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Review article

Forensic experiments on animal scavenging: A systematic literature review on what we have and what we need

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ABSTRACT

Vertebrate scavengers frequently affect forensic casework by feeding on human remains or by scattering body parts and bones. Therefore, animal activity can influence complete recovery of bodies, trauma analysis, and the estimation of the postmortem interval (PMI), potentially hampering identification of the deceased and elucidation of the perimortem circumstances. Experimental research is well suited to investigate scavengers and their impact on carcasses over time, generating knowledge on the forensic relevance of certain scavenger species or communities. However, there are currently no systematised standards to conduct these investigations with a forensic focus, impeding comparison and synthesis of the studies. In our work, we performed a systematic literature review and found 79 publications featuring terrestrial experiments on vertebrate scavenging and/or scattering within a forensic context. We extracted 21 variables describing the study environment, experimental design and the specimens. The results show that there is considerable inconsistency in the study designs and that some of the variables are insufficiently reported. We point out research questions and areas that require attention in future studies, stressing the importance of infrequently mentioned or applied variables. Furthermore, we recommend guidelines to include and report a list of variables in forensic scavenging and scattering experiments. These guidelines will help standardising future research in the field, facilitating inter-study consolidation of results and conclusions, and consequently, inform forensic casework.

1. Introduction

Animal scavenging and vertebrate-inflicted dispersal of human remains are frequent occurrences in forensic practice [1,2]. For example, scavenging rates of 4.8–60% were stated in forensic anthropological casework surveys from South Africa, the USA, the UK, and Switzerland [2–6]. The challenges that go along with animal activity at a scene containing human remains are manifold. For instance, vertebrates can remove and scatter bones and body parts, complicating the search and potentially preventing a full recovery [7]. Also, scavenging degrades the remains, including bones, so that recognition, recovery, and analysis of them are compromised [8]. Scattering and degradation are both factors that contribute to the difficulties of identifying unknown bodies [9]. In addition, scavenging can alter the rate and pattern of decomposition and subsequently affect the estimation of the postmortem interval (PMI) [10,11]. However, vertebrate and invertebrate activity and its potential to alter forensic contexts still seems to be underrepresented in forensic literature and further research is needed [7,12,13].

Publications that cover the impact of vertebrates on an outdoor forensic scene or human remains include regional overviews [14,15], case studies [16,17], case reviews [2,6], and experiments [18,19]. However, case studies are relatively rare, and scavengers are even less frequently directly observed therein. In outdoor scenes, the scavengers were sometimes identified by their presence [20–22], by the match of

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Table 1
Keywords selected for systematic literature review. The specific combinations as search strings for each of the three databases are included; for journal, proceedings, and grey literature searching using Google Scholar, various combinations were used. "Animal" narrowed down the search too much when applying strings, but was useful in manual searching, hence, kept as a keyword.

Keywords		Search Strings	
		Database	String
Scaveng*	Taph*	Web of Science™	ALL= ("forensic" AND ("scaveng*" OR "scatter*" OR "dispersal") AND "taph* ")
Forensic	Dispersal	Scopus	TITLE-ABS-KEY ("forensic" AND ("scaveng*" OR "scatter*" OR "dispersal") AND "taph* ") AND PUBYEAR < 2024
Scatter*	Animal	PubMed	"forensic" AND ("scaveng*" OR "scatter*" OR "dispersal") AND "taph* "

lesions with animal teeth [23], or by circumstantial evidence such as scats [24]. Species identification through faunal evidence (e.g. feathers) leaves some doubt whether the attributed animal actually caused the observed damage and, in the case of multiple scavenger taxa, the analysis becomes even more challenging. DNA typing of the lesions [25], the discovery of human tissue, e.g. bone or hair, in scats, in dens and burrows of scavengers [17] can further help to identify the species. However, such analyses are costly, limiting the extent of their use particularly in resource-constrained forensic investigative environments.

Field studies bear the advantage that researchers can monitor carcasses over time and identify scavengers through direct observations or recording devices such as cameras, whereby motion-activated infrared-capable trail cameras being a popular choice. Subsequently, the species can be matched with the lesions observed, the scavenging and scattering patterns, and provide useful references for the real cases. However, such experiments are relatively rare, rather diverse and lack standardisation, with rigorous protocols mostly missing. Guidelines and standards do exist for general carrion experiments, meant to identify common flaws, and enhance statistical power and applicability to real scenarios [26]. Nevertheless, previously published systematic reviews of forensic decomposition experiments focus on decomposition, arthropod activity, or general experimental design and analysis in forensic taphonomy [26–29], rather than explicitly looking at scavenging and scattering. Moreover, the aforementioned standards [26] speak mostly to the effects of study design on carrion entomofauna, with little attention paid to vertebrate scavengers.

To enable a more robust and scientifically sound synthesis for forensic applications that overarches different geographic regions and environments, a higher level of consistency in taphonomic experimental design would be beneficial. To achieve that, we performed a literature review on experiments that cover scavenging and scattering in outdoor forensic contexts. We focussed on the technical details of the field studies, further detecting research gaps, flagging where evaluation is needed, and indicating the potential of certain methodological approaches.

