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Citation for final published version:

Evans, Meaghan N., Waller, Simon, Muller, Carsten T. , Goossens, Benoit , Smith, Jeremy A., Bakar, Mohd Soffian Abu and Kille, Peter 2022. The price of persistence: Assessing the drivers and health implications of metal levels in indicator carnivores inhabiting an agriculturally fragmented landscape. Environmental Research 207 , 112216. 10.1016/j.envres.2021.112216

Publishers page: http://dx.doi.org/10.1016/j.envres.2021.112216

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Title: The price of persistence: Assessing the drivers and health implications of metal levels in indicator carnivores inhabiting an agriculturally fragmented landscape

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Table S1 Summary of published hair metal concentrations reported from carnivorous species in the peer-reviewed literature. ND denotes metal not detected.

			Mean Hair Metal Concentrations (mg kg^{-1})												
Study	**Species**	**n**	**Al**	**As**	**Ba**	**Cd**	**Co**	**Cr**	**Cu**	**Fe**	**Hg**	**Mn**	**Ni**	**Pb**	**Zn**
Current	Malay civet *Viverra tangalunga*	69	114	0.114	16.8	0.0162	0.165	3.50	10.1	532	2.39	14.6	1.54	0.521	191
Arnhold et al., 2002	Opossum *Didelphis virginiana*	12	-	-	-	-	-	-	10.5	-	-	5.0	-	-	182
Arnhold et al., 2002	Gray fox *Urocyon cinereoargenteus*	3	-	-	-	-	-	-	-	-	-	-	-	-	247
Badea et al., 2016	Domestic cat *Felis catus*	6	31.3	-	-	0.15	-	-	0.93	24.6	-	-	0.15	0.05	11.2
Bechshoft et al., 2019	Polar bear *Ursus maritimus*	44	-	-	-	-	-	-	-	-	5.3–8.1	-	-	-	-
Becker et al., 2017	Vampire bat *Desmodus rotundus*	41	-	-	-	-	-	-	-	-	0.25	-	-	-	-
Behrooz & Poma, 2021	Iranian felid sp.	40	-	-	-	-	-	-	-	-	0.49#	-	-	-	-
Benson et al., 1974	Black bear *Ursus americanus*	4	-	-	-	-	-	-	-	-	0.18	-	-	-	-
Bocharova et al., 2013	Artic fox *Vulpes lagopus*	51	-	-	-	-	-	-	-	-	3.55 – 10.6	-	-	-	-
Brait et al.,	Ocelot	3	-	-	-	0.4	-	1.3	6.3	194.2	-	8.3	-	1.4	135.

2009	*Leopardus pardalis*														6
Brait et al., 2009	Crab-eating fox *Cerdocyon thous*	8	-	-	-	0.4	-	1.1	9.5	200.7	-	4.6	-	2.3	135.8
Brait et al., 2009	Maned wolf *Chrysocyon brachyurus*	22	-	-	-	0.2	-	1.2	6.9	120.3	-	5.0	-	1.0	113.1
Cardona-Marek et al., 2009	Polar bear *Ursus maritimus*	52	-	-	-	-	-	-	-	-	7.4	-	-	-	-
Cumbie, 1975	Bobcat *Lynx lynx*	5	-	-	-	-	-	-	-	-	13.1	-	-	-	-
Cumbie, 1975	Raccoon *Procyon lotor*	2–36	-	-	-	-	-	-	-	-	0.17 – 10.1	-	-	-	-
Curi et al., 2012	Crab-eating fox *Cerdocyon thous*	14	-	-	-	ND	-	2.95	10.2	783.4	-	18.8	-	2.45	130.6
Curi et al., 2012	Maned wolf *Chrysocyon brachyurus*	10	-	-	-	ND	-	2.89	7.56	220.8	-	12.6	-	2.34	127.4
Curi et al., 2012	Hoary fox *Lycalopex vetulus*	2	-	-	-	ND	-	3.55	9.55	1995	-	60.8	-	1.50	121.4
Dainowski et al., 2015	Red fox *Vulpes vulpes*	200	-	-	-	-	-	-	-	-	2.58	-	-	-	-
Dietz et al., 2006	Polar bear *Ursus maritimus*	399	-	-	-	-	-	-	-	-	0.39–7.45	-	-	-	-
Dietz et al.,	Polar bear	11	-	-	-	-	-	-	-	-	3.5–	-	-	-	-

