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Supplementary material

Supplementary material for: Mateo-Tomás et al. **Species and individual replacements contribute more than nestedness to shape vertebrate scavenger metacommunities**

Appendix 1

Table A1. Main characteristics of the ecosystems where we monitored ungulate carcasses in mainland Spain. Further details on location and habitat characteristics of each study area can be obtained through Google Street View or Panoramio by clicking on their names. *According to Olson *et al.,* 2001. †See Fig. 1. §Number of individual carcasses monitored in each study area.

*Ecosystem	†Location	§N	**Carcass type (N)	Ungulate species (N)	Season (N)
Temperate	Cordillera Cantábrica (CC)	72	Entire corpses (21) Guts (42) Mixed remains (9)	Red deer *Cervus elaphus* (25) Wild boar *Sus scrofa* (24) Cantabrian chamois *Rupicapra rupicapra* (22) Roe deer *Capreolus capreolus* (1)	Autumn (32) Winter (18) Spring (7) Summer (15)
	Valle de Arán (AR)	15	Entire corpses (4) Mixed remains (11)	Red deer (8) Wild boar (5) Roe deer (2)	Autumn (15)
Mediterranean	Montes de Toledo (MT)	61	Entire corpses (5) Guts (53) Mixed remains (3)	Red deer (33) Wild boar (28)	Autumn (22) Winter (13) Spring (19) Summer (7)
	Sierra Morena (SM)	47	Entire corpses (3) Guts (33) Mixed remains (11)	Red deer (31) Wild boar (16)	Autumn (12) Winter (20) Spring (8) Summer (7)
	Cazorla (CZ)	32	Entire corpses (32)	Fallow deer *Dama dama* (16) Mouflon *Ovis orientalis* (6) Red deer (10)Red deer (8)	Winter (17) Summer (15)
	Sierra Espuña (ES)	11	Entire corpses (11)	Barbary sheep *Ammotragus lervia* (9) Wild boar (2)	Autumn (2) Winter (4) Spring (2) Summer (3)
	Doñana (DN)	13	Entire corpses (13)	Fallow deer (8) Red deer (5)	Autumn (13)

**The types of hunting remains were: i) entire corpses, including those just lacking the head and/or <10% of the animal body (e.g. one leg); ii) guts, normally up to 3 animals together; and iii) mixed remains, i.e. meat and guts resulting from processing ≤ 3 animals in the field.

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Table A2. Total species abundance (i.e. all carcasses together) of vertebrate scavengers recorded feeding at ungulate carcasses in seven ecosystems in mainland Spain. % Percentage from the total number of individuals of all species recorded. N number of carcasses monitored per ecosystem. Species in bold on shaded rows were recorded scavenging in all the monitored ecosystems. Species in bold on white background were recorded scavenging only in one ecosystem. **Milvus* spp. and *Neophron percnopterus* are migratory species.

