Supplementary Material
A cross-species framework to identify vocal learning abilities in mammals
Ravignani & Garcia

Supplementary Table 1. For each PGLS regression model, number of species (total and outliers to the regression) in VPL and non-VPL clades among 164 mammals. Barnard's tests with two-tailed statistics are reported.

		VPL	non-VPL	Total	Barnard's test
minDF	**Outliers**	23	10	33	Z = -4.62 P < 0.001
	Non-outliers	35	96	131	
	Total	58	106	164	
		VPL	**non-VPL**	**Total**	**Barnard's test**
maxDF	**Outliers**	12	13	25	Z = -1.44 P = 0.16
	Non-outliers	46	93	139	
	Total	58	106	164	
		VPL	**non-VPL**	**Total**	**Barnard's test**
rangeDF	**Outliers**	17	15	32	Z = -2.34 P = 0.02
	Non-outliers	41	91	132	
	Total	58	106	164	
		VPL	**non-VPL**	**Total**	**Barnard's test**
meanDF	**Outliers**	8	11	19	Z = -0.65 P = 0.58
	Non-outliers	50	95	145	
	Total	58	106	164	

Supplementary Table 2. Results from the PGLS models fitted on regressions of acoustic parameters over body mass using the full dataset (N = 164, including both VPL and non-VPL species). For each regression, bold text highlights the best fitting model fitted using REML for model comparison, and the final model (i.e. the best model refitted using Maximum Likelihood - see main text). Statistical significance of the final model is indicated with asterisks (* P < 0.05, ** P < 0.01, *** P < 0.001).

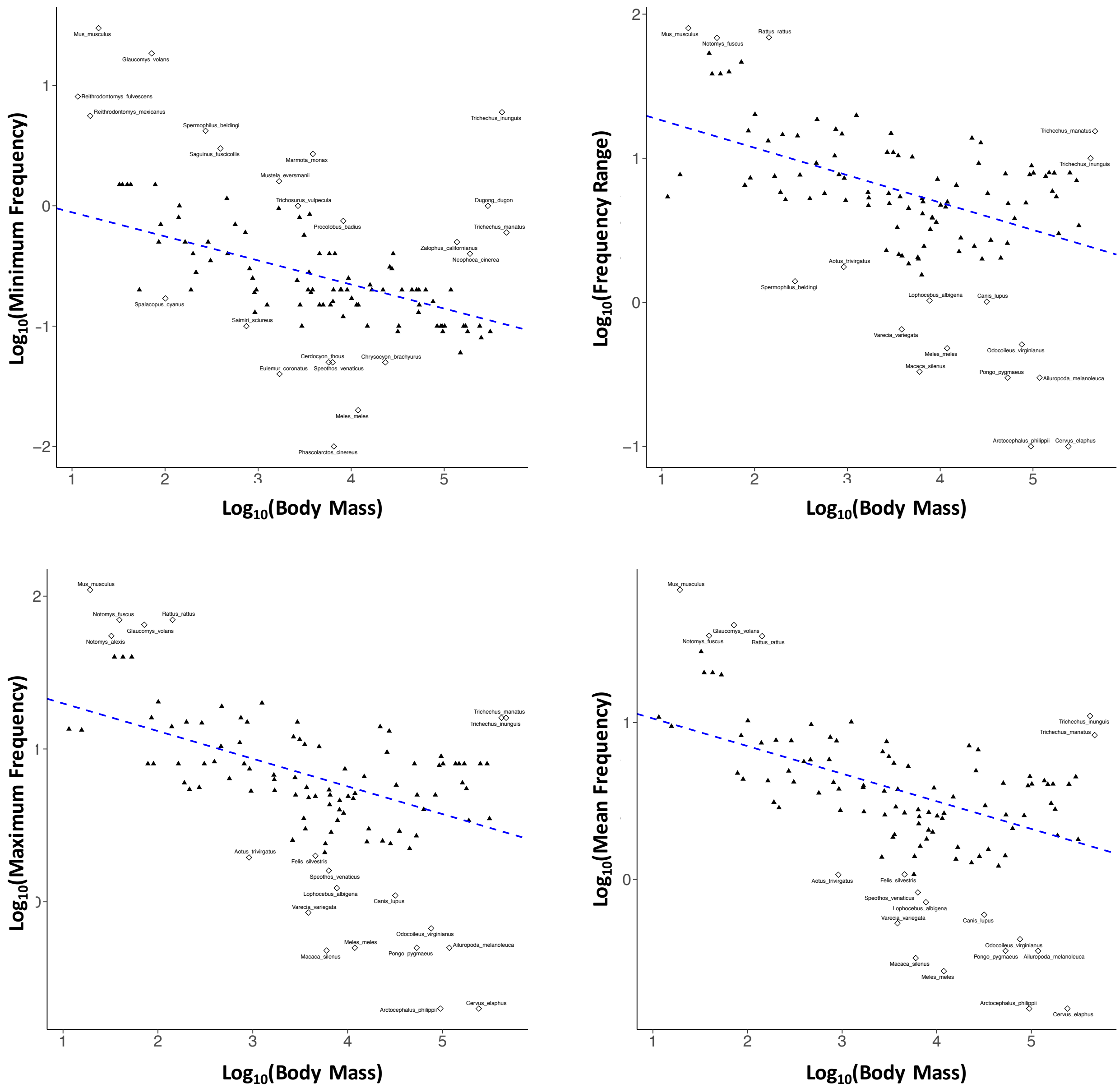
Acoustic variable	PGLS model	Intercept	Log_{10} Body Mass	SE	t	AICc
Log_{10} MinDF	BM	0.21	-0.21	0.09	-2.34	405.75
	BM + λ	0.82	-0.37	0.05	-7.11	267.12
	BM + ρ	0.95	-0.35	0.05	-6.59	277.97
	OU (α = 0.1)	0.62	-0.27	0.04	-6.65	326.74
	OU (α = 0.5)	0.51	-0.24	0.03	-7.32	334.79
	OU (α = 1)	0.51	-0.24	0.03	-7.43	335.51
	OU (α = 10)	0.51	-0.24	0.03	-7.47	334.96
	Best model (ML fitted)	**0.82**	**-0.37*** **	**0.05**	**-7.18**	**263.22**
Log_{10} MaxDF	BM	0.95	0.00024	0.07	0.003	321.46
	BM + λ	1.39	-0.12	0.04	-2.87	222.21
	BM + ρ	1.34	-0.1	0.04	-2.25	216.47
	OU (α = 0.1)	1.28	-0.1	0.03	-3.16	246.03
	OU (α = 0.5)	1.23	-0.08	0.03	-3.11	259.38
	OU (α = 1)	1.23	-0.08	0.03	-3.05	263.72
	OU (α = 10)	1.22	-0.08	0.03	-2.97	266.11
	Best model (ML fitted)	**1.34**	**-0.1***	**0.04**	**-2.3**	**210.32**
Log_{10} RangeDF	BM	0.77	0.03	0.08	0.43	357.79
	BM + λ	1.2	-0.09	0.04	-1.9	262.97
	BM + ρ	1.12	-0.07	0.05	-1.41	260.33
	OU (α = 0.1)	1.08	-0.07	0.03	-2.06	272.36
	OU (α = 0.5)	1.07	-0.06	0.03	-2.18	278.93
	OU (α = 1)	1.07	-0.06	0.03	-2.14	283.15
	OU (α = 10)	1.07	-0.06	0.03	-2.06	285.53
	Best model (ML fitted)	**1.12**	**-0.07**	**0.05**	**-1.47**	**254.12**
Log_{10} MeanDF	BM	0.74	-0.02	0.07	-0.24	304.44
	BM + λ	1.19	-0.14	0.04	-3.3	204.25
	BM + ρ	1.15	-0.12	0.04	-2.69	198.35
	OU (α = 0.1)	1.08	-0.11	0.03	-3.64	236.32
	OU (α = 0.5)	1.01	-0.09	0.03	-3.5	253.62
	OU (α = 1)	1.00	-0.09	0.03	-3.43	257.89
	OU (α = 10)	1.00	-0.08	0.03	-3.35	260.21
	Best model (ML fitted)	**1.15**	**-0.12*** *	**0.04**	**-2.73**	**192.17**