2011	*Ursus maritimus*	7									9.4[#]				
Dobrzański et al., 2014	Red fox *Vulpes vulpes*	19; 18	-	-	-	-	-	-	-	-	0.019 – 0.021; 0.015 – 0.018	-	-	-	-
Dobrzański et al., 2014	Artic fox *Vulpes lagopus*	15; 13	-	-	-	-	-	-	-	-	0.007 – 0.015; 0.007 – 0.009	-	-	-	-
Dunlap et al., 2007	Domestic dog *Canis familiaris*	5–18	-	-	-	-	-	-	-	-	0.04 – 10.0	-	-	-	-
Evans et al., 1998	River otter *Lontra canadensis*	52	-	-	-	-	-	-	-	-	8.87–10.7	-	-	-	-
Evans et al., 2000	River otter *Lontra canadensis*	41	-	-	-	-	-	-	-	-	10.6	-	-	-	-
Evans et al., 2000	Mink *Mustela vison*	19	-	-	-	-	-	-	-	-	17.3	-	-	-	-
Filistowicz et al., 2011	Red fox *Vulpes vulpes*	8; 12	-	-	-	-	-	0.263; 0.207	3.32; 2.97	-	-	-	0.30; 0.48	0.633; 0.642	42.1; 95.3
Filistowicz et al., 2012	Red fox *Vulpes vulpes*	16	-	-	-	-	-	0.145 – 0.268	2.52 – 3.44	-	-	-	0.46 – 0.51	0.640 – 0.649	79.9 –111
Filistowicz et	Arctic fox	16	-	-	-	-	-	0.147	3.76	-	-	-	0.41	0.543	58.6

al., 2012	*Vulpes lagopus*							– 0.193	– 4.09				– 0.56	– 0.645	– 73.4
Flache et al., 2015	Bat spp.	8–14	-	-	-	0.02 – 0.81[#]	-	-	20.9 – 70.2[#]	-	-	23.5 – 65.5	-	0.39 – 34.2[#]	88.5 – 383[#]
Fonesca et al., 2005	Giant otter *Pteronura brasiliensis*	2	-	-	-	-	-	-	-	-	3.3	-	-	-	-
Fortin et al., 2001	River otter *Lontra canadensis*	12	-	-	-	-	-	-	-	-	20.7	-	-	-	-
Fortin et al., 2001	Mink *Mustela vison*	39	-	-	-	-	-	-	-	-	30.1	-	-	-	-
Gospodinova & Markov, 2020	Red fox *Vulpes vulpes*	10	-	-	-	0.20	0.24	-	13.1	-	-	-	0.87	4.65	150
Gray et al., 2008	Leopard seal *Hydrurga leptonyx*	27; 11	7.62; 8.87	1.63; 0.85	-	1.12; 0.31	-	3.81; 4.12	3.37; 3.66	73.1; 76.8	3.07; 4.64	1.36 ; 1.36	1.35; 0.76	0.06; 0.01	103; 128
Gray et al., 2008	Weddell seal *Leptonychotes weddellii*	12	9.13	2.51	4.8 2	2.81	0.04	5.87	15.1	73.9	5.60	1.15	3.52	1.29	137
Harley et al., 2016	Artic fox *Vulpes lagopus*	11	-	-	-	-	-	-	-	-	1.23	-	-	-	-
Hermoso et al., 2011	Iberian wolf *Canis lupus signatus*	15 8	-	-	-	0.037	-	-	10.0	-	-	-	-	1.23	205. 2
Hernández-Moreno et	Iberian wolf *Canis lupus*	33	-	-	-	0.026	-	-	-	-	-	-	-	0.196	150. 9