2. Material and methods

We systematically reviewed the existing online forensic literature using the ‘preferred reporting items for systematic literature reviews and meta-analyses’ (PRISMA) guidelines.

2.1. Literature search strategy

Our search strategy targeted three large scientific databases: Scopus, Web of Science™, and PubMed. Additionally, we searched the following forensically-oriented journals: *Forensic Science International*, *Journal of Forensic Sciences*, and *Science & Justice*, along with the Proceedings of the Annual Meetings of the American Academy of Forensic Sciences (AAFS).

Table 2
Inclusion and exclusion criteria for the systematic literature review and appraisal of identified studies.

Inclusion	Exclusion	
	Preliminary	At screening
Experimental, carcass-based taphonomy	Not related to scavenging	Focus on scavenger artefacts (e.g. toothmark analysis, delineating scavenger artefacts from other forms of hard tissue trauma)
Terrestrial-based (sub-aerial and/or shallowly buried)	Entomology-focused (i.e., invertebrate scavengers)	Case report-based
Assessing vertebrate scavenging	No forensic focus (e.g. palaeotaphonomic, palaeopathological)	Scavenging not the focus
Assessing vertebrate scavenger-mediated scattering	Review articles	Lacking an experimental taphonomic approach
		Aquatic
		Not published in English
		Textbook (whole)

We used a suite of keywords (Table 1) to construct search terms for these databases, journals, and proceedings. We undertook grey literature and citation searching using Google Scholar, again using combinations of the keywords, or specific information derived from citations. We included records published before 1 April 2023 and reviewed these against inclusion and exclusion criteria (Table 2), the latter split into two levels: exclusion criteria pre-screening, and exclusion criteria employed during the screening process. Importantly, for this systematic review we focused on carcass experiments looking specifically at vertebrate scavenging and/or scattering (e.g. no insect scavenging) in terrestrial environments (e.g. no water-deposited remains), exposed or shallowly buried. We excluded research with an emphasis on tooth mark analysis only, due to the different experimental designs (e.g. feeding bones to captive animals).

In the following, we distinguish between publication (e.g. articles), experiment (one coherent study) and, where applicable, trials (part of an experiment, e.g. two trials comparing summer and winter). We extracted the following variables from the publications:

Type: Type and year of publication. We expressed the publication type as article, thesis, or abstract of posters and presentations.

Topic: Focus of publication being scavenging, scattering, or the combination.

Location: Country, environment with habitat and detailed description, Köppen-Geiger climate classification [30], previous land use.

Temporal data: Season, and study duration rounded to months, e.g. 32 days were one month, and studies of less than one counted as zero months (though the precise number of days were noted in parentheses). Trials of different lengths within one experiment were treated separately in the study length section. We separated seasons as follows: spring (Mar-May), summer (Jun-Aug), autumn (Sep-Nov), and winter (Dec-Feb) for the northern hemisphere, and spring (Sep-Nov), summer (Dec-Feb), autumn (Mar-May) and winter (Jun-Aug) for the southern hemisphere. A season was considered as studied even if only one month fell into that season.

Specimen: Carcass type, carcass part, specimen weight, sample size, biomass availability. We separated human and animal carcass type, and full bodies and body parts including bones. We translated weight and distances into metric units (kg and km/m), where necessary. If a weight range was given for several carcasses, we used the average. We defined biomass availability by the total weight of all specimens deployed per trial, regardless of the distance between them.

Treatment: Cause of death, handling between death and deposition, presence and absence of clothing.

