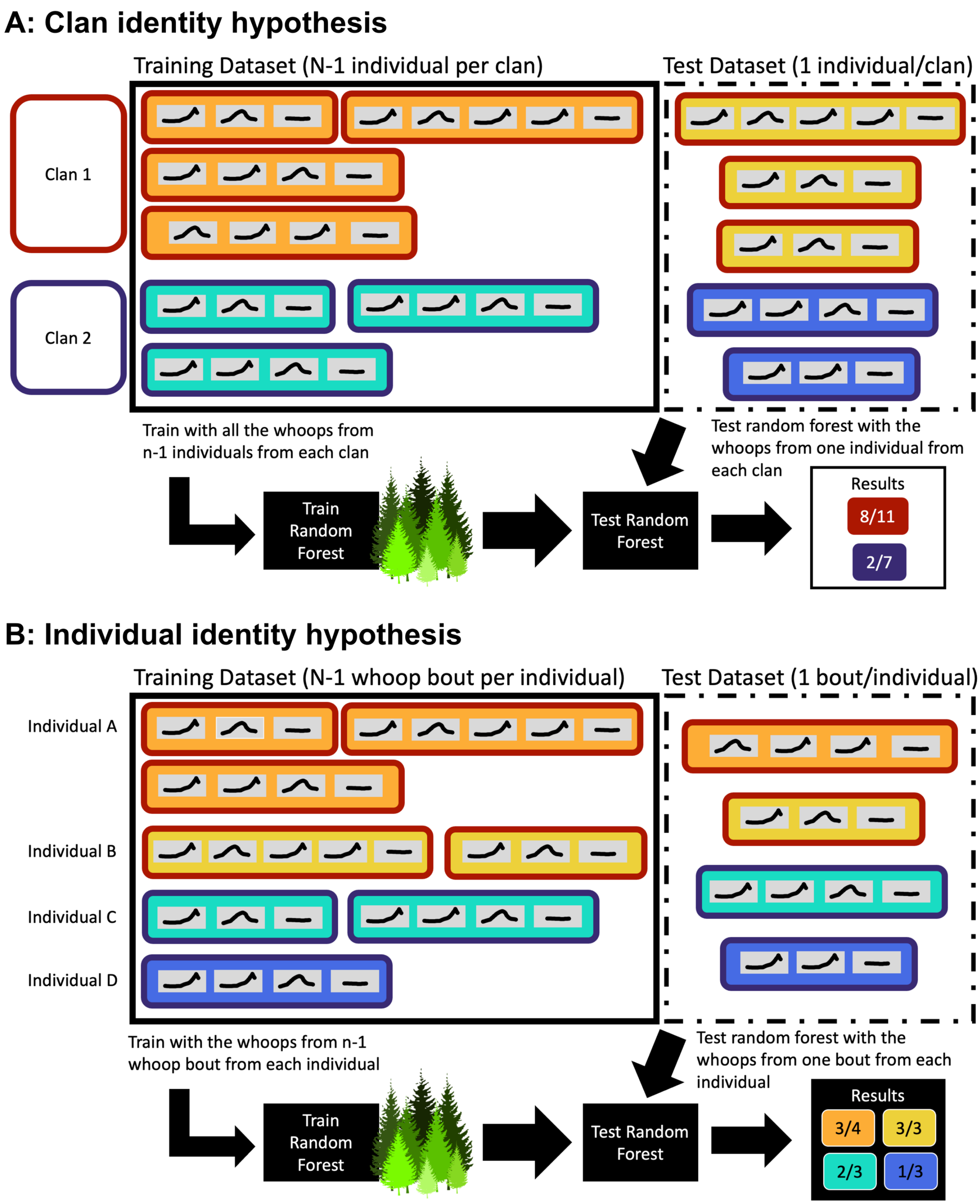

Figure S3: Random forest testing and training dataset for (A) clan signature analysis and (B) individual signatures analysis. Colored rectangles represent whoop bouts (with variable number of whoops), with box fill indicating the individual and box border indicating clan. For the clan signature analysis (A), the random forest was trained using whoops from all but one individual per clan, with the remaining individuals (one per clan) used for testing. The random forest was trained on single whoops and was *blind to the individual and bout. The random forest was then used to predict the clan membership of each whoop and the proportion of correct guesses was recorded. This procedure avoids pseudo-replication of individuals and ensures that the accuracy is not artificially inflated by the model learning signatures of the individuals comprising the clan rather than signatures of the clan itself. For the individual signatures analysis (B), the random forest was trained on whoops from all but one bout per individual, with the remaining bout held out for testing. The trained random forest model was then used to predict the caller of each whoop in the test dataset. This procedure prevents psuedo-replication of bouts and eliminates the possibility of within-bout similarities affecting the analysis of individual signatures.*