al., 2013	*signatus*														
Hou et al., 2010	Raccoon dog *Nyctereutes procyonoides*	-	-	-	-	-	-	-	17.7; 16.9	227.6; 179.6	-	-	-	-	201; 158
Julian & Cunningham, 2013	Black bear *Ursus americanus*	4	-	-	-	-	-	-	-	-	0.67	-	-	-	-
Klenavic et al., 2008	River otter *Lontra canadensis*	71; 80; 48	-	-	-	-	-	-	-	-	7.9; 16; 38	-	-	-	-
Klenavic et al., 2008	Mink *Mustela vison*	25; 54; 65	-	-	-	-	-	-	-	-	7.4; 24; 24	-	-	-	-
Kosik-Bogacka et al., 2020	Raccoon *Procyon lotor*	28	-	-	-	-	-	-	-	-	1.51	-	-	-	-
Kosik-Bogacka et al., 2020	European wildcat *Felis silvestris*	15	-	-	-	-	-	-	-	-	0.69	-	-	-	-
Kosla & Skibniewska, 2010a	Domestic cat *Felis domesticus*	20	-	-	1.45	-	-	-	-	-	-	-	-	-	-
Kosla & Skibniewska, 2010b	Domestic dog *Canis familiaris*	76	93.8	-	-	-	-	-	-	-	-	-	-	-	-
Kolsa et al., 2011	Domestic cat *Felis domesticus*	20	-	-	-	-	-	-	-	-	-	-	0.73	-	-
Lazarus et al., 2020	Brown bear *Ursus arctos*	34; 16	-	0.119; 0.048	-	0.0368;	0.092; 0.018	-	10.1; 9.8	86.9; 37.1	0.16; 0.07	13.0; 4.5	-	0.479; 0.225	143; 134

						0.0067									
Lord et al., 2002	Raccoon *Procyon lotor*	95	-	-	-	-	-	-	-	-	0.65 – 1.65	-	-	-	-
Malvandi et al., 2010	Golden jackal *Canis aureus*	21	-	-	-	-	-	-	-	-	0.18	-	-	-	-
May Júnior et al., 2018	Jaguar *Panthera onca*	4; 5	-	-	-	-	-	-	-	-	673; 29.7	-	-	-	-
Mora et al., 2000	Ocelot *Leopardus pardalis*	32	-	-	-	-	-	-	-	-	0.5 – 1.25	-	-	0.56 – 26.8	-
Newman et al., 2004	Florida panther *puma concolor coryi*	16	-	-	-	-	-	-	-	-	1.62	-	-	-	-
Noël et al., 2014	Grizzly bear *Ursus arctos*	20	-	-	-	-	-	-	-	-	2.28	-	-	-	-
Noël et al., 2016	Harbour seal *Phoca vitulina*	16 7	-	-	-	-	-	-	-	-	3.5 – 24.4	-	-	-	-
Park et al., 2005	Domestic dog *Canis familiaris*	20 4	-	-	-	0.09	-	0.48	-	-	0.21	-	-	0.82	-
Peterson et al., 2021	Raccoon *Procyon lotor*	37	-	-	-	-	-	-	-	-	28.5	-	-	-	-
Peterson et al., 2021	Striped skunk *Mephitis mephitis*	87	-	-	-	-	-	-	-	-	4.85	-	-	-	-
Porcella et al., 2004	Raccoon *Procyon lotor*	20 3	-	-	-	-	-	-	-	-	7.50	-	-	-	-
Smith & Rongstad,	Coyote *Canis latrans*	2	-	0.175	-	0.6	-	-	15.0	-	0.18	-	0.67	12	160

1981															
Solgi & Ghasempouri, 2015	Brown bear *Ursus arctos*	35	-	-	-	-	-	-	-	-	0.19	-	-	-	-
Souza et al., 2013	Raccoon *Procyon lotor*	30	21.5–84.5#	0.092–0.456#	1.7–2.0#	-	0.025–0.086#	0.23–0.49#	9.4–19.6#	37.7–96.5#	0.3–0.48#	7.0–14.9#	0.09–0.21#	-	219–233#
Treu et al., 2018	Artic fox *Vulpes lagopus*	35	-	-	-	-	-	-	-	-	3.22–10.15	-	-	-	-
Wenzel et al., 1993	Harbour seal *Phoca vitulina*	47	-	-	-	0.12	-	-	-	-	33.5	-	-	0.6	-