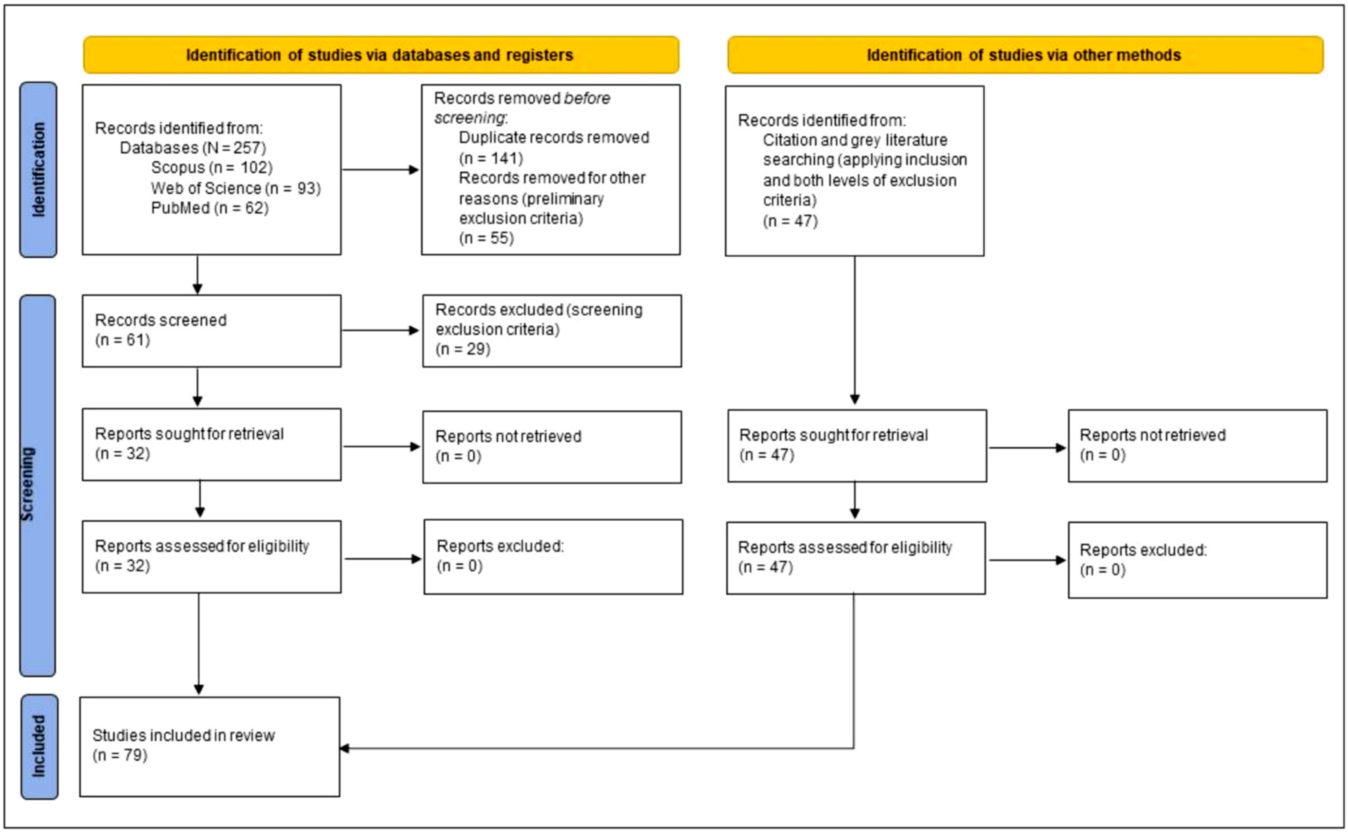

Fig. 1. The PRISMA 2020 flow diagram illustrating our systematic review process, based on the publication by Page et al. (2021) [31].

Setup: Cage, enclosure, tethering, inter-carcass distance, scavenger habituation. Besides absence or presence, we also noted the material used for any restrictive measures such as fences. Scavenger habituation was defined as vertebrate animals increasingly recognising the site as a food source due to successively deposited carcasses [26]. We declared habituation as present ("yes") in captive scavenger environments, feeding places, decomposition research facilities, and where previous experiments were conducted less than one year ago. Habituation was "possible" where previous experiments were carried out one year or longer ago. We determined habituation as absent ("no") where we assumed, or it was stated, that it was an uninfluenced area in nature.

Documentation: Camera traps (photographic and/or videographic), site visit frequency by researchers, use of decomposition parameters, species identification. Quantitative parameters include accumulated degree days (ADD), Kelvin scale ADD (KADD), accumulated degree minutes (ADM), carcass weight loss in kg/lbs over time, and pseudo-quantitative variables comprising total body score (TBS) and total desiccation score (TBDS).

3. Results

We present the PRISMA flow diagram from the systematic review in Fig. 1. In total, 79 publications met our inclusion criteria of experimental research on vertebrate scavenging and/or animal-induced dispersal of body parts and bones. In the Tables 3 and 4, we present the reviewed literature with the extracted information.

3.1. Type

Type. Of all 79 reviewed publications, 57.0% were journal articles (45/79), followed by Master's theses (17.7%, n = 14) and conference presentation or poster abstracts (25.3%, n = 20). Of the 45 journal articles, 91.1% (41/45) are published in forensic journals.

Publication year. The experiments were published between 1989 and 2022, 96.2% of them since 2005 (76/79), 3.8% before 2000 (3/79).

3.2. Topic

65.8% of the publications had their focus on vertebrate scavenging only (52/79), followed by those studying scavenging and scattering (26.6%, n = 21) and scattering only (7.6%, n = 6). For four of these experiments, we found one scavenging and one scattering publication each: King et al. [57,58], Pharr et al. [76,78], Spies et al. [18,93] and Young et al. [19,103]. Because the emphases of the pairs differ, we treat them independently.

3.3. Location

Country. 72.2% of studies were conducted in the USA (n = 57), the others in South Africa (7.6%, n = 6), Australia (5.1%, n = 4), Canada (6.3%, n = 5), the UK (3.6%, n = 3), Brazil (2.5%, n = 2) and Spain (1.3%, n = 1) (Fig. 2). One additional publication describes two similar experiments, one in Canada and Australia, each (1.3%, n = 1) [73]. Of the 57 published experiments from the USA, 50.9% (29/57) were conducted in taphonomy research facilities: the Forensic Anthropology Research Facility (FARF) in Texas (n = 11), the Outdoor Research Facility (ORF) in Massachusetts with only animal carcasses (n = 3), the Forensic Investigation Research Station (FIRS) in Colorado (n = 4), the Anthropological Research Facility (ARF) in Tennessee (n = 5), the Forensic Osteology Research Station (FOREST) in North Carolina (n = 2), the Complex for Forensic Anthropology Research (CFAR) in Southern Illinois (n = 2), and the Southeast Texas Applied Forensic Science (STAFS) facility in Southern Texas (n = 2).