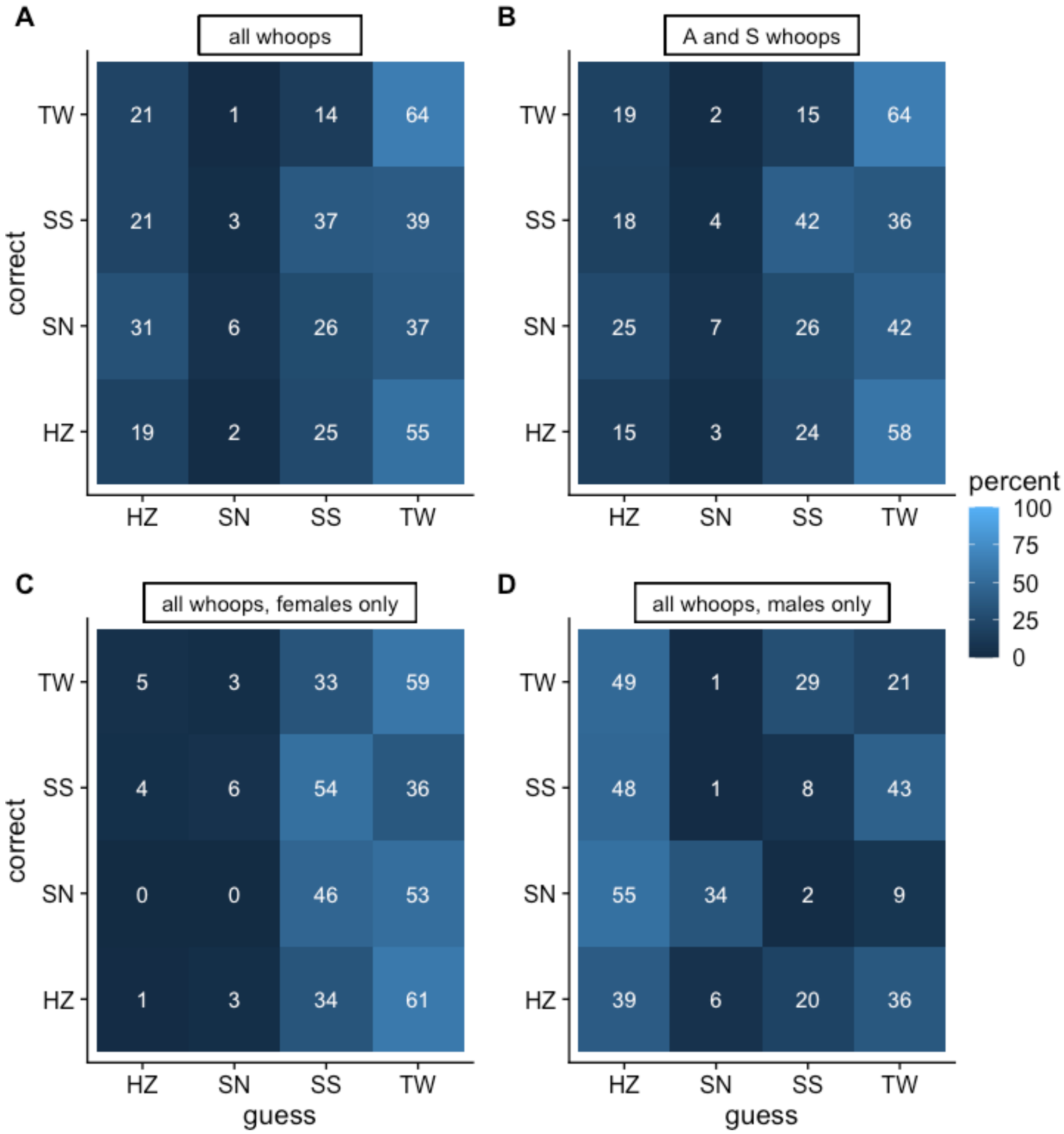

Figure S4: Confusion matrices for clan signature. (A) Using all whoop types. (B) Using only A and S type whoops. (C) Using all whoop types from females only. (D) Using all whoop types from males only. Rows represent true categories while columns represent the random forest assignments. Each row shows how the random forest classified calls for that particular clan. Each cell represents the percentage of calls that were assigned to the column category from the true category. Guesses that lie along the diagonal are correct assignments while guesses on either side of the diagonal are incorrect assignments. Numbers in white text show the percentage of calls assigned to category x (column x) when it came from category y (row y).

