

Supplemental Materials

Table S1. Acoustic parameters summary for each wolf subspecies

Subspecies	Variables	Meanf	Maxf	Minf	Range	Endf	Duration	Cofv	Posmax	Posmin
Himalayan wolf	Range	228.8-981.9	245.4-1145.8	144.4-978.3	5.50-678.3	147.7-1105.7	0.52-7.90	0.35-32.02	0-1.00	0-1.00
	Mean	428.5	465.4	369.5	101.8	404.5	2.56	6.22	0.33	0.53
	SE	125.7	141.9	126.3	107.1	141.9	1.68	5.97	0.28	0.45
North African wolf	Range	424.2-856.0	476.1-1461.9	242.3-661.4	120.1-929.9	242.3-661.4	1.03-5.99	10.80-27.47	0-0.59	0-1.00
	Mean	725.9	963.4	485.6	477.8	495.3	3.26	18.68	0.073	0.89
	SE	104.7	187.6	109.4	150.2	110.8	1.55	5.45	0.11	0.30
Indian wolf	Range	323.0-1503.4	366.1-1604.2	107.7-1367.4	21.5-1013.6	107.7-1496.6	0.61-12.43	0.67-31.56	0.006-1.00	0.0063-1.00
	Mean	593.5	692.0	496.9	197.1	572.5	2.71	8.96	0.38	0.57
	SE	211.4	243.3	202.6	137.4	225.8	2.11	4.87	0.33	0.38
Arctic wolf	Range	418.8-751.8	478.8-858.2	240.0-490.0	126.0-587.3	273.8-698.8	1.43-6.83	10.10-31.61	0.00-1.00	0.00-1.00
	Mean	541.6	707.67	318.2	389.5	401.6	4.60	21.11	0.28	0.27
	SE	90.0	95.0	59.2	103.4	110.4	1.29	6.69	0.21	0.45
European wolf	Range	218.8-628.5	252.7-747.4	125.5-455.7	45.4-500.7	159.5-617.3	1.78-15.12	3.12-30.68	0.00-0.98	0.00-1.00
	Mean	418.7	520.7	294.7	225.9	343.4	5.85	13.69	0.27	0.58
	SE	109.1	125.8	72.7	99.7	102.2	2.72	5.97	0.31	0.47
Iberian wolf	Range	272.9-722.9	296.0-1116.0	92-638.0	64.0-777.0	92.0-706.0	1.10-12.80	2.03-44.63	0.00-0.99	0.00-1.00
	Mean	438.2	586.1	280.7	305.7	308.5	6.55	18.66	0.16	0.81
	SE	96.3	151.7	87.4	136.3	105.1	2.34	7.97	0.21	0.35
Italian wolf	Range	274.2-908.7	301.5-1356.6	193.8-646.0	21.5-1033.6	215.3-796.7	0.75-9.55	0.84-45.44	0.00-1.00	0.00-1.00
	Mean	482.6	657.0	342.1	314.9	377.3	3.74	18.19	0.21	0.68
	SE	131.0	223.3	80.4	200.5	108.7	1.89	10.09	0.24	0.39
Israeli wolf	Range	234.1-1236.6	291.5-1413.8	172.3-940.3	45.3-925.0	173.0-966.0	1.0-4.87	2.65-37.90	0.00-0.84	0.00-1.00
	Mean	619.0	788.4	459.2	329.1	470.0	2.92	15.72	0.25	0.86
	SE	227.6	279.0	190.6	177.6	190.0	1.11	7.17	0.23	0.30
Mackenzie Valley Wolf	Range	254.3-661.5	280.5-840.8	147.1-551.5	38.1-506.8	147.1-551.5	1.40-15.44	2.24-30.16	0.00-0.86	0.00-1.00
	Mean	492.5	567.1	356.3	210.8	374.1	4.14	10.77	0.24	0.73
	SE	98.5	134.9	78.9	125.1	79.2	2.90	6.19	0.21	0.44
Mexican wolf	Range	380.6-577.3	399.8-796.2	202.6-410.3	38.1-496.7	202.6-418.3	3.74-10.20	1.35-27.44	0.020-0.71	0.00-1.00
	Mean	429.5	528.8	335.6	193.2	363.8	7.64	11.61	0.14	0.55
	SE	38.5	95.4	60.9	120.2	54.6	1.68	7.13	0.13	0.48

Table S2: Sources of wolf howls in the current study. Country where recorded refers to the place of origin for captive wolves and the location of recording session for wild wolves.