3.3.1. Climate classification

Using the Köppen-Geiger classification [30] as the descriptive

Table 3

Information retrieved from the 79 reviewed publications in alphabetical order including literature type/topic, environment, temporal data and specimen. Topic is either scavenging (scav), scattering (scat) or the combination of the two (both). Seasons are summer (Su), autumn (A), winter (W) and spring (Sp). Values separated by a semicolon relate to single trials within an experiment.

		Type and topic		Environment				Temporal data		Specimen				
Author	Year	Type	Topic	Country	Köppen-Geiger	Environment	Land use	Duration	Season	Carcass type	Carcass part	Weight	Sample size	Biomass
Adair and Kolz[32]	1998	Article	Scat	USA, CO	Bsk	Grassland	Research	3; 2; 16	SuA	Pig	Full body	13–27 kg	3	22.5 kg; 27 kg; 13 kg
Baigent et al.[33]	2020	Abstract	Scav	USA, CO	BSk	Unclear	Body farm	1; 1	Su	Pig	Full body	Unclear	4	Unclear
Baigent et al.[34]	2019	Abstract	Scav	USA, CO	Dfb-Dfc, BSk	Unclear	Unclear	2	Su	Pig	Full body	Unclear	4	Unclear
Baigent et al.[35]	2014	Abstract	Scav	USA, CO	BSk	Grassland	Body farm	8	SuA	Pig	Full body	Unclear	4	Unclear
Bailey[36]	2020	Abstract	Scav	USA, NC	Cfa	Unclear	Body farm	0 (10 days)	Su	Human	Full body	Unclear	1	81 kg
Bankaitis[37]	2012	Thesis	Scav	USA, MT	Dfb	Woodland	Captive	0 (14 days)	All	Pig	Full body	118 kg	1	225 kg
Beck et al.[9]	2015	Article	Both	USA, AZ	BSk	Desert	Wild land	1	Su	Pig	Full body	27 kg	3	68 kg exposed (plus 54 kg buried); 146 kg
Bright[38]	2011	Thesis	Scav	USA, CA	Csa-Csb	Woodland, savanna	Reserve	Unclear	AW	Pig	Full body	45.4 kg	5	83 kg/45 kg; 65 kg/55 kg; 26.5 kg/50 kg; 45 kg; 20 kg
Brinkley[39]	2012	Thesis	Scav	USA, TX	Cfa	Woodland	Private	5; 3	SpSuA	Pig	Full body	54.4–81.7 kg	4	100 kg
Brown et al.[40]	2006	Article	Scav	Australia	BSh	Open woodland	Grazing	Unclear	All	Cangaroo, emu, pig	Full body	20–45 kg	15	Unclear
Cameron and Oxenham[12]	2012	Article	Scat	Australia	Cfb	Grassland	Grazing	2	Sp	Pig	Full body	20–30 kg	4	34 kg; 115.8 kg; 231.4 kg; 34 kg; 223.2 kg
Cleary et al.[41]	2012	Abstract	Scav	USA, IL	Cfa	Unclear	Body farm	9; 9	All	Pig	Full body	1–64 kg	12	60 kg; 60 kg; 60 kg
Dabbs and Martin [42]	2013	Article	Scav	USA, IL	Cfa	Grassland	Body farm	Unclear	All	Pig	Full body	34–192.8 kg	8	90 kg
Demo et al.[43]	2013	Article	Scav	Brazil	Aw	Savanna	Unclear	Unclear	All	Pig	Full body	60 kg	3	Unclear
Dibner et al.[44]	2019	Article	Scav	USA, HI	BSh	Grassland	Unclear	1	WSp	Pig	Full body	30 kg	3	Unclear
Domínguez-Solera and Domínguez-Rodrigo[45]	2011	Article	Both	Spain	Csa	Grassland	Feeding spot	0 (1 h)	Unclear	Deer	Full body	Unclear	1	181.6 kg
Dupuis[46]	2005	Abstract	Scav	USA, CA	Csb	Unclear	Unclear	Unclear	SpSuA	Pig	Full body	Unclear	8	Unclear
Forbes et al.[47]	2022	Article	Scav	Canada	Dfb	Woodland, grassland	Wild land	0 (10 days); 4; 2	SpSuA	Pig	Full body	70–90 kg	18	140–180 kg for each location in each season
Garcia et al.[48]	2020	Article	Scav	USA, CO	BSk	Desert	Body farm	1	Unclear	Human	Full body	Unclear	2	Unclear
Garcia-Putnam[49]	2014	Thesis	Both	USA, NC	Csa	Grassland	Research	5	SuA	Pig	Full body	45.4 kg	4	58 kg; 197 kg
Hannigan[50]	2015	Thesis	Both	USA, ME	Dfb	Woodland	Decomposition research	Unclear	Unclear	Pig	Full body	Unclear	1	120 kg; 180 kg; 120 kg; 180 kg
Jeong et al.[51]	2016	Article	Scav	USA, TN	Cfa	Woodland	Body farm	Unclear	All	Human	Full body	Unclear	178	300 kg; 300 kg