#Denotes median

Table S2 Instrumentation specifications and operating parameters for the analysis of metal content in Malay civet (*Viverra tangalunga*) hair by ICP-MS. *denotes internal standard (IS)

ICP-MS Parameters (Agilent 7900)	
RF power (W)	1550
Nebuliser	MicroMist (concentric)
Argon nebuliser flow (L min^{-1})	1
Gas He flow (mL min^{-1})	4.3
Lens	x-Lens
Lens voltage (V)	10 (auto tune)
Ext 1 (V)	0 (auto tune)
Ext 2 (V)	-220
Omega bias (V)	-90
Omega lens (V)	10
Deflect (V)	0.8
Energy discrimination (V)	5
Acquisition mode	Spectrum
Stabilisation time (s)	5
Integration time (ms)	100- Al, Mn, Fe, Co, Cu, Zn, Ba, Pb 300- Cr, Ni, Cd 500- As, Hg
Sweeps/replicate	100
Replicates	5
Isotopes measured	^{27}Al, ^{52}Cr, ^{55}Mn, ^{57}Fe, ^{59}Co, ^{60}Ni, ^{65}Cu, ^{66}Zn, ^{75}As, ^{103}Rh*, ^{137}Ba, ^{111}Cd, ^{159}Tb*, ^{175}Lu*, ^{202}Hg, ^{208}Pb

Table S3 Sample uptake and rinse times of ICP-MS nebuliser

	Time (s)	**Peristaltic pump speed (rps)**
Sample uptake	30	0.5
Stabilise	20	0.3
Probe rinse (sample)	5	0.5
Probe rinse (Std)	5	0.5
Rinse 1	15	0.3

Table S4 Description of target analyte specifications and during ICP-MS analysis of Malay civet (*Viverra tangalunga*) hair. Detection limits displayed are the minimum and the maximum batch detection limits from the four calibration curves utilised to quantify the metal content of acid-digested hair samples throughout the analysis.

Target Analyte	IS	Range of Detection Limits (mg/l)	Spiked Recovery Rates (%)
^{27}Al	^{103}Rh	3.656×10^{-4} – 1.060×10^{-3}	96.50
^{52}Cr	^{103}Rh	4.539×10^{-5} – 7.530×10^{-4}	97.20
^{55}Mn	^{103}Rh	2.568×10^{-5} – 6.417×10^{-5}	96.30
^{57}Fe	^{103}Rh	6.913×10^{-4} – 5.800×10^{-3}	93.40
^{59}Co	^{103}Rh	5.401×10^{-6} – 1.705×10^{-5}	95.01
^{60}Ni	^{103}Rh	4.431×10^{-5} – 3.812×10^{-4}	106.7
^{65}Cu	^{103}Rh	1.932×10^{-5} – 6.515×10^{-5}	102.2
^{66}Zn	^{103}Rh	1.276×10^{-4} – 4.644×10^{-4}	92.18
^{75}As	^{103}Rh	1.466×10^{-5} – 2.560×10^{-5}	106.0
^{137}Ba	^{159}Tb	1.776×10^{-5} – 4.219×10^{-5}	97.07
^{111}Cd	^{159}Tb	7.335×10^{-7} – 1.612×10^{-6}	99.16
^{208}Pb	^{175}Lu	3.355×10^{-6} – 1.068×10^{-5}	100.2
^{202}Hg	^{175}Lu	8.471×10^{-6} – 4.390×10^{-5}	98.70

Table S5 Summary hair metal concentrations from Malay civets (*Viverra tangalunga*; n= 69) sampled within the Lower Kinabatangan Floodplain from 2013–2017, values expressed as mg kg^{-1}.