Clade	Wolf subspecies	Scientific Classification	# of Individuals (# packs [captive:wild])	Country where recorded	Number of howls	Sources
Himalayan	Himalayan wolf	<i>Canis lupus chanco-</i> Himalayan haplotype	~15 (4 packs [2:2])	India	301	This study
North African	North African wolf	<i>Canis lupus lupaster</i>	4 packs [4:0]	Senegal	33	Kershenbaum <i>et al.</i> 2016
Indian	Indian wolf	<i>Canis lupus pallipes</i>	~10 (4 packs [0:4])	India	117	This study
Holarctic	Arctic wolf	<i>Canis lupus arctos</i>	~12 (7 packs [1:6])	Canada	26	Kershenbaum <i>et al.</i> 2016
	European wolf	<i>Canis lupus lupus</i>	~20 packs [7:13]	Poland, Russia, Greece	65	Kershenbaum <i>et al.</i> 2016
	Iberian wolf	<i>Canis lupus signatus</i>	11 (1 pack [1:0])	Spain	176	Palacios <i>et al.</i> 2007
	Italian wolf	<i>Canis lupus italicus</i>	7 packs [0:7]	Italy	164	Passilongo <i>et al.</i> 2010
	Israeli wolf	<i>Canis lupus arabs</i>	5(1[1:0])	Israel	30	Kershenbaum <i>et al.</i> 2016
	Mackenzie Valley Wolf	<i>Canis lupus occidentalis</i>	9 packs [7:2]	Canada	127	Kershenbaum <i>et al.</i> 2016
	Mexican wolf	<i>Canis lupus baileyi</i>	2 packs [1:1]	U.S.A	31	Kershenbaum <i>et al.</i> 2016

Table S3. Descriptions of each howl acoustic parameter.

Howl acoustic parameter	Abbreviation	Description
Mean frequency	Meanf	Mean of the fundamental frequency calculated every 0.05 seconds (Hz) for Himalayan, Indian, Iberian, and Italian wolves. For the other wolf subspecies, Meanf was calculated by averaging 50 measurements for each howl, ranging from every 0.02 seconds to 0.31 seconds.
Maximum frequency	Maxf	Maximum frequency of the fundamental one (Hz)
Minimum frequency	Minf	Minimum frequency of the fundamental one (Hz)
End frequency	Endf	Frequency at the end of the fundamental one (Hz)
Duration	Duration	0.13
Range	Range	Difference between maximum and minimum frequencies (Hz)
Coefficient of frequency variation	cofv	$[(SD/Meanf) * 100]$
Position of maximum frequency	Posmax	Position at which the maximum frequency occurs (time of Maxf/Duration) in the howl
Position of minimum frequency	Posmin	Position at which the minimum frequency occurs (time of Minf/Duration) in the howl

Table S4-S12. Acoustic parameter comparisons across all wolf subspecies using a post-hoc Kruskal-Wallis one-way analysis of variance under Dunn’s tests with Bonferroni p-value adjustments. Each subspecies was treated as an independent unit. Bolded values indicate p-values below 0.01.

Table S4. Mean frequency

	Himalayan	North African	Indian	Arctic	European	Iberian	Mackenzie Valley	Israeli	Italian	Mexican
Himalayan		<0.01	<0.01	<0.01	1.00	0.24	<0.01	<0.01	<0.01	1.00
North African	<0.01		<0.01	0.14	<0.01	<0.01	<0.01	0.19	<0.01	<0.01
Indian	<0.01	<0.01		1.00	<0.01	<0.01	0.19	1.00	<0.01	<0.01
Arctic	<0.01	0.43	1.00		<0.01	<0.01	0.60	1.00	0.084	0.018
European	1.00	<0.01	<0.01	<0.01		1.00	<0.01	<0.01	0.018	1.00
Iberian	0.24	<0.01	<0.01	<0.01	1.00		<0.01	<0.01	0.051	1.00
Mackenzie Valley	<0.01	<0.01	0.19	0.60	<0.01	<0.01		0.24	1.00	0.24
Israeli	<0.01	0.19	1.00	1.00	<0.01	<0.01	0.24		0.018	<0.01
Italian	<0.01	<0.01	<0.01	0.084	0.018	0.051	1.00	0.018		1.00
Mexican	1.00	<0.01	<0.01	0.018	1.00	1.00	0.24	<0.01	1.00	