(*continued on next page*)

Table 3 (*continued*)

		Type and topic		Environment				Temporal data		Specimen				
Author	Year	Type	Topic	Country	Köppen-Geiger	Environment	Land use	Duration	Season	Carcass type	Carcass part	Weight	Sample size	Biomass
Johnston and Martin [52]	2013	Abstract	Scav	USA, NC	Cfa	Unclear	Body farm	Unclear	Unclear	Human	Full body	Unclear	6	82.5 kg; 187.5 kg; 70 kg; 82.5 kg
Jones[53]	2011	Thesis	Scav	USA, LA	Csa	Woodland	Reserve	0 (25 days); 0 (18 days)	SpSu	Pig	Full body	52.6–64.4 kg	4	Unclear
Keyes et al.[54]	2020	Article	Both	South Africa	Cwa	Agricultural	Agriculture	Unclear	SpSuW	Pig	Full body	40–80 kg	10	480 kg; 480 kg
Keyes et al.[55]	2022	Article	Both	South Africa	Cwb	Urban	Research	10; 8	All	Pig	Full body	30–80 kg	12	185 kg; 266 kg
Keyes et al.[56]	2021	Article	Both	South Africa	Cwa	Savanna	Research	0 (1 week); 0 (1 week)	SuW	Pig	Full body	40–80 kg	10	Unclear
King[57]	2014	Thesis	Both	USA, OK	Csa	Woodland, grassland	Reserve	0 (10 days); 2; 3; 3	All	Pig	Full body	20–70 kg	10	2’000 kg
King et al.[58]	2016	Article	Scav	USA, OK	Csa	Woodland, grassland	Reserve	1; 3; 2	All	Pig	Full body	Unclear	9	Unclear
Kjorlien et al.[7]	2009	Article	Scat	Canada	Dfb	Woodland, grassland	Agriculture	3; 3	SpSu	Pig	Full body	35–45 kg	24	Unclear
Klippel and Synstelien[59]	2007	Article	Scav	USA, TN	Cfa	Woodland	Body farm	30	All	Human	Full body	Unclear	50	Unclear
Komar and Beattie [60]	1998	Article	Scav	Canada	Dfb	Woodland, grassland	Research	Unclear	SuA	Pig	Full body	80 kg	25	Unclear
Labanowski[61]	2017	Thesis	Scav	USA, ME	Dfb	Woodland	Unclear	1; 7	AWSp	Pig	Full body	Unclear	2	Unclear
Lewis[62]	2018	Thesis	Both	USA, TX	Cfa	Grassland	Body farm	2; 7	All	Human	Full body	Unclear	12	Unclear
Lira et al.[63]	2020	Article	Scav	Brazil	Aw	Woodland, savanna	Unclear	Unclear	Unclear	Pig	Full body	2–2.5 kg	72	67.5 kg; 42 kg; 13.5 kg; 27 kg
Marshall et al.[64]	2009	Abstract	Scav	USA, MI	Unclear	Agricultural	Unclear	Unclear	Unclear	Pig	Full body	Unclear	2	45 kg; 45 kg
Martin and Johnston [65]	2012	Abstract	Both	USA, NC	Cfa	Unclear	Unclear	6; 4	SuAW	Pig	Full body	4.5–13.6 kg	7	Unclear
Martin and Johnston [66]	2014	Abstract	Scav	USA, NC	Cfa	Woodland	Body farm	17	All	Human	Full body	Unclear	6	Unclear
Meckel et al.[67]	2018	Article	Scav	USA, TX	Cfa	Woodland	Body farm	5	SuAW	Human	Full body	Unclear	1	129.5 kg; 388.5 kg
Miranker et al.[68]	2020	Article	Scat	USA, TX	Cfa	Open woodland	Body farm	Unclear	All	Human	Full body	Unclear	5	Unclear
Morton and Lord [69]	2006	Article	Scav	USA, VA	Cfa	Woodland	Unclear	1; 1; 2; 2	All	Pig	Full body	11.25–27 kg	11	Unclear
Moss[70]	2012	Thesis	Both	USA, TX	Cfa	Woodland	Body farm	9; 4; 2; 8; 8; 3; 15; 14; 9; 9; 13; 13	All	Human	Full body	Unclear	12	Unclear
O’Brien et al.[71]	2007	Article	Scav	Australia	Csa	Woodland	Reserve	0 (25 days); 1	SuW	Pig	Full body	45 kg	2	Unclear
O’Brien et al.[72]	2010	Article	Both	Australia	Csa, Csb	Woodland	Various	Unclear	All	Pig	Full body	40–50 kg	Unclear	1.1 kg; 1.1 kg
O’Brien et al.[73]	2017	Article	Scav	Australia and Canada	Csa, Csb, Dfb	Agricultural, other unclear	Various	Unclear	All	Pig	Full body	Unclear	Unclear	Unclear
Petersen[74]	2013	Thesis	Both	USA, MA	Csa	Open woodland	Private	1; 1	SpSu	Pig	Full body	54.4–63.1 kg	8	90 kg; 63 kg; 36 kg; 27 kg
Pharr[75]	2017	Abstract	Scav	USA, TX	Cfa	Unclear	Body farm	2; 2; 2; 2; 2; 2; 2; 2; 2	A	Pig	Full body	Unclear	21	108 kg
Pharr[76]	2014	Abstract	Scav	USA, TX	Cfa	Unclear	Body farm	Unclear	All	Pig	Full body	Unclear	43	Unclear