Supplementary Table 3. Results from the PGLS models fitted on regressions of acoustic parameters over body mass using non-VPL species only (N = 106). For each regression, bold text highlights the best fitting model fitted using REML for model comparison, and the final model (i.e. the best model refitted using Maximum Likelihood - see main text). Statistical significance of the final model is indicated with asterisks (* P < 0.05, ** P < 0.01, *** P < 0.001).

Acoustic variable	PGLS model	Intercept	Log_{10} Body Mass	SE	t	AICc
Log_{10} MinDF	BM	-0.1	-0.14	0.06	-2.25	141.80
	BM + λ	0.13	-0.2	0.06	-3.09	139.82
	BM + ρ	0.18	-0.19	0.06	-3.14	152.5
	OU (α = 0.1)	0.38	-0.25	0.05	-5.24	148.73
	OU (α = 0.5)	0.43	-0.26	0.04	-6.31	159.84
	OU (α = 1)	0.44	0.26	0.04	-6.45	160.48
	OU (α = 10)	0.44	-0.26	0.04	-6.47	160.62
	Best model (ML fitted)	**0.15**	**-0.2****	**0.06**	**-3.17**	**136.53**
Log_{10} MaxDF	BM	1.40	-0.14	0.08	-1.78	198.82
	BM + λ	1.52	-0.18	0.05	-3.77	122.9
	BM + ρ	1.47	-0.18	0.05	-3.37	120
	OU (α = 0.1)	1.53	-0.21	0.04	-4.73	135.32
	OU (α = 0.5)	1.6	-0.23	0.04	-6.34	130.45
	OU (α = 1)	1.61	-0.23	0.04	-6.52	130.93
	OU (α = 10)	1.61	-0.23	0.04	-6.53	131.12
	Best model (ML fitted)	**1.48**	**-0.18*****	**0.05**	**-3.52**	**113.51**
Log_{10} RangeDF	BM	1.37	-0.15	0.09	-1.6	228.61
	BM + λ	1.48	-0.19	0.05	-3.53	148.20
	BM + ρ	1.44	-0.19	0.06	-3.22	145.93
	OU (α = 0.1)	1.43	-0.2	0.05	-4	159.15
	OU (α = 0.5)	1.51	-0.22	0.04	-5.52	151.46
	OU (α = 1)	1.53	-0.22	0.04	-5.7	151.79
	OU (α = 10)	1.53	-0.22	0.04	-5.71	151.93
	Best model (ML fitted)	**1.45**	**-0.19*****	**0.06**	**-3.40**	**139.65**
Log_{10} MeanDF	BM	1.12	-0.14	0.07	-1.90	180.14
	BM + λ	1.25	-0.18	0.05	-3.87	109.44
	BM + ρ	1.19	-0.17	0.05	-3.44	106.49
	OU (α = 0.1)	1.29	-0.21	0.04	-5.13	122.80
	OU (α = 0.5)	1.36	-0.23	0.03	-6.76	120.43
	OU (α = 1)	1.37	-0.24	0.03	-6.94	121.01
	OU (α = 10)	1.37	-0.24	0.0	-6.95	121.21
	Best model (ML fitted)	**1.20**	**-0.18*****	**005**	**-3.57**	**99.92**

Supplementary Table 4: List of non-VPL species found as outliers to allometry scaling for each of the 4 models using the 'VPL-free' dataset (i.e. only including non-VPL species). The direction of the deviation from acoustic allometry scaling is indicated either as U (denotes an upward outlier, i.e. one above the regression line), or D (denotes a downward outlier, i.e. one below the regression line). N = 37 species.

Binomial name	Common name	MaxDF	MeanDF	MinDF	RangeDF	Category
Ailuropoda melanoleuca	Giant panda	D	D		D	2
Aotus trivirgatus	Three-striped night monkey	D	D		D	2
Arctocephalus philippii	Juan Fernández fur seal	D	D		D	2
Canis lupus	Wolf	D	D		D	2
Cerdocyon thous	Crab-eating fox			D		2
Cervus elaphus	Red deer	D	D		D	2
Chrysocyon brachyurus	Maned wolf			D		2
Dugong dugon	Dugong			U		4
Eulemur coronatus	Crowned lemur			D		2
Felis silvestris	Wild cat	D	D			2
Glaucomys volans	Southern flying squirrel	U	U	U		4
Lophocebus albigena	Grey-cheeked mangabey	D	D		D	2
Macaca silenus	Lion-tailed macaque	D	D		D	2
Marmota monax	Groundhog			U		4
Meles meles	European badger	D	D	D	D	2
Mus musculus	House mouse	U	U	U	U	4
Mustela eversmanii	Steppe polecat			U		4
Neophoca cinerea	Australian sea lion			U		4
Notomys alexis	Spinifex hopping mouse	U				4
Notomys fuscus	Dusky hopping mouse	U	U		U	4
Odocoileus virginianus	White-tailed deer	D	D		D	2
Phascolarctos cinereus	Koala			D		2
Procolobus badius	Western red colobus			U		4
Pongo pygmaeus	Bornean orangutan	D	D		D	2
Rattus rattus	Black rat	U	U		U	4
Reithrodontomys fulvescens	Fulvous harvest mouse			U		4
Reithrodontomys mexicanus	Mexican harvest nouse			U		4
Saguinus fuscicollis	Brown-mantled tamarin			U		4
Saimiri sciureus	Squirrel monkey			D		2
Spalacopus cyanus	Coruro			D		2
Speothos venaticus	Bush dog	D	D	D		2
Spermophilus beldingi	Belding's ground squirrel			U	D	5
Trichechus inunguis	Amazonian manatee	U	U	U	U	4
Trichechus manatus	West Indian manatee	U	U	U	U	4
Trichosurus vulpecula	Common brushtail possum			U		4
Varecia variegata	Black-and-white ruffed lemur	D	D		D	2
Zalophus californianus	California sea lion			U		4



Supplementary Figure 1: PGLS regressions representing acoustic allometry relationships between acoustic features and body mass (all variables log-transformed), including non-VPL species only (N= 106 species). Outliers (see defining criteria in the Methods) are indicated by empty diamonds, while non-outliers are indicated by filled triangles. All regressions showed statistically significant associations between the acoustic feature considered and body mass (see Supplementary Table 3).