Table S5. Maximum frequency

	Himalayan	North African	Indian	Arctic	European	Iberian	Mackenzie Valley	Israeli	Italian	Mexican
Himalayan		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.046
North African	<0.01		<0.01	0.39	<0.01	<0.01	<0.01	0.22	<0.01	<0.01
Indian	<0.01	<0.01		0.72	<0.01	0.052	0.016	0.88	1.00	0.031
Arctic	<0.01	0.39	0.72		<0.01	0.011	<0.01	1.00	0.21	<0.01
European	<0.01	<0.01	<0.01	<0.01		0.28	0.75	<0.01	<0.01	1.00
Iberian	<0.01	<0.01	<0.01	0.011	0.28		1.00	0.016	0.52	0.89
Mackenzie Valley	<0.01	<0.01	0.016	<0.01	0.75	1.00		<0.01	0.22	1.00
Israeli	<0.01	0.22	0.88	1.00	<0.01	0.016	<0.01		0.28	<0.01
Italian	<0.01	<0.01	1.00	0.21	<0.01	0.52	0.22	0.28		0.20
Mexican	0.046	<0.01	0.031	<0.01	1.00	0.88	1.00	<0.01	0.20	

Table S6. Minimum frequency

	Himalayan	North African	Indian	Arctic	European	Iberian	Mackenzie Valley	Israeli	Italian	Mexican
Himalayan		<0.01	<0.01	0.38	<0.01	<0.01	1.00	0.10	1.00	1.00
North African	<0.01		1.00	<0.01	<0.01	<0.01	<0.01	1.00	<0.01	<0.01
Indian	<0.01	1.00		1.00	<0.01	<0.01	<0.01	1.00	<0.01	<0.01
Arctic	0.38	<0.01	<0.01		1.00	1.00	0.25	<0.01	1.00	1.00
European	<0.01	<0.01	<0.01	1.00		1.00	<0.01	<0.01	0.017	0.27
Iberian	<0.01	<0.01	<0.01	<0.01	1.00		<0.01	<0.01	<0.01	<0.01
Mackenzie Valley	1.00	<0.01	<0.01	0.25	<0.01	<0.01		0.35	0.97	1.00
Israeli	0.10	1.00	1.00	<0.01	<0.01	<0.01	0.35		0.013	0.22
Italian	1.00	<0.01	<0.01	1.00	0.016	<0.01	0.97	0.013		1.00
Mexican	1.00	<0.01	<0.01	1.00	0.27	<0.01	1.00	0.22	1.00	

Table S7. End Frequency

	Himalayan	North African	Indian	Arctic	European	Iberian	Mackenzie Valley	Israeli	Italian	Mexican
Himalayan		<0.01	<0.01	1.00	0.037	<0.01	1.00	0.84	1.00	1.00
North African	<0.01		1.00	0.063	<0.01	<0.01	<0.01	1.00	<0.01	0.011
Indian	<0.01	1.00		<0.01	<0.01	<0.01	<0.01	0.31	<0.01	<0.01
Arctic	1.00	0.063	<0.01		0.96	<0.01	1.00	1.00	1.00	1.00
European	0.037	<0.01	<0.01	0.96		0.58	0.31	<0.01	1.00	1.00
Iberian	<0.01	<0.01	<0.01	<0.01	0.58		<0.01	<0.01	<0.01	0.018
Mackenzie Valley	1.00	<0.01	<0.01	1.00	0.31	<0.01		0.58	1.00	1.00
Israeli	0.84	1.00	0.31	1.00	<0.01	<0.01	0.58		0.13	1.00
Italian	1.00	<0.01	<0.01	1.00	1.00	<0.01	1.00	0.13		1.00
Mexican	1.00	0.011	<0.01	1.00	1.00	0.018	1.00	1.00	1.00	

Table S8. Duration

	Himalayan	North African	Indian	Arctic	European	Iberian	Mackenzie Valley	Israeli	Italian	Mexican
Himalayan		0.52	1.00	<0.01	<0.01	<0.01	<0.01	1.00	<0.01	<0.01
North African	0.52		0.72	0.21	<0.01	<0.01	1.00	1.00	1.00	<0.01
Indian	1.00	0.72		<0.01	<0.01	<0.01	<0.01	1.00	<0.01	<0.01
Arctic	<0.01	0.21	<0.01		1.00	0.25	0.72	0.055	0.41	0.030
European	<0.01	<0.01	<0.01	1.00		1.00	<0.01	<0.01	<0.01	0.19
Iberian	<0.01	<0.01	<0.01	0.25	1.00		<0.01	<0.01	<0.01	0.95
Mackenzie Valley	<0.01	1.00	<0.01	0.72	<0.01	<0.01		0.72	1.00	<0.01
Israeli	1.00	1.00	1.00	0.055	<0.01	<0.01	0.72		0.96	<0.01
Italian	<0.01	1.00	<0.01	0.41	<0.01	<0.01	1.00	0.96		<0.01
Mexican	<0.01	<0.01	<0.01	0.030	0.19	0.95	<0.01	<0.01	<0.01	