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Table 3 (*continued*)

Author	Year	Type and topic		Environment				Temporal data		Specimen				
		Type	Topic	Country	Köppen-Geiger	Environment	Land use	Duration	Season	Carcass type	Carcass part	Weight	Sample size	Biomass
Pharr[77]	2012	Abstract	Scav	USA, TX	Cfa	Unclear	Body farm	Unclear	Unclear	Pig	Full body	1.38–2.06 kg	6	29.38 kg; 44.25 kg
Pharr et al.[78]	2015	Abstract	Scav	USA, TX	Cfa	Unclear	Body farm	Unclear	Unclear	Pig	Full body	Unclear	42	350 kg; 350 kg
Pokines[79]	2022	Article	Both	USA, MA	Dfb	Island (grassland, wetland)	Wild land	0 (15 days)	Su	Cow	Body parts	218.5 g	16	1.748 kg; 1.748 kg
Pokines and Pollock [80]	2018	Article	Scav	USA, MA	Cfa	Woodland, grassland	Body farm	4	SuA	Pig	Body parts	Unclear	36	Unclear
Pokines et al.[81]	2021	Article	Both	USA, MA	Cfa	Woodland	Public park	Unclear	Unclear	Deer	Body parts	0.007–0.195 kg	44	Unclear
Potmesil[82]	2005	Article	Both	USA, NE	BSk	Grassland	Grazing	Unclear	Unclear	Cow	Full body	Unclear	3	240 kg
Reeves[83]	2009	Article	Scav	USA, TX	Cfa	Grassland	Body farm	0 (26 days); 0 (8 days); 0 (10 days); 0 (12 days)	SuA	Pig, goat	Full body	27–63 kg	5	60 kg
Ricketts[84]	2010	Thesis	Both	USA, MA	Cfa	Woodland	Body farm	2; 1	SuAW	Pig	Full body	14–16 kg	5	60 kg
Rippley et al.[85]	2012	Article	Scav	USA, TX	Cfa	Woodland	Body farm	1	W	Human	Full body	Unclear	1	Unclear
Robinson and Blake [86]	2016	Abstract	Scav	USA, NY	Dfb	Woodland, grassland	Research	2; 3	SpA	Pig	Full body	Unclear	8	45 kg; 45 kg; 45 kg
Schultz and Mitchell [87]	2018	Article	Both	USA, FL	Cfa	Grassland	Unclear	1	Sp	Pig	Full body	27 kg	4	105 kg; 105 kg
Séguin et al.[88]	2021	Article	Scav	Canada	Cfa	Woodland, grassland	Wild land	2; 3	SuA	Pig	Full body	70 kg	10	Unclear
Smith[89]	2021	Article	Scav	USA, CO	Cfa	Desert	Body farm	-	All	Human	Full body	Unclear	9	177 kg
Smith[90]	2015	Thesis	Scav	USA, MA	BSk	Woodland	Body farm	-	All	Human	Full body	Unclear	10	230 kg
Sorg et al.[91]	2012	Abstract	Scav	USA, ME	Dfb	Woodland	Unclear	8	All	Pig	Full body	Unclear	3	630 kg
Spies et al.[92]	2020	Article	Scav	South Africa	Csa-Csb	Woodland	Unclear	3	WSpSu	Pig	Full body	60 kg	4	12 kg; 18 kg; 164 kg
Spies et al.[93]	2018	Article	Both	South Africa	Csa-Csb	Thicket	Unclear	3	AW	Pig	Full body	20 kg	3	36 kg; 164 kg
Spies et al.[18]	2018	Article	Scav	South Africa	Csa-Csb	Thicket	Unclear	4	AW	Pig	Full body	20 kg	3	Unclear
Spradley et al.[11]	2012	Article	Scat	USA, TX	Cfa	Steppe	Body farm	7	All	Human	Full body	Unclear	1	Unclear
Stamper et al.[94]	2020	Article	Scav	USA, MT	Dfb	Grassland	Unclear	0 (3 days); 0 (2 days); 0 (1 day)	Su	Pig	Full body	10–20 kg	9	Unclear
Starkie et al.[95]	2013	Article	Scat	UK	Cfb	Woodland	Unclear	28	Unclear	Pig	Full body	1–50 kg	12	Unclear
Steadman et al.[96]	2018	Article	Scav	USA, TN	Cfa	Woodland	Body farm	1; 2; 4	WSpSu	Human, pig, rabbit	Full body	Unclear	45	27 kg; 13.6 kg
Suckling[97]	2011	Abstract	Scav	USA, TX	Cfa	Unclear	Body farm	Unclear	All	Human	Full body	Unclear	10	Unclear
Synstelien[98]	2009	Abstract	Scav	USA, TN	Cfa	Unclear	Body farm	Unclear	All	Human	Full body	Unclear	Unclear	Unclear
Synstelien and Klippel[99]	2005	Abstract	Scav	USA, TN	Cfa	Unclear	Body farm	Unclear	All	Human	Full body	Unclear	Unclear	Unclear