List of modifications to the original dataset

Initial inspection of the raw data suggested that some modifications needed to be made, either because of typos (e.g. with values off by an order of magnitude), misreading from the literature cited in the original Martin et al's study [1], or obvious omissions from the existing literature.

Modifications of body mass were made for four species:

- *Caperea marginata*: weight modified to 3.2 Tons instead of 32 Tons

- *Pteronura brasiliensis*: weight modified to 26 Kg instead of 2.6 Kg

- *Semnopithecus entellus*: weight modified to 11450 g instead of 1715 g (the new value is the average of the weight range retrieved from https://animaldiversity.org/accounts/Semnopithecus_entellus/)

- *Trachypithecus johnii*: weight modified to 11950 g instead of 1150 g (the new value is the average of the weight range retrieved from https://animaldiversity.org/accounts/Trachypithecus_johnii/)

Modifications of frequencies were made for thirteen species (all modifications were based on values found within the articles cited in the original Martin et al's study [1], except for the Asian elephant (*Elephas maximus*). The maximum frequency for this species was indeed obviously underestimated, because the literature cited only focused on rumble vocalizations (which created a major discrepancy with the other elephant species – *Loxodonta Africana* – present in this dataset):

- *Arctocephalus tropicalis*: minimum frequency modified to 0.1 kHz instead of 0.01 kHz

- *Elephas maximus*: maximum frequency modified to 6.15 kHz instead of 0.2 kHz (based on [2])

- *Hyperoodon ampullatus*: minimum frequency modified to 0.5 kHz instead of 3 kHz

- *Lemur catta*: maximum frequency modified to 2.53 kHz instead of 2.35 kHz

- *Martes americana*: maximum frequency modified to 15 kHz and not 8 kHz

- *Mesoplodon carlhubbsi*: minimum frequency modified to 0.3 kHz instead of 3 kHz

- *Mustela frenata*: minimum frequency modified to 0.2 kHz and not 0.5 kHz

- *Nycticebus coucang*: maximum frequency modified to 7.4 kHz instead of 5.95 kHz

- *Ommatophoca rossii*: minimum frequency modified to 0.1 kHz instead of 0.25 kHz

- *Orcinus orca*: minimum frequency modified to 0.05 kHz instead of 1.5 kHz

- *Panthera tigris*: maximum frequency modified to 6 kHz instead of 10 kHz

- *Phascolarctos cinereus*: minimum frequency modified to 0.01 kHz instead of 1 kHz

- *Stenella frontalis*: minimum frequency modified to 0.1 kHz instead of 5 kHz

ADDITIONAL ANALYSES

To further probe the question at hand - a potential association between acoustic allometry scaling and VPL abilities -, we performed two additional sets of analyses. First, toothed whales (a family known to include several species capable of VPL) can produce echolocation clicks of high frequencies and do so with non-laryngeal mechanisms [3]. This could potentially affect our results and calls for a parallel analysis excluding this clade from the analysis dataset. Second, we chose to extend VPL abilities to all species within a clade known to present at least one species with demonstrated evidence of VPL abilities. A more restrictive analysis, including as VPL species only those for which this ability has been demonstrated, is also warranted.

Analysis excluding odontocetes (toothed whales)

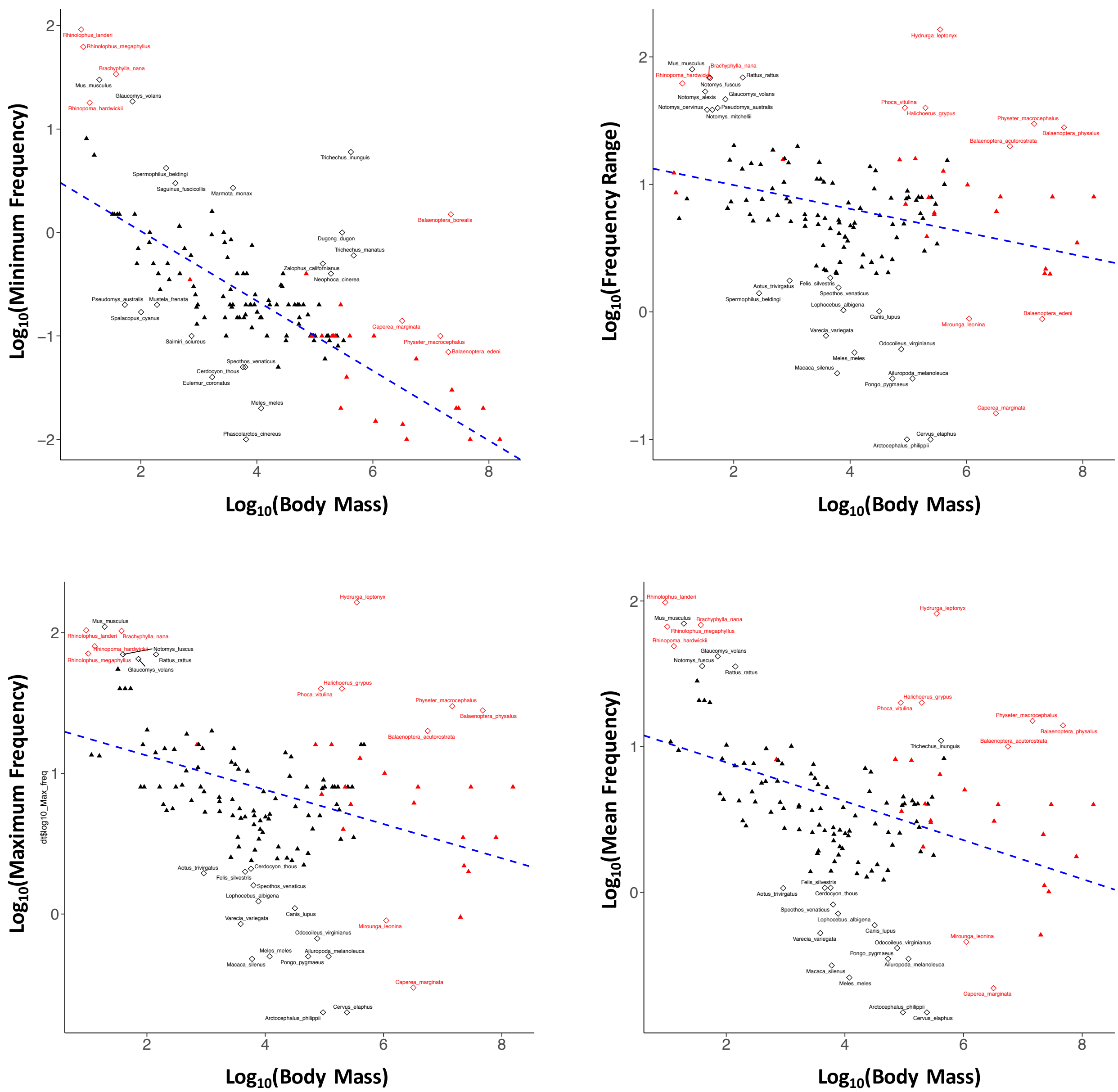
Excluding toothed whales resulted in a dataset of 137 species (this means 27 species less than our original analysis). PGLS models revealed significant negative allometric scaling between body mass and all acoustic parameters (MinDF, MaxDF, MeanDF) except RangeDF (Supplementary Table 5, Supplementary Figure 2). This therefore matches perfectly the results obtained using the full dataset. When looking at the proportions of VPL and non-VPL species being allometric outliers, we obtained opposite results, namely with significant differences for MaxDF and MeanDF but not for RangeDF and MinDF (Supplementary Table 6). While this still suggests an association between being an allometric outlier and possessing VPL abilities, it seems that toothed whales were driving the differences in MinDF and RangeDF. Assuming that high-frequency echolocation clicks should have pulled the difference for MaxDF (and by extension potentially to RangeDF and MeanDF), we conclude that the effect of such high-frequency signals is negligible in our full dataset. This idea is supported by our main MaxDF regression (see Figure 3 in the main manuscript), which shows that only 3 outliers belong to toothed whales.