Element	Mean ± SD	Median ± IQR	Min – Max
Al	171 ± 271	114 ± 107	29.8 – 2278.9
As	0.114 ± 0.227	0.0642 ± 0.0907	0.00363 – 1.68
Ba	16.8 ± 29.8	8.37 ± 13.8	0.816 – 192
Cd	0.0162 ± 0.0125	0.0124 ± 0.0112	0.00281 – 0.0614
Co	0.165 ± 0.150	0.128 ± 0.105	0.00859 – 1.03
Cr	3.50 ± 7.53	0.918 ± 2.60	0.0847 – 56.5
Cu	10.1 ± 4.69	9.79 ± 2.06	1.10 – 34.3
Fe	532 ± 684	361 ± 229	52.1 – 3766
Hg	2.39 ± 1.33	2.23 ± 1.76	0.0805 – 6.59
Mn	14.6 ± 13.4	11.1 ± 8.5	0.226 – 84.5
Ni	1.54 ± 1.64	1.06 ± 0.830	0.0949 – 8.85
Pb	0.521 ± 1.08	0.245 ± 0.254	0.0951 – 8.216
Zn	191 ± 72.5	188 ± 34.4	15.0 – 579

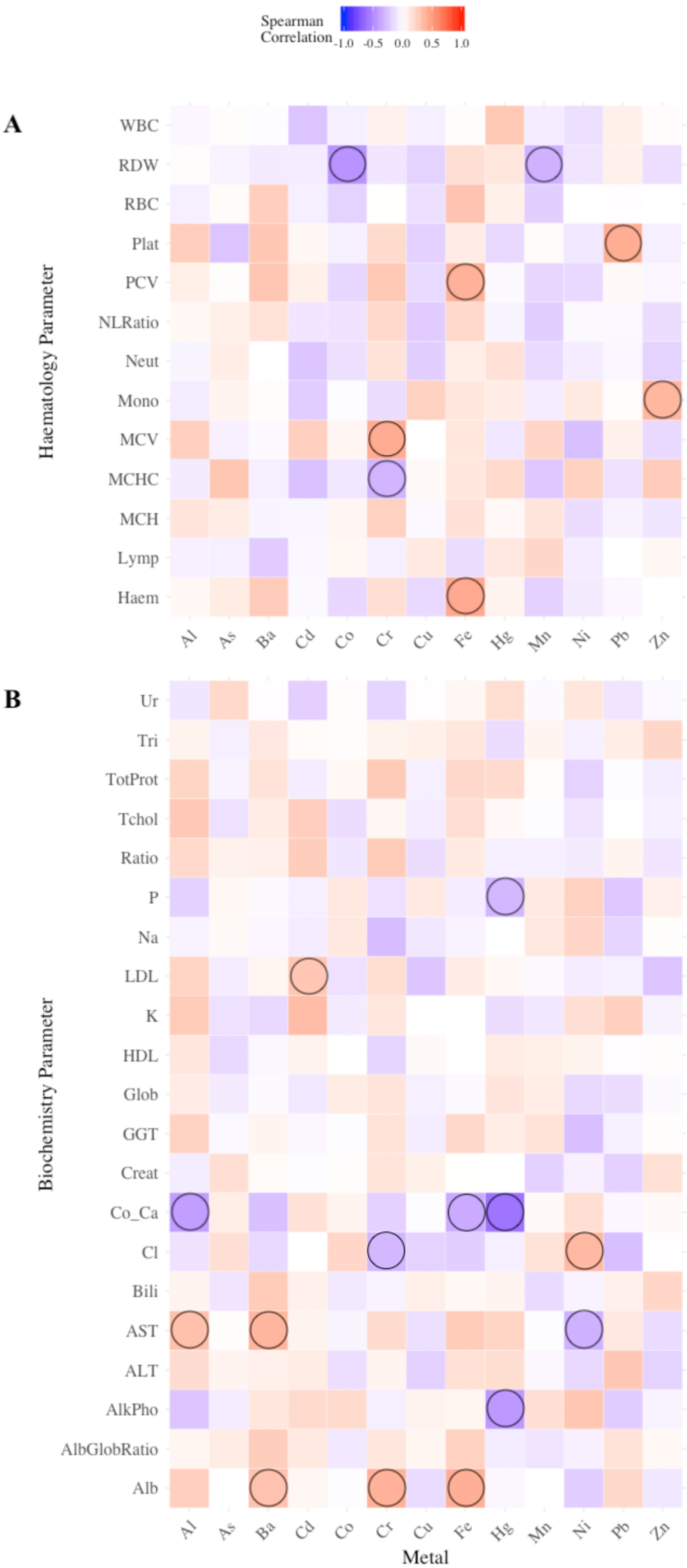
Table S6 Top candidate (ΔAICc<2) model structures included in model averaging, log-likelihood (Log*L*), Akaike's Information Criterion with the small sample bias adjustment (AICc), and Akaike weights (*wi*) for predicting relationships between standardised independent variables and metal concentrations of Malay civet (*Viverra tangalunga*) hair. Sex= male or female civet; Age= immature or mature civet; Plant= proximity to nearest accessible oil palm plantation; Trib= proximity to nearest accessible semi-permanent tributary; Lake= access or no to oxbow lake. #denotes a non-averaged final model (i.e. there were 0 additional models whereby ΔAICc<2.