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Table 3 (*continued*)

Author	Year	Type and topic: Type	Type and topic: Topic	Environment: Country	Environment: Köppen-Geiger	Environment: Environment	Environment: Land use	Temporal data: Duration	Temporal data: Season	Specimen: Carcass type	Specimen: Carcass part	Specimen: Weight	Specimen: Sample size	Specimen: Biomass
Vanlaerhoven and Hughes[100]	2008	Article	Both	Canada	Dfa	Woodland, grassland	Unclear	0 (6 days)	Su	Pig	Full body	23 kg	10	Unclear
Wescott et al.[101]	2013	Abstract	Scav	USA, TX	Cfa	Unclear	Body farm	Unclear	All	Human	Full body	Unclear	68	Unclear
White[102]	2013	Thesis	Scav	USA, MT	Dfb	Grassland	Unclear	0 (20 days); 12	All	Pig	Full body	36–78 kg	3	Unclear
Willey and Snyder [10]	1989	Article	Both	USA, TN	Csc	Woodland	Unclear	Unclear	All	Deer	Full body	16–68 kg	15	Unclear
Young et al.[19]	2014	Article	Scav	UK	Cfb	Woodland	Unclear	7	WSp	Deer	Both	2–6 kg, 23–59 kg	12 baits, 5 full bodies	Unclear
Young et al.[103]	2014	Article	Scav	UK	Cfb	Woodland	Unclear	7	WSp	Deer, pig	Both	2–6 kg, 23–59 kg	270 baits, 5 full bodies	Unclear

framework, 68.4% of experiments (or single trials therein) were conducted in a *warm temperate* climate ("C", 54/79), followed by *snow* ("D", 17.7%, n = 14), *arid* ("B", 12.7%, n = 10), and *equatorial* ("A", 2.5%, n = 2). Two of these publications included combinations of two climates each, and in one paper, the climate remained unclear (1.3%, n = 1). Precipitation type was *no dry season* ("f", 63.3%, n = 50), *dry summer* ("s", 19.0%, n = 15), *semi-arid or steppe* ("S", 12.7%, n = 10), and *dry winter* ("w", 6.3%, n = 5). The level of heat was *hot summer* ("a", 60.8%, n = 48), *warm summer* ("b", 30.4%, n = 24), *cold* ("k", 10.1%, n = 8), *cold summer* ("c", 2.5%, n = 2), and *hot* ("h", 2.5%, n = 2). These values add up to more than 100% because some studies included different climate types, precipitation and/or heat levels. No studies report experiments in polar ("E"), desert ("W"), monsoonal ("m") or extremely continental ("d") environments.

3.3.2. Environment

All 79 publications studied subaerially exposed carcasses or portions thereof, while some additionally report hanging (3.8%, 3/79) [46,60,65] or subterranean carcasses with shallow burial depths of 25–60 cm (7.6%, 6/79) [32,39,41,69,84,95]. 64.6% (51/79) of the reviewed publications concentrated on a single homogenous environment, while 16.5% (13/79) evaluated heterogeneous environments and/or compared different habitats. Woodland was the predominant environment (44.3%, n = 35), followed by grassland (29.1%, n = 23), and open woodland/ savannah/ steppe (10.1%, n = 8). Others were agricultural land and desert (each 3.8%, n = 3), thicket (2.5%, n = 2), urban (1.3%, n = 1) or wetland (1.3%, n = 1). These values include studies covering more than one environment, thus adding up to over 100%. 19.0% (15/79) did not specify the study environment. 48.1% (38/79) of the studies did not detail further than e.g. "wooded", while 51.9% (41/79) include details such as weather data and/or known local scavenger communities. We show examples for a wooded and a steppe environment in Fig. 3.

3.3.3. Land use

Experimental land use included multi-year decomposition research (39.2%, n = 31), nature reserves, feeding spots or public parks (8.9%, n = 7), grazing or agricultural land (6.3%, n = 5), other research, e.g. geological (7.6%, n = 6), wild land (5.1%, n = 4), private land (2.5%, n = 2) or an animal enclosure (1.3%, n = 1). No details were available in 29.1% (23/79) of the reviewed studies.

3.4. Temporal data

3.4.1. Study duration

32.9% (26/79) did not specify the study duration, but we could extract the duration of the single trials from 67.1% (53/79). The 108 trials lasted between one hour [45] (= 0 months) and ca. 30 months [59] (Fig. 4). 91.7% (99/108) were concluded within 12 months; eight experiments exceeded the study duration of one year [32,59,66,95].