Supplementary Table 5. Results from the PGLS regression models fitted to regressions of acoustic parameters over body mass using the dataset without Odontocetes (N = 137). For each regression, bold text highlights the best fitting model fitted using REML for model comparison, and the final model (i.e. the best model refitted using Maximum Likelihood - see main text). Statistical significance of the final model is indicated with asterisks (* P < 0.05, ** P < 0.01, *** P < 0.001).

Acoustic variable	PGLS model	Intercept	Log_{10} Body Mass	SE	t	AICc
Log_{10} MinDF	BM	0.42	-0.27	0.07	-3.82	248.68
	BM + λ	0.68	-0.34	0.05	-6.36	200.71
	BM + ρ	0.8	-0.34	0.05	-6.61	214.12
	OU (α = 0.1)	0.78	-0.34	0.04	-9.32	223.47
	OU (α = 0.5)	0.69	-0.32	0.03	-10.88	230.07
	OU (α = 1)	0.68	-0.31	0.03	-11	231.05
	OU (α = 10)	0.67	-0.31	0.03	-11.01	231.35
	Best model (ML fitted)	**0.69**	**-0.34*****	**0.05**	**-6.46**	**196.9**
Log_{10} MaxDF	BM	1.28	-0.09	0.08	-1.08	292.96
	BM + λ	1.45	-0.14	0.04	-3.2	196.28
	BM + ρ	1.37	-0.12	0.04	-2.53	188.46
	OU (α = 0.1)	1.43	-0.15	0.03	-4.43	210.85
	OU (α = 0.5)	1.36	-0.13	0.03	-4.9	211.25
	OU (α = 1)	1.35	-0.13	0.03	-4.84	214.15
	OU (α = 10)	1.35	-0.13	0.03	-4.80	215.04
	Best model (ML fitted)	**1.37**	**-0.12****	**0.05**	**-2.6**	**182.51**
Log_{10} RangeDF	BM	1.17	-0.08	0.09	-0.86	317.54
	BM + λ	1.26	-0.1	0.04	-2.4	220.23
	BM + ρ	1.18	-0.09	0.05	-1.85	215.3
	OU (α = 0.1)	1.22	-0.12	0.04	-3.27	229.15
	OU (α = 0.5)	1.2	-0.11	0.03	-3.76	226.65
	OU (α = 1)	1.19	-0.11	0.03	-3.73	229.43
	OU (α = 10)	1.19	-0.1	0.03	-3.7	230.26
	Best model (ML fitted)	**1.18**	**-0.09**	**0.05**	**-1.93**	**209.32**
Log_{10} MeanDF	BM	1.03	-0.1	0.08	-1.21	279.31
	BM + λ	1.23	-0.15	0.04	-3.52	184.46
	BM + ρ	1.16	-0.13	0.05	-2.86	176.56
	OU (α = 0.1)	1.22	-0.16	0.03	-4.94	202.67
	OU (α = 0.5)	1.14	-0.14	0.03	-5.4	204.96
	OU (α = 1)	1.13	-0.14	0.03	-5.33	207.82
	OU (α = 10)	1.13	-0.14	0.03	-5.28	208.7
	Best model (ML fitted)	**1.16**	**-0.13****	**0.05**	**-2.92**	**170.58**

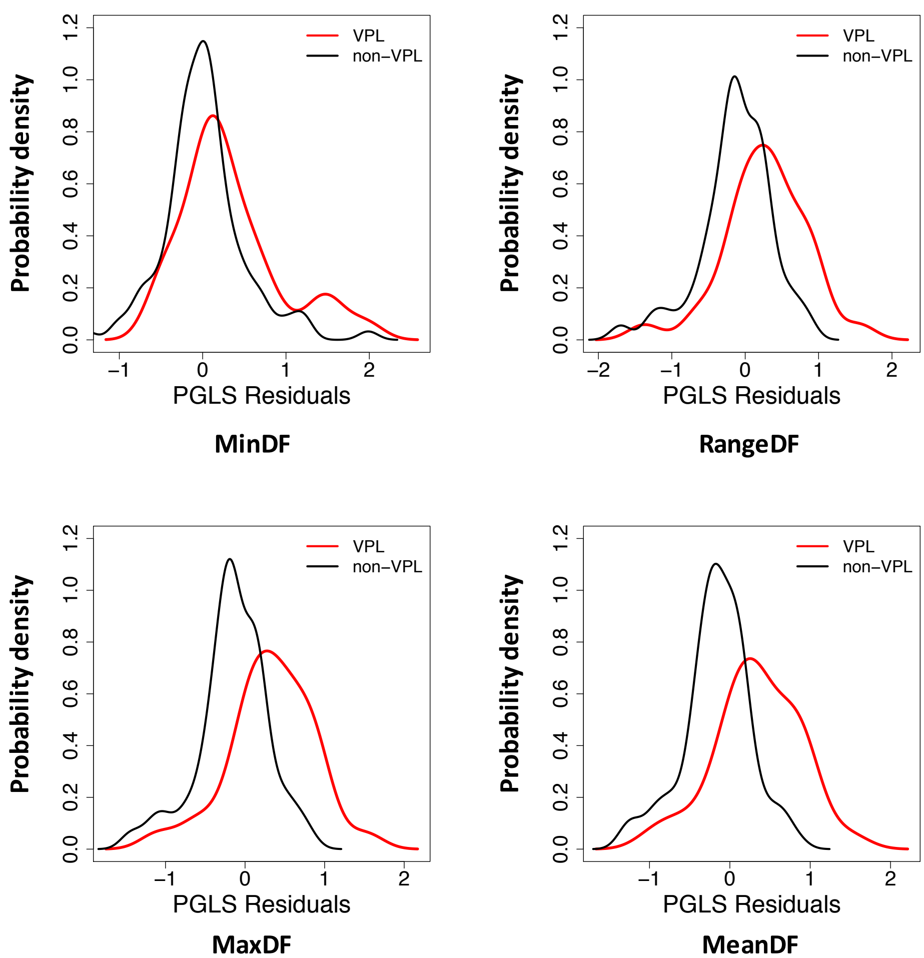
Supplementary Table 6. For each PGLS regression model, number of species (total and outliers to the regression) in VPL and non-VPL clades among 137 mammals. Barnard's tests with two-tailed statistics are reported.