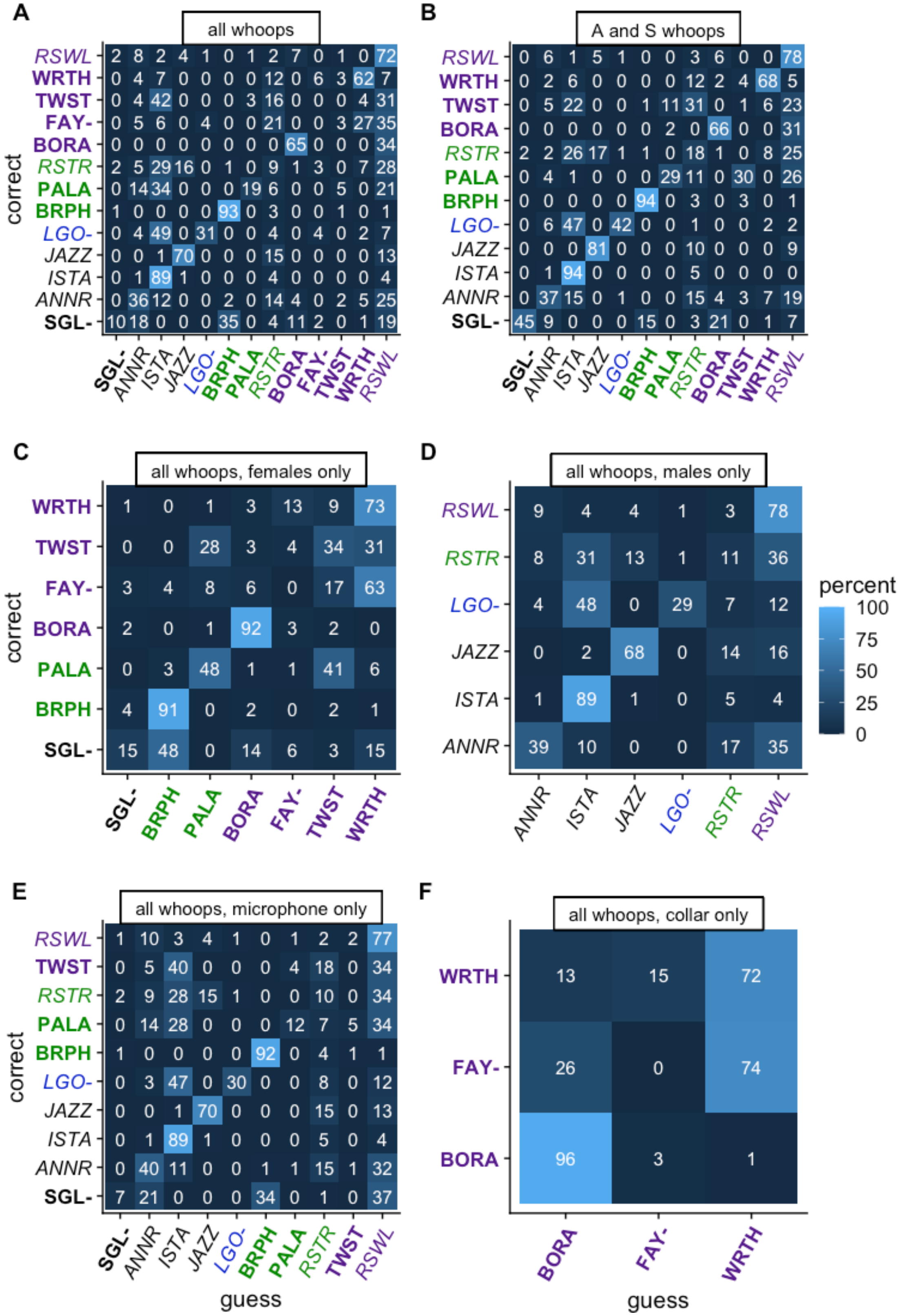

Figure S5: Confusion matrix for individual signature (A) Using all whoop types, (B) Using only A and S type whoops, (C) Using all whoop types from females only, (D) Using all whoop types from males only, *(E) Using all whoop types from microphone recordings, (F) Using all whoop types from collar recordings. Rows represent true categories while columns represent the random forest assignments. Each row shows how the random forest classified calls for that particular individual. Each cell represents the percentage of calls that were assigned to the column category from the true category. Guesses that lie along the diagonal are correct assignments while guesses on either side of the diagonal are incorrect assignments. Numbers in white text show the percentage of calls assigned to individual x (column x) when it came from individual y (row y). Text color indicates clan (black: HZ, blue: SN, green, SS, purple: TW), bolded text indicates adult females, and italicized text indicates adult males.*

References

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