3.4.2. Season

35.4% (28/79) of the publications cover all four seasons, while the seasons studied remain unclear in 13.9% (11/79). Spring and winter were covered in 55.7% (44/79) each, summer in 70.9% (56/79), and autumn in 59.5% (47/79).

3.5. Specimen

Carcass type. 76.0% (60/79) of the reviewed publications studied animal carcasses only, including pig, deer, cow, goat, kangaroo, emu and rabbit. 22.8% (18/79) studied donated human bodies only and one publication studied both, humans and animals (1.3%, n = 1) [96]. Pigs were the most frequent human proxies (69.6%, n = 55).

Carcass part. Full bodies were deployed in 96.2% (76/79) of the publications, with three of them additionally studying body parts. In

Table 4
Information retrieved from the 79 reviewed publications in alphabetical order including treatment, setup and documentation.

		Treatment			Setup					Documentation			
Author	Year	Cause of death	Treatment	Clothing	Cage	Fence	Tethering	Distance	Habituation	Camera trap	Site visits	Parameters	Species ID
Adair and Kolz[32]	1998	Unclear	Unclear	Unclear	No	Unclear	No	Unclear	Possible	No	Unclear	No	No
Baigent et al.[33]	2020	Unclear	Unclear	No	Both	Yes	No	11–50 m	Yes	Yes	Thrice weekly, decr.	ADD+TBS	Yes
Baigent et al.[34]	2019	Unclear	Unclear	No	Both	Yes	No	11–50 m	No	Yes	Thrice a week	TBS	Yes
Baigent et al.[35]	2014	Unclear	Unclear	No	No	Yes	Unclear	Unclear	Yes	Yes	Daily	ADD	Yes
Bailey[36]	2020	Natural	Unclear	Unclear	No	Yes	No	Sample size 1	Yes	Yes	Unclear	ADD	Yes
Bankaitis[37]	2012	Shot	Cooling	No	No	Yes	No	Sample size 1	Yes	Yes	Daily	No	Yes
Beck et al.[9]	2015	Shot	Fresh	Yes	Both	Yes	No	101–500 m	No	Yes	Daily	ADD+TBS	Yes
Bright[38]	2011	Unclear	Fresh	No	No	No	Yes	1001–1500 m	No	Yes	Daily	No	Yes
Brinkley[39]	2012	Unclear	Fresh	No	Both	No	No	0–10 m	No	Yes	Daily	ADD	Yes
Brown et al.[40]	2006	Natural, roadkill, shot	Fresh	No	No	Unclear	No	Unclear	Possible	No	Daily, decr.	No	Yes
Cameron and Oxenham [12]	2012	Shot	Fresh	No	Both	Unclear	No	51–100 m	No	No	Unclear	No	No
Cleary et al.[41]	2012	Shot	Fresh	No	No	Yes	Yes	Unclear	Yes	Yes	Daily	TBS	Yes
Dabbs and Martin[42]	2013	Shot, natural	Fresh	No	Both	Yes	Both	Unclear	Yes	Yes	Daily	KADD	Yes
Demo et al.[43]	2013	Unclear	Unclear	No	No	Unclear	No	Unclear	Possible	Yes	Unclear	No	Yes
Dibner et al.[44]	2019	Exsanguination	Fresh	No	No	Unclear	No	0–10 m	No	Yes	Twice daily, decr.	ADD+TBS	Yes
Domínguez-Solera and Domínguez-Rodrigo[45]	2011	Natural	Fresh	No	No	No	No	Sample size 1	Yes	No	Constant	No	Yes
Dupuis[46]	2005	Unclear	Unclear	No	Yes	No	No	Unclear	Yes	Unclear	Unclear	Unclear	Unclear
Forbes et al.[47]	2022	Termination	Fresh	No	No	No	Both	151–200 m; 1 km; 50 km	No	Yes	Unclear	No	Yes
Garcia et al.[48]	2020	Natural	Unclear	No	No	Yes	No	0–10 m	Yes	Yes	Daily, decr.	ADD+TBS+TBDS	Yes
Garcia-Putnam[49]	2014	Shot	Fresh	No	Both	Unclear	No	11–50 m	Yes	Yes	Daily, decr.	No	Yes
Hannigan[50]	2015	Unclear	Unclear	Yes	No	Unclear	Unclear	Sample size 1	Unclear	Yes	Unclear	ADD+TBS	Yes
Jeong et al.[51]	2016	Natural	Unclear	No	No	Yes	No	Unclear	Yes	No	Daily	No	Yes
Johnston and Martin[52]	2013	Unclear	Unclear	No	No	Yes	Unclear	Unclear	Yes	Yes	Unclear	ADD+TBS	Unclear
Jones[53]	2011	Termination	Cooling, freezing	No	No	No	No	Unclear	No	Yes	Daily	No	Yes
Keyes et al.[54]	2020	Natural	Unclear	No	No	Yes	Yes	11–50 m	Yes	Yes	Biweekly	No	Yes
Keyes et al.[55]	2022	Natural	Unclear	No	No	Yes	Both