Element	Candidate Model	df	Log*L*	AICc	ΔAICc	*wi*
As	Age + Lake + Trib + Weight	6	-109.34	232.06	0	0.42
	Age + Trib + Weight	5	-110.67	232.31	0.25	0.37
	Age + Plant + Trib + Weight	6	-110.08	233.53	1.47	0.20
Ba	Trib	3	-105.08	216.54	0	0.51
	Age + Trib	4	-104.57	217.77	1.22	0.27
	Lake + Trib	4	-104.78	218.20	1.66	0.22
Cd	Trib	3	-68.85	144.07	0	0.34
	Plant + Trib	4	-68.33	145.30	1.23	0.19
	Lake + Trib	4	-68.41	145.46	1.39	0.17
	Trib + Weight	4	-68.42	145.47	1.40	0.17
	Sex + Trib	4	-68.66	145.96	1.90	0.13
Cr#	Lake + Trib	4	-102.84	214.32	0	1
Fe	Lake + Sex + Trib	5	-71.96	154.89	0.00	0.15
	Age + Lake + Sex + Trib	6	-70.91	155.21	0.31	0.13
	Lake + Sex + Plant + Trib	6	-70.98	155.34	0.44	0.12
	Age + Lake + Sex + Trib + Weight	7	-70.01	155.89	0.99	0.09
	Lake + Trib	4	-73.71	156.06	1.17	0.09
	Age + Lake + Sex + Plant +Trib	7	-70.11	156.10	1.20	0.08
	Age + Lake + Trib + Weight	6	-71.46	156.29	1.40	0.08
	Sex + Trib	4	-73.88	156.39	1.49	0.07
	Age + Lake + Trib	5	-72.76	156.49	1.60	0.07
	Age + Lake + Sex + Plant + Trib + Weight	8	-69.18	156.81	1.91	0.06
	Lake + Plant + Trib	5	-72.94	156.85	1.96	0.06
Hg	Age + Trib	4	-94.00	196.63	0.00	0.28
	Age + Lake + Trib	5	-93.31	197.60	0.96	0.17
	Age + Sex + Trib	5	-93.37	197.71	1.08	0.16
	Age + Plant + Trib	5	-93.53	198.02	1.39	0.14
	Age + Trib + Weight	5	-93.64	198.24	1.61	0.13
	Age + Lake + Sex + Trib	6	-92.50	198.38	1.75	0.12
Ni	Weight	3	-83.34	173.05	0.00	0.23
	Lake + Weight	4	-82.41	173.46	0.41	0.19

	Age + Lake + Weight	5	-81.46	173.89	0.84	0.15
	Age + Weight	4	-82.68	173.99	0.94	0.14
	Sex + Weight	4	-82.93	174.50	1.45	0.11
	Plant + Weight	4	-83.03	174.69	1.64	0.10
	Trib + Weight	4	-83.19	175.02	1.98	0.08

Table S7 Hair metal concentrations of GPS-collared Malay civets (*Viverra tangalunga*) with home ranges contained exclusively within the forest and those using both forest and oil palm plantations. Values expressed as mg kg^{-1}; bold text denotes the directionality of significance, with bold indicating statistically greater concentrations.