		VPL	non-VPL	Total	Barnard's test
minDF	**Outliers**	8	19	27	Z = -0.97 P = 0.36
	Non-outliers	23	87	110	
	Total	31	106	137	
		VPL	**non-VPL**	**Total**	**Barnard's test**
maxDF	**Outliers**	12	18	30	Z = -2.57 P = 0.02
	Non-outliers	19	88	107	
	Total	31	106	137	
		VPL	**non-VPL**	**Total**	**Barnard's test**
rangeDF	**Outliers**	11	22	33	Z = -1.69 P = 0.11
	Non-outliers	20	84	104	
	Total	31	106	137	
		VPL	**non-VPL**	**Total**	**Barnard's test**
meanDF	**Outliers**	12	19	31	Z = -2.43 P = 0.02
	Non-outliers	19	87	106	
	Total	31	106	137	



Supplementary Figure 2. PGLS regressions representing acoustic allometry relationships between acoustic features and body mass (all variables log-transformed). VPL species are indicated in red, while non-VPL species are indicated in black. Outliers are indicated by empty diamonds, while non-outliers are indicated by filled triangles. Apart from the regression involving frequency range (top-right panel), all regressions showed that acoustic features are significantly predicted by body mass.

Comparison of the residual values from the dataset excluding odontocetes showed very similar results to those obtained from the full dataset including odontocetes. In particular, whether considering all species together or only outlier species, we systematically found significant differences between signed residuals of VPL vs. non-VPL species (Supplementary Table 7). This shows that, here again, VPL species are generally placed significantly higher than non-VPL species relative to the allometric regressions for all four acoustic parameters considered (Supplementary Figure 3). Inspection of the absolute residuals showed mainly no significant differences between VPL and non-VPLs (except for MaxDF and MeanDF when comparing absolute residuals of species using the full dataset). This suggests that overall, the magnitude of deviation from standard allometric scaling is similar in VPL and non-VPL outlier species, while this magnitude can differ when looking at all species instead of outliers only (in which case VPL species deviate more than non-VPL species from standard allometric scaling – see MaxDF & MeanDF in Supplementary Table 7). The effect of toothed whales on these results does not seem very strong, given that similar results were obtained when looking specifically at absolute residuals from outlier species (see Table 1 in the main text and Supplementary Table 7).



Supplementary Figure 3: For each PGLS regression, density plots showing the distribution of signed residuals for VPL and non-VPL species.

Supplementary Table 7. For each PGLS regression, comparisons (Using Mann-Whitney U-tests) between residuals from VPL and non-VPL clades, either based on the full dataset (N = 137 species) or only outliers, and either using the absolute residual values or the signed residual values.

Dataset	PGLS regression	MinDF		MaxDF		MeanDF		RangeDF	
		VPL	non-VPL	VPL	non-VPL	VPL	non-VPL	VPL	non-VPL
Full dataset	Mean signed residuals	0.33	0.01	0.33	-0.16	0.34	-0.16	0.27	-0.13
	Mann-Whitney U-test (VPL/non-VPL)	W = 2156, P = 0.008		W = 2567, P < 0.001		W = 2610, P < 0.001		W = 2373, P < 0.001	
	Mean absolute residuals	0.48	0.34	0.5	0.35	0.5	0.33	0.49	0.37
	Mann-Whitney U-test (VPL/non-VPL)	W = 1887, P = 0.21		W = 2035, P = 0.044		W = 2112, P = 0.02		W = 1935, P = 0.13	
Outliers only	Mean signed residuals	1.17	0.14	0.59	-0.59	0.63	-0.5	0.45	-0.41
	Mann-Whitney U-test (VPL/non-VPL)	W = 114, P = 0.045		W = 187, P < 0.001		W = 202, P < 0.001		W = 195, P = 0.004	
	Mean absolute residuals	1.16	0.96	0.89	0.92	0.9	0.87	0.92	0.92
	Mann-Whitney U-test (VPL/non-VPL)	W = 89, P = 0.51		W = 107, P = 0.98		W = 134, P = 0.43		W = 130, P = 0.75	

Finally, inspection of the position of outliers as either upward or downward from the regression for each of the parameters considered showed similar results to that carried out using VPL clades in the main text (in particular, the same categories were obtained, and in most cases VPL outliers were found as upward outliers from the allometric regression while non-VPL outliers were often found as downward outliers - see supplementary Tables 8 & 9). The species found in these tables overlap greatly with those found using VPL clades, despite inherent differences existing due to the use of the different datasets.

Supplementary Table 8. List of VPL species found as outliers to allometry scaling for each of the 4 models using the dataset with no Odontocetes. The direction of the deviation from acoustic allometry scaling is indicated either as U (denotes an upward outlier) or D (denotes a downward outlier). N = 14 species.

Binomial name	Common name	MaxDF	MeanDF	MinDF	RangeDF	Category
Balaenoptera acutorostrata	Minke whale	U	U		U	1
Balaenoptera borealis	Sei whale			U		1
Balaenoptera edeni	Bryde's whale			U	D	5
Balaenoptera physalus	Fin whale	U	U		U	1
Brachyphylla nana	Cuban fruit-eating bat	U	U	U	U	1
Caperea marginata	Pygmy right whale	D	D	U	D	5
Halichoerus grypus	Grey seal	U	U		U	1
Hydrurga leptonyx	Leopard seal	U	U		U	1
Mirounga leonina	Southern elephant seal	D	D		D	3
Phoca vitulina	Harbor seal	U	U		U	1
Physeter macrocephalus	Sperm whale	U	U	U	U	1
Rhinolophus landeri	Lander's horseshoe bat	U	U	U		1
Rhinolophus megaphyllus	Smaller horseshoe bat	U	U	U		1
Rhinopoma hardwickii	Lesser mouse-tailed bat	U	U	U	U	1

Supplementary Table 9. List of non-VPL species found as outliers to allometry scaling for each of the 4 models using the dataset with no Odontocetes. The direction of the deviation from acoustic allometry scaling is indicated either as U (denotes an upward outlier) or D (denotes a downward outlier). N = 35 species.