Table S9. Range

	Himalayan	North African	Indian	Arctic	European	Iberian	Mackenzie Valley	Israeli	Italian	Mexican
Himalayan		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
North African	<0.01		<0.01	1.00	<0.01	<0.01	<0.01	0.14	<0.01	<0.01
Indian	<0.01	<0.01		<0.01	0.76	<0.01	1.00	<0.01	<0.01	1.00
Arctic	<0.01	1.00	<0.01		<0.01	0.32	<0.01	1.00	0.068	<0.01
European	<0.01	<0.01	0.76	<0.01		0.051	1.00	0.41	0.44	1.00
Iberian	<0.01	<0.01	<0.01	0.32	0.051		<0.01	1.00	1.00	<0.01
Mackenzie Valley	<0.01	<0.01	1.00	<0.01	1.00	<0.01		0.031	<0.01	1.00
Israeli	<0.01	0.14	<0.01	1.00	0.41	1.00	0.031		1.00	0.046
Italian	<0.01	<0.01	<0.01	0.68	0.44	1.00	<0.01	1.00		0.039
Mexican	<0.01	<0.01	1.00	<0.01	1.00	<0.01	1.00	0.046	0.039	

Table S10. Coefficient of frequency variation (covf)

	Himalayan	North African	Indian	Arctic	European	Iberian	Mackenzie Valley	Israeli	Italian	Mexican
Himalayan		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
North African	<0.01		<0.01	1.00	0.18	1.00	<0.01	1.00	1.00	0.011
Indian	<0.01	<0.01		<0.01	<0.01	<0.01	1.00	<0.01	<0.01	1.00
Arctic	<0.01	1.00	<0.01		0.038	1.00	<0.01	0.72	0.72	<0.01
European	<0.01	0.18	<0.01	0.038		0.034	0.20	1.00	0.56	1.00
Iberian	<0.01	1.00	<0.01	1.00	0.034		<0.01	1.00	1.00	<0.01
Mackenzie Valley	<0.01	<0.01	1.00	<0.01	0.20	<0.01		0.085	<0.01	1.00
Israeli	<0.01	1.00	<0.01	0.72	1.00	1.00	0.085		1.00	0.72
Italian	<0.01	1.00	<0.01	0.72	0.56	1.00	<0.01	1.00		0.028
Mexican	<0.01	0.011	1.00	<0.01	1.00	<0.01	1.00	0.72	0.028	

Table S11. Position of maximum frequency (posmax)

	Himalayan	North African	Indian	Arctic	European	Iberian	Mackenzie Valley	Israeli	Italian	Mexican
Himalayan		<0.01	1.00	1.00	0.047	<0.01	0.16	1.00	<0.01	0.084
North African	<0.01		<0.01	<0.01	0.052	0.56	<0.01	<0.01	0.036	0.68
Indian	1.00	<0.01		1.00	0.37	<0.01	1.00	1.00	0.015	0.32
Arctic	1.00	<0.01	1.00		0.68	0.015	1.00	1.00	0.25	0.44
European	0.68	0.18	0.37	0.68		1.00	1.00	1.00	1.00	1.00
Iberian	0.015	0.56	<0.01	0.015	1.00		0.033	0.24	1.00	1.00
Mackenzie Valley	1.00	<0.01	1.00	1.00	1.00	0.033		1.00	1.00	1.00
Israeli	1.00	<0.01	1.00	1.00	1.00	0.24	1.00		1.00	1.00
Italian	0.25	0.036	0.015	0.25	1.00	1.00	1.00	1.00		1.00
Mexican	0.44	0.67	0.32	0.44	1.00	1.00	1.00	1.00	1.00	

Table S12. Position of minimum frequency (posmin)

	Himalayan	North African	Indian	Arctic	European	Iberian	Mackenzie Valley	Israeli	Italian	Mexican
Himalayan		<0.01	1.00	0.25	1.00	<0.01	<0.01	<0.01	1.00	1.00
North African	<0.01		<0.01	<0.01	<0.01	0.030	0.22	1.00	<0.01	<0.01
Indian	1.00	<0.01		0.32	1.00	<0.01	<0.01	<0.01	1.00	1.00
Arctic	0.25	<0.01	0.32		0.048	<0.01	<0.01	<0.01	0.042	0.26
European	1.00	<0.01	1.00	0.048		0.88	0.22	0.21	1.00	1.00
Iberian	<0.01	0.030	<0.01	<0.01	0.88		1.00	1.00	0.053	1.00
Mackenzie Valley	<0.01	0.22	<0.01	<0.01	0.22	1.00		1.00	<0.01	0.35
Israeli	<0.01	1.00	<0.01	<0.01	0.21	1.00	1.00		0.041	0.25
Italian	1.00	<0.01	1.00	0.042	1.00	0.053	<0.01	0.040		1.00
Mexican	1.00	<0.01	1.00	0.26	1.00	1.00	0.35	0.25	1.00	