	Forest Only (n = 8)		**Mix (n = 8)**	
Element	**Mean ± SE**	**Median ± IQR**	**Mean ± SE**	**Median ± IQR**
Al	64.4 ± 19.2	64.0 ± 26.2	427 ± 761	**110 ± 273**
As	0.0599 ± 0.0397	0.0630 ± 0.0495	0.0501 ± 0.0489	0.0319 ± 0.0644
Ba	13.2 ± 11.7	9.95 ± 10.6	43.3 ± 68.3	11.3 ± 26.9
Cd	0.00651 ± 0.00173	0.00558 ± 0.00259	0.0177 ± 0.0114	**0.0151 ± 0.011**
Co	0.182 ± 0.0904	0.166 ± 0.0882	0.190 ± 0.207	0.0826 ± 0.197
Cr	1.43 ± 1.60	0.847 ± 0.74	5.41 ± 5.20	4.25 ± 5.16
Cu	8.68 ± 2.28	9.58 ± 1.03	11.3 ± 7.90	9.62 ± 1.49
Fe	306 ± 138	341 ± 235	1370 ± 1620	316 ± 2690
Hg	**3.08 ± 1.16**	3.02 ± 1.16	1.36 ± 0.541	1.36 ± 0.550
Mn	19.5 ± 14.7	14.5 ± 8.68	18.6 ± 27.4	9.59 ± 6.33
Ni	0.878 ± 0.307	0.885 ± 0.563	0.985 ± 0.832	0.681 ± 0.957
Pb	0.137 ± 0.0403	0.135 ± 0.0384	1.69 ± 2.90	**0.303 ± 1.20**
Zn	177 ± 49.2	189 ± 37.1	214 ± 159	182 ± 50.1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Tri
TotProt
Tchol
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GGT
Creat
Co_Ca
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AlkPho
AlbGlobRatio
Alb
Al As Ba Cd Co Cr Cu Fe Hg Mn Ni Pb Zn
Metal

Fig. S1. Spearman correlation matrix plots of Malay civet (n=41–48) blood parameter and transformed hair metal concentrations. Tile colours denote directionality of correlation (Spearman's correlation coefficient, rho; +1 is a highly positive linear correlation, -1 is a highly negative relationship). Circled plots indicate statistically significant correlations ($p < 0.05$). WBC= white blood cell count; RDW= red blood cell distribution width; RBC= red blood cell count; Plat= platelet count; PCV= packed cell volume; NLRatio= ratio of neutrophils to leukocytes; Neut= neutrophil count; Mono= monocyte count; MCV= mean corpuscular volume; MCHC= mean corpuscular haemoglobin concentration; Lymp= lymphocyte count; Haem= haemoglobin concentration. Ur= urea; Tri= triglyceride; TotProt= total protein; Tchol= total cholesterol; Ratio= ratio of total cholesterol to high density lipoprotein; P= phosphate; Na= sodium; LDL= low-density lipoprotein; K= potassium; HDL= high-density lipoprotein; Glob= globulin; GGT= gamma-glutamyl transpeptidase; Creat= creatinine; Co_Ca= corrected calcium; Cl= chloride; Bili= bilirubin; AST= aspartate aminotransferase; ALT= alanine transaminase; AlkPho= alkaline phosphatase; AlbGlobRatio= ratio of albumin to globulin; Alb= albumin.