	Scavenger groups		Study area								
			Cordillera Cantábrica	Valle de Arán	Montes de Toledo	Sierra Morena	Cazorla	Sierra Espuña	Doñana	Total	%
Gyps fulvus	Bird	Obligate scavenger	620	133	329	159	481	12	27	1761	56.79
Sus scrofa	Mammal	Generalist	36	10	51	50	41	8	51	247	7.96
Vulpes vulpes	Mammal	Generalist	71	5	65	43	34	14	13	245	7.90
Corvus corax	Bird	Generalist	104	23	24	2	23	34	12	222	7.16
Corvus corone	Bird	Generalist	86	8			31			125	4.03
Pica pica	Bird	Generalist	25		24	13	5	7	40	114	3.68
Aegypius monachus	Bird	Obligate scavenger	1		93	13	1		1	109	3.51
Cyanopica cyanus	Bird	Generalist			13	60			1	74	2.39
Aquila chrysaetos	Bird	Apex predator	9	4	1	3	5	11		33	1.06
Martes spp	Mammal	Generalist	17	1	3	8		2		33	1.00
Canis familiaris	Mammal	Generalist	13	2	1	4	5		4	29	0.93
Buteo buteo	Bird	Generalist	21	3	3					27	0.87
Garrulus glandarius	Bird	Generalist		1	8	7	1			17	0.55
Canis lupus	Mammal	Apex predator	12							12	0.39
*Milvus milvus**	Bird	Generalist	1	3	1				4	9	0.29
Aquila adalberti	Bird	Apex predator			5	1			2	8	0.26
Genetta genetta	Mammal	Generalist	1		2	5				8	0.26
Milvus migrans	Bird	Generalist			6		1			7	0.23
Herpestes ichneumon	Mammal	Generalist				3			2	5	0.16
Circus aeruginosus	Bird	Predator			2				1	3	0.09
Accipiter gentilis	Bird	Predator			2					2	0.06
Apodemus spp	Mammal	Generalist	1			1				2	0.06
Gypaetus barbatus	Bird	Obligate scavenger		1			1			2	0.06
*Neophron percnopterus**	Bird	Obligate scavenger	1		1					2	0.06
Ursus arctos	Mammal	Apex predator	2							2	0.06
Aquila fasciata	Bird	Apex predator				1				1	0.03
Bubo bubo	Bird	Apex predator				1				1	0.03
Bubulcus ibis	Bird	Other							1	1	0.03
Felis silvestriscatus	Mammal	Generalist				1				1	0.03
Meles meles	Mammal	Generalist		1						1	0.03
TOTAL			1021	195	634	375	629	88	159	3101	100
N			72	15	61	47	32	11	13	251	

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Table A3. Environmental variables potentially affecting vertebrate scavenging at each ecosystem.

Variable	Description	Hypothesis
Carcass characteristics		
Weight	Weight (kg) of the monitored carcass	Larger carcasses can provide food for more scavenging species but can also facilitate the gathering of obligate scavengers
Entire corpse	Number of carcasses consisting of entire corpses monitored at each ecosystem (see Table S1)	Entire corpses can provide both more quantity and variety of food but can be also more difficult for some species to access than remains and guts
Remains	Number of carcasses consisting of mixed remains monitored at each ecosystem (see Table S1)	
Guts	Number of carcasses consisting of guts monitored at each ecosystem (see Table S1)	
Carcass Type	Number of different carcass types (i.e. from 1 to 3) monitored at each ecosystem (see Table S1)	
Carcass WildBoar **Carcass RedDeer** **Carcass RoeDeer** **Carcass Chamois** **Carcass FallowDeer** **Carcass Mouflon** **Carcass BarbarySheep**	Proportion of carcasses of a concrete ungulate species monitored per ecosystem.	Different ungulate species provide carcasses of different sizes that can gather different number of species and/or individuals
Carcass Species Diversity	Shannon entropy ($H = -\sum^{S}_{i=1} pi \ln pi$) of carcasses per species and ecosystem; S is the total number of ungulate species providing carcasses (N = 7), and p_i the frequency of the i^{th} species per ecosystem	
Season diversity	Coefficient of variation, i.e. ratio of the standard deviation to the mean for the frequency of season when carcasses were placed at each ecosystem	Seasonal changes in both scavenging species presence (e.g. for migratory birds) and phenology would influence carcass consumption
Autumn **Winter** **Spring** **Summer**	Proportion of carcass monitored per ecosystem in each considered season	
Habitat characteristics (at 10, 50 and 100-m radius around each carcass)		
Forest **Shrubland** **Openland**	Mean percentage of surface covered by each vegetation type around all carcasses in each ecosystem at the considered scale	Vegetation structure determine the access of scavenging species, mainly birds and specially vultures, to carcasses
Habitat diversity	Coefficient of variation, i.e. ratio of the standard deviation to the mean for the mean percentage of habitat coverage around carcasses per ecosystem at each considered scale	
Elevation	Mean elevation (m.a.s.l.) at carcass locations per ecosystem	Topography can influence the scavenging species accessing the carcass
Slope	Mean slope (%) at carcass locations per ecosystem	
Latitude **Longitude**	Mean coordinates of carcass locations per ecosystem	Location can determine the scavenging species present at a site
Climate characteristics		
Mean annual temperature	Mean temperature (in ºC) of the monthly mean temperatures at the center of each study area	Climatic conditions influence species distributions while temperature, humidity and solar radiation influence also carcass decomposition and therefore their consumption by vertebrates
Mean annual precipitation	Mean precipitation (mm) of the monthly mean precipitations at the center of each study area	
Mean annual solar radiation	Mean solar radiation of the monthly mean solar radiations at the center of each study area	
Vertebrate richness **Bird and mammal richness**	Number of vertebrate species (all or only birds and mammals) per ecosystem according to the Spanish Biodiversity Inventory (MAGRAMA 2013). Available at http://www.mapama.gob.es.	Competition and facilitation among species influences carcass consumption by scavengers