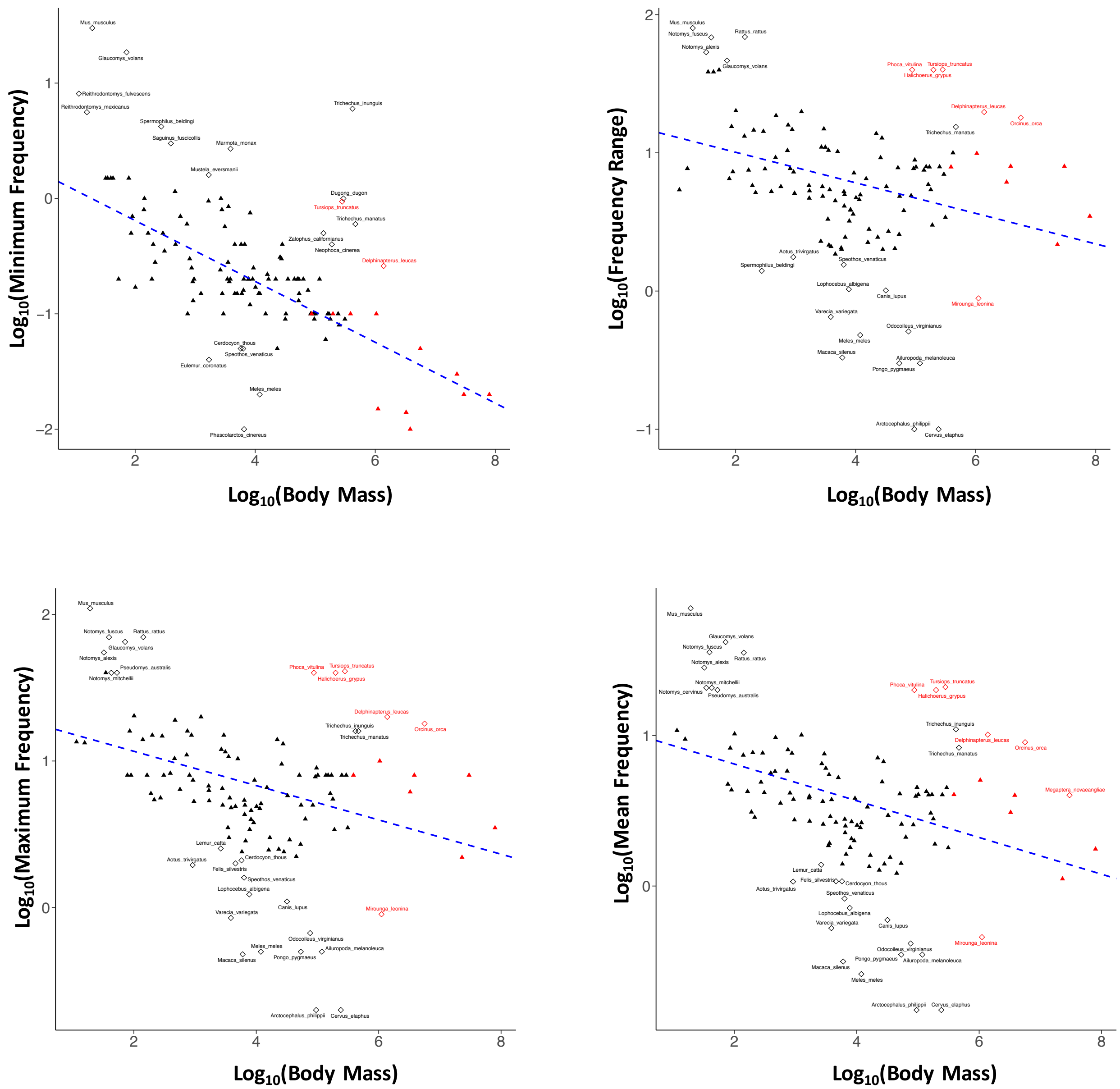
Binomial name	Common name	MaxDF	MeanDF	MinDF	RangeDF	Category
Ailuropoda melanoleuca	Giant panda	D	D		D	2
Aotus trivirgatus	Three-striped night monkey	D	D		D	2
Arctocephalus philippii	Juan Fernández fur seal	D	D		D	2
Canis lupus	Wolf	D	D		D	2
Cerdocyon thous	Crab-eating fox	D	D	D		2
Cervus elaphus	Red deer	D	D		D	2
Dugong dugon	Dugong			U		4
Eulemur coronatus	Crowned lemur			D		2
Felis silvestris	Wild cat	D	D		D	2
Glaucomys volans	Southern flying squirrel	U	U	U	U	4
Lophocebus albigena	Grey-cheeked mangabey	D	D		D	2
Macaca silenus	Lion-tailed macaque	D	D		D	2
Marmota monax	Groundhog			U		4
Meles meles	European badger	D	D	D	D	2
Mus musculus	House mouse	U	U	U	U	4
Mustela frenata	Long-tailed weasel			D		2
Neophoca cinerea	Australian sea lion			U		4
Notomys alexis	Spinifex hopping mouse				U	4
Notomys cervinus	Fawn hopping mouse				U	4
Notomys fuscus	Dusky hopping mouse	U	U		U	4
Notomys mitchellii	Mitchell's hopping mouse				U	4
Odocoileus virginianus	White-tailed deer	D	D		D	2
Phascolarctos cinereus	Koala			D		2
Pongo pygmaeus	Bornean orangutan	D	D		D	2
Pseudomys australis	Plains rat			D	U	5
Rattus rattus	Black rat	U	U		U	4
Saguinus fuscicollis	Brown-mantled tamarin			U		4
Saimiri sciureus	Squirrel monkey			D		2
Spalacopus cyanus	Coruro			D		2
Speothos venaticus	Bush dog	D	D	D	D	2
Spermophilus beldingi	Belding's ground squirrel			U	D	5
Trichechus inunguis	Amazonian manatee		U	U		4
Trichechus manatus	West Indian manatee			U		4
Varecia variegata	Black-and-white ruffed lemur	D	D		D	2
Zalophus californianus	California sea lion			U		4

Analysis including only proven VPL species

Only including species for which there is proven evidence of VPL abilities (VPL strict thereafter) led to a final dataset of 119 species (among which 106 non-VPL and 13 VPL strict). In performing this analysis, we excluded species that belong to a clade known to contain a VPL strict species but for which VPL abilities are unknown to date; especially classifying sister species of vocal learners as non-vocal learners would have biased our results, so we decided for the less controversial option, namely exclusion.

PGLS models revealed significant negative allometric scaling between body mass and all acoustic parameters, in this case also including RangeDF (Supplementary Figure 4, Supplementary Table 8). This closely matches the results obtained using the full dataset.

When looking at the proportions of VPL and non-VPL species being allometric outliers, we obtained yet different results from the other two analyses (full analysis and analysis without Odontocetes analysis), namely with significant differences for RangeDF and MeanDF but not for MaxDF and MinDF (Supplementary Table 9). Here again this suggests that an association exists between being an allometric outlier and possessing VPL abilities, yet unlike in the full analysis, MaxDF and MinDF do not show these associations. However, these results should be interpreted with caution, given the reduced sample size for these analyses (including only 13 VPL strict species).