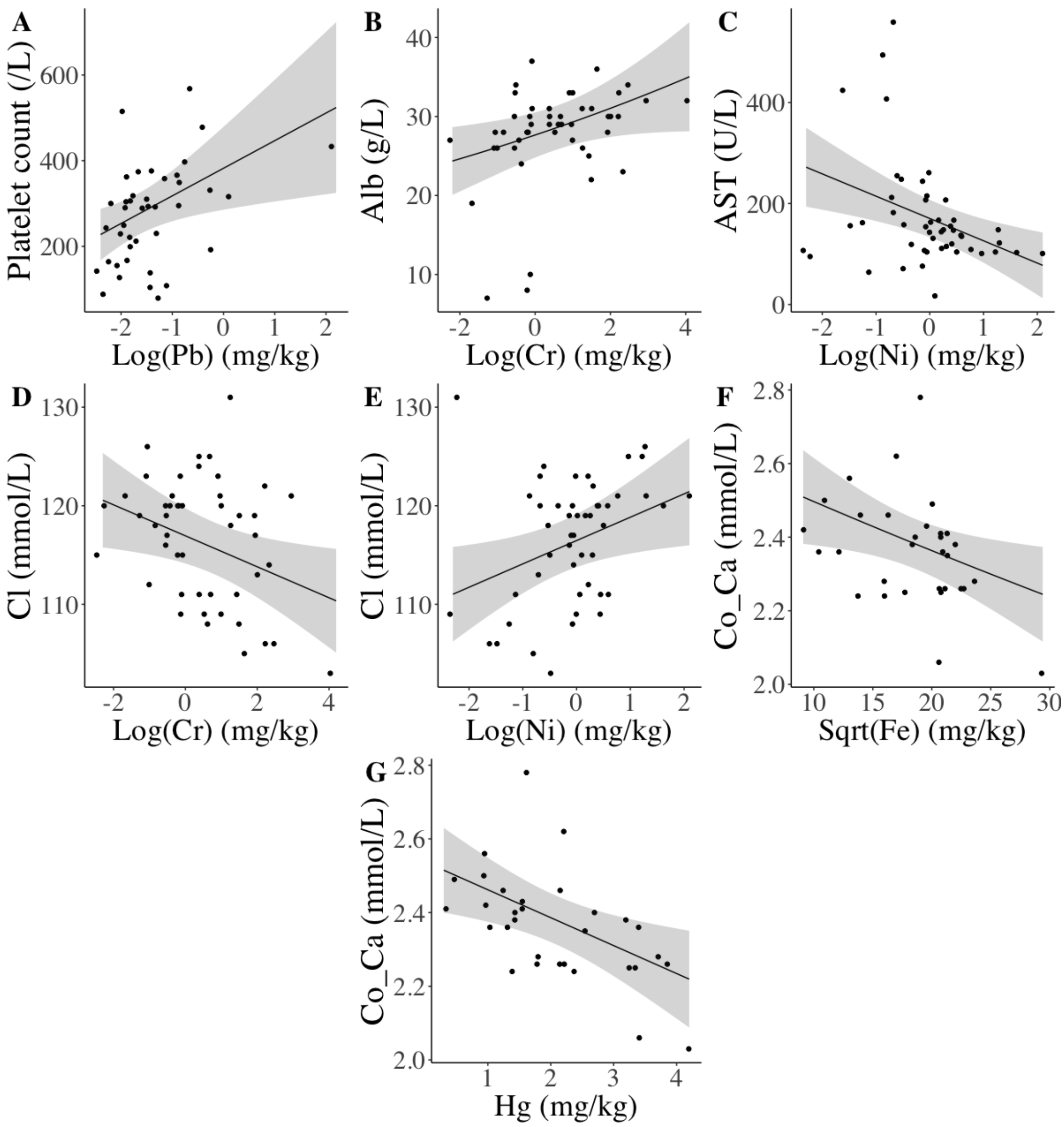

Fig. S2. Statistically significant relationships between transformed hair metal concentrations and blood metrics from Malay civets (*Viverra tangalunga*); shaded regions denote model confidence intervals (CI). Plots display the original collected data and the predicted relationship calculated accounting for covariates of civet sex and age; the model and CIs are derived from adult male civets. Alb= albumin; AST= aspartate aminotransferase; Cl= chloride; Co_Ca= corrected calcium.

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