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Table A4. Beta diversity partitioning of pairwise incidence-based (species turnover + nestedness, above), and abundance-based (balanced variation + abundance gradient, below) dissimilarities among ecosystems posed on equal-sample sizes (N = 11; top line within each row) and considering complete samples (bottom line within each row, *in cursive*). Extreme dissimilarity values (minimum and maximum) are in bold.

Species richness	Valle de Arán	Montes de Toledo	Sierra Morena	Cazorla	Doñana	Sierra Espuña
Cordillera Cantábrica	**0.24 + 0.05** *0.23 + 0.10*	0.42 + 0.06 ***0.24 + 0.04***	0.45 + 0.05 *0.35 + 0.02*	0.21 + 0.12 *0.25 + 0.13*	0.47 + 0.04 *0.38 + 0.08*	0.10 + 0.20 *0.00 + 0.42*
Valle de Arán		0.43 + 0.06 *0.23 + 0.14*	0.47 + 0.04 *0.38 + 0.10*	0.16 + 0.14 *0.25 + 0.03*	**0.49 + 0.02** ***0.54 + 0.00***	0.18 + 0.20 *0.14 + 0.26*
Montes de Toledo			0.31 + 0.07 *0.28 + 0.02*	0.36 + 0.10 *0.17 + 0.19*	0.30 + 0.07 *0.15 + 0.16*	0.25 + 0.15 *0.00 + 0.46*
Sierra Morena				0.40 + 0.09 *0.25 + 0.15*	0.39 + 0.05 *0.23 + 0.12*	0.25 + 0.16 *0.00 + 0.44*
Cazorla					0.35 + 0.12 *0.42 + 0.02*	0.24 + 0.07 *0.14 + 0.23*
Doñana						0.29 + 0.19 *0.29 + 0.21*

Species abundance	Valle de Arán	Montes de Toledo	Sierra Morena	Cazorla	Doñana	Sierra Espuña
Cordillera Cantábrica	**0.17 + 0.11** *0.03 + 0.66*	0.33 + 0.14 *0.23 + 0.18*	0.38 + 0.16 *0.28 + 0.33*	0.18 + 0.17 ***0.01 + 0.23***	0.56 + 0.06 *0.25 + 0.55*	0.43 + 0.14 ***0.02 + 0.82***
Valle de Arán		0.35 + 0.11 *0.08 + 0.49*	0.44 + 0.13 *0.19 + 0.25*	0.13 + 0.17 *0.04 + 0.51*	0.64 + 0.02 *0.63 + 0.04*	0.51 + 0.12 *0.40 + 0.23*
Montes de Toledo			0.30 + 0.14 *0.18 + 0.21*	0.28 + 0.23 *0.30 + 0.00*	0.48 + 0.10 *0.16 + 0.50*	0.53 + 0.08 *0.23 + 0.58*
Sierra Morena				0.34 + 0.27 *0.33 + 0.17*	0.43 + 0.14 *0.28 + 0.29*	0.56 + 0.06 *0.45 + 0.34*
Cazorla					**0.57 + 0.10** *0.35 + 0.39*	0.52 + 0.20 *0.24 + 0.57*
Doñana						0.45 + 0.11 *0.41 + 0.17*

References

MAGRAMA, Ministerio de Agricultura, Alimentación y Medio Ambiente (2013). Inventario Español de Especies Terrestres. Available at http://www.mapama.gob.es/es/biodiversidad/temas/inventarios-nacionales/inventario-especies-terrestres/inventario-nacional-de-biodiversidad/bdn-ieet-default.aspx. Last accessed 20 December 2017.

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