Supplementary Figure 4. PGLS regressions representing acoustic allometry relationships between acoustic features and body mass (all variables log-transformed). VPL strict species are indicated in red, while non-VPL species are indicated in black. Outliers are indicated by empty diamonds, while non-outliers are indicated by filled triangles. All regressions showed that acoustic features are significantly predicted by body mass.

Supplementary Table 10. Results from the PGLS regression models fitted to regressions of acoustic parameters over body mass using the dataset with VPL species (but not VPL clades; N = 119). For each regression, bold text highlights the best fitting model fitted using REML for model comparison, and the final model (i.e. the best model refitted using Maximum Likelihood - see main text). Statistical significance of the final model is indicated with asterisks (* P < 0.05, ** P < 0.01, *** P < 0.001).

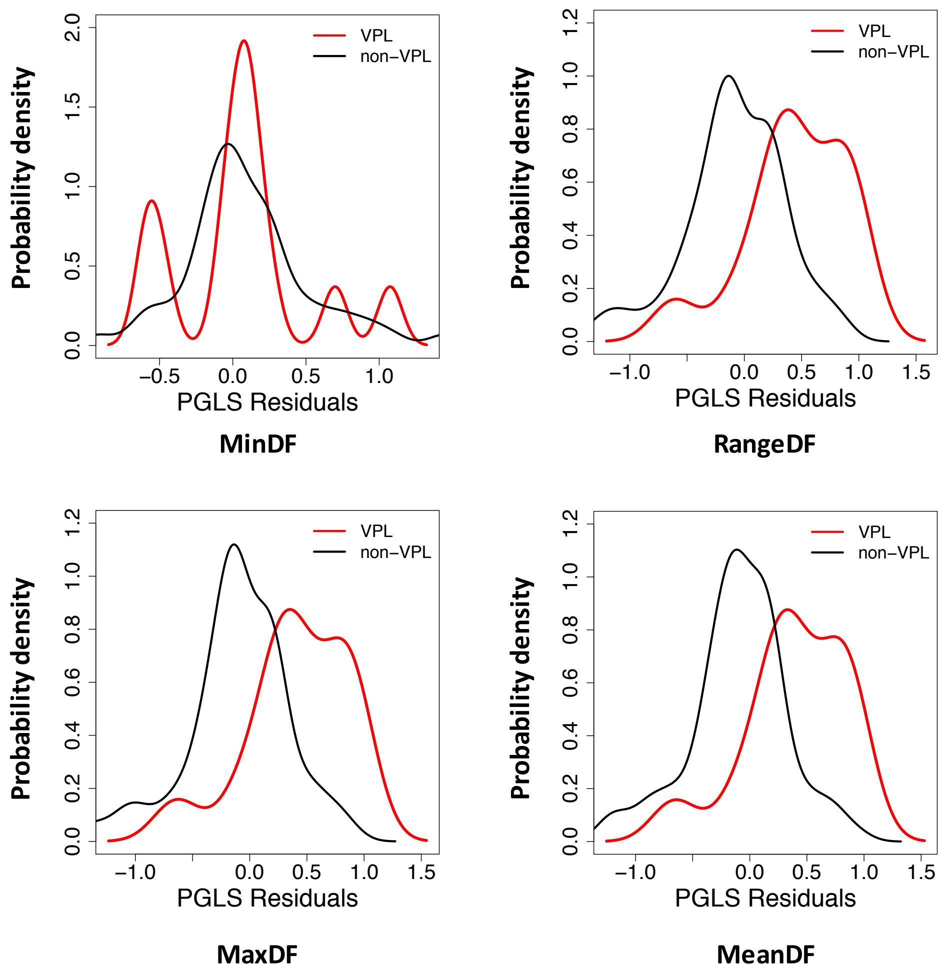
Acoustic variable	PGLS model	Intercept	Log_{10} Body Mass	SE	t	AICc
Log_{10} MinDF	BM	0.05	-0.19	0.06	-3.4	162.73
	BM + λ	0.33	-0.26	0.05	-4.74	156.85
	BM + ρ	0.45	-0.27	0.05	-5.26	172.31
	OU (α = 0.1)	0.45	-0.27	0.04	-7.57	164.65
	OU (α = 0.5)	0.47	-0.27	0.03	-8.61	176.62
	OU (α = 1)	0.47	-0.27	0.03	-8.71	177.25
	OU (α = 10)	0.47	-0.27	0.03	-8.73	177.37
	Best model (ML fitted)	**0.34**	**-0.26*** **	**0.05**	**-4.83**	**153.21**
Log_{10} MaxDF	BM	1.40	-0.14	0.07	-1.86	220.34
	BM + λ	1.36	-0.12	0.05	-2.67	152.33
	BM + ρ	1.31	-0.12	0.05	-2.38	152.29
	OU (α = 0.1)	1.25	-0.11	0.04	-3.22	163.62
	OU (α = 0.5)	1.27	-0.12	0.03	-3.94	170.4
	OU (α = 1)	1.29	-0.13	0.03	-4.07	171.71
	OU (α = 10)	1.29	-0.13	0.03	-4.09	171.92
	Best model (ML fitted)	**1.30**	**-0.12***	**0.05**	**-2.39**	**146.21**
Log_{10} RangeDF	BM	1.37	-0.14	0.08	-1.65	251.71
	BM + λ	1.29	-0.12	0.05	-2.29	177.46
	BM + ρ	1.24	-0.11	0.05	-2.06	177.47
	OU (α = 0.1)	1.14	-0.1	0.04	-2.56	186.67
	OU (α = 0.5)	1.17	-0.11	0.03	-3.27	189.52
	OU (α = 1)	1.19	-0.11	0.03	-3.4	190.67
	OU (α = 10)	1.19	-0.11	0.03	-3.41	190.85
	Best model (ML fitted)	**1.23**	**-0.11***	**0.05**	**-2.08**	**171.65**
Log_{10} MeanDF	BM	1.13	-0.14	0.07	-2.01	200.94
	BM + λ	1.11	-0.13	0.04	-2.91	138.72
	BM + ρ	1.06	-0.12	0.05	-2.6	139.02
	OU (α = 0.1)	1.01	-0.12	0.03	-3.64	151.29
	OU (α = 0.5)	1.04	-0.13	0.03	-4.36	160.71
	OU (α = 1)	1.05	-0.13	0.03	-4.48	162.09
	OU (α = 10)	1.05	-0.13	0.03	4.5	162.31
	Best model (ML fitted)	**1.05**	**-0.12** **	**0.05**	**-2.61**	**132.82**

Supplementary Table 11. For each PGLS regression model, number of species (total and outliers to the regression) in VPL and non-VPL clades among 119 mammals. Barnard's tests with two- tailed statistics are reported.

		VPL	non-VPL	Total	Barnard's test
minDF	**Outliers**	2	18	20	Z = 0.15 P = 0.98
	Non-outliers	11	88	99	
	Total	13	106	119	
		VPL	**non-VPL**	**Total**	**Barnard's test**
maxDF	**Outliers**	6	24	30	Z = -1.84 P = 0.068
	Non-outliers	7	82	89	
	Total	13	106	119	
		VPL	**non-VPL**	**Total**	**Barnard's test**
rangeDF	**Outliers**	6	19	25	Z = -2.36 P = 0.047
	Non-outliers	7	87	94	
	Total	13	106	119	
		VPL	**non-VPL**	**Total**	**Barnard's test**
meanDF	**Outliers**	7	25	32	Z = -2.32 P = 0.047
	Non-outliers	6	81	87	
	Total	13	106	119	

Comparison of the residual values led to similar results to those produced in the other two analyses. Here again, whether considering all species together or only outlier species, we systematically found significant differences between signed residuals of VPL vs. non-VPL species (for all acoustic parameters except MinDF – see Supplementary Table 10). As before, this underscores that VPL strict species are generally placed significantly above non-VPL species relative to the allometric regressions (except for MinDF – see Supplementary Figure 5).

Inspection of the absolute residuals showed no significant differences between VPL strict and non-VPLs when considering outliers only. When comparing all species however, we found significant differences between VPL strict and non-VPL species (except for MinDF – see Supplementary Table 10). This shows that the magnitude of deviation from standard allometric scaling is similar in VPL strict and non-VPL outliers. However, this magnitude significantly differs overall between VPL strict and non-VPL species, with VPL strict showing greater absolute values (hence greater deviation from standard allometric scaling) than non-VPL species. Therefore, restricting VPL to only strictly demonstrated cases of VPL (as opposed to extending our definition to entire clades) remains relatively well aligned with results from our initial analysis.



Supplementary Figure 5. For each PGLS regression, density plots showing the distribution of signed residuals for VPL (strict VPL species and not VPL clades) and non-VPL species.

Supplementary Table 12. For each PGLS regression, comparisons (Using Mann-Whitney U-tests) between residuals from VPL and non-VPL clades, either based on the full dataset (N = 119 species) or only outliers, and either using the absolute residual values or the signed residual values.

Dataset	PGLS regression	MinDF		MaxDF		MeanDF		RangeDF	
		VPL	non-VPL	VPL	non-VPL	VPL	non-VPL	VPL	non-VPL
Full dataset	Mean signed residuals	0.06	0.1	0.42	-0.1	0.4	-0.1	0.45	-0.11
	Mann-Whitney U-test (VPL/non-VPL)	W = 676, P = 0.92		W = 1136, P < 0.001		W = 1134, P < 0.001		W = 1137, P < 0.001	
	Mean absolute residuals	0.33	0.34	0.53	0.33	0.51	0.32	0.55	0.36
	Mann-Whitney U-test (VPL/non-VPL)	W = 676, P = 0.92		W = 975, P = 0.02		W = 975, P = 0.02		W = 965, P = 0.019	
Outliers only	Mean signed residuals	0.89	0.49	0.6	-0.31	0.56	-0.25	0.63	-0.49
	Mann-Whitney U-test (VPL/non-VPL)	W = 20, P = 0.85		W = 125, P = 0.004		W = 145, P = 0.007		W = 102, P = 0.003	
	Mean absolute residuals	0.89	0.99	0.81	0.8	0.75	0.76	0.83	0.95
	Mann-Whitney U-test (VPL/non-VPL)	W = 16, P = 0.85		W = 80, P = 0.7		W = 88, P = 1		W = 47, P = 0.56	

Finally, inspection of the position of outliers as either upward or downward from the regression for each of the parameters considered showed similar results to that carried out using VPL clades in the main text (as for the analyses with no odontocetes, the same categories were obtained, and in most cases VPL outliers were found as upward outliers from the allometric regression while non-VPL outliers were often found as downward outliers - see supplementary Tables 13 & 14). Again, the species found in these tables overlap greatly with those found using VPL clades, despite inherent differences existing due to the use of the different datasets.

Supplementary Table 13. List of VPL species found as outliers to allometry scaling for each of the 4 models using the dataset with VPL species only (and not clades). The direction of the deviation from acoustic allometry scaling is indicated either as U (denotes an upward outlier) or D (denotes a downward outlier). N = 7 species.

Binomial name	Common name	MaxDF	MeanDF	MinDF	RangeDF	Category
Delphinapterus leucas	Beluga whale	U	U	U	U	1
Halichoerus grypus	Grey seal	U	U		U	1
Megaptera novaeangliae	Humpback whale		U			1
Mirounga leonina	Southern elephant seal	D	D		D	3
Orcinus orca	Killer whale	U	U		U	1
Phoca vitulina	Harbor seal	U	U		U	1
Tursiops truncatus	Bottlenose dolphin	U	U	U	U	1

Supplementary Table 14. List of non-VPL species found as outliers to allometry scaling for each of the 4 models using the dataset with VPL species only (and not clades). The direction of the deviation from acoustic allometry scaling is indicated either as U (denotes an upward outlier) or D (denotes a downward outlier). N = 36 species.

Binomial name	Common name	MaxDF	MeanDF	MinDF	RangeDF	Category
Ailuropoda melanoleuca	Giant panda	D	D		D	2
Aotus trivirgatus	Three-striped night monkey	D	D		D	2
Arctocephalus philippii	Juan Fernández fur seal	D	D		D	2
Canis lupus	Wolf	D	D		D	2
Cerdocyon thous	Crab-eating fox	D	D	D		2
Cervus elaphus	Red deer	D	D		D	2
Dugong dugon	Dugong			U		4
Eulemur coronatus	Crowned lemur			D		2
Felis silvestris	Wild cat	D	D			2
Glaucomys volans	Southern flying squirrel	U	U	U	U	4
Lemur catta	Ring-tailed lemur	D	D			2
Lophocebus albigena	Grey-cheeked mangabey	D	D		D	2
Macaca silenus	Lion-tailed macaque	D	D		D	2
Marmota monax	Groundhog			U		4
Meles meles	European badger	D	D	D	D	2
Mus musculus	House mouse	U	U	U	U	4
Mustela eversmanii	Steppe polecat			U		4
Neophoca cinerea	Australian sea lion			U		4
Notomys alexis	Spinifex hopping mouse	U	U		U	4
Notomys cervinus	Fawn hopping mouse		U			4
Notomys fuscus	Dusky hopping mouse	U	U		U	4
Notomys mitchellii	Mitchell's hopping mouse	U	U			4
Odocoileus virginianus	White-tailed deer	D	D		D	2
Phascolarctos cinereus	Koala			D		2
Pongo pygmaeus	Bornean orangutan	D	D		D	2
Pseudomys australis	Plains rat	U	U			4
Rattus rattus	Black rat	U	U		U	4
Reithrodontomys fulvescens	Fulvous harvest mouse			U		4
Reithrodontomys mexicanus	Mexican harvest nouse			U		4
Saguinus fuscicollis	Brown-mantled tamarin			U		4
Speothos venaticus	Bush dog	D	D	D	D	2
Spermophilus beldingi	Belding's ground squirrel			U	D	5
Trichechus inunguis	Amazonian manatee	U	U			4
Trichechus manatus	West Indian manatee	U	U	U	U	4
Varecia variegata	Black-and-white ruffed lemur	D	D	U	D	2
Zalophus californianus	California sea lion			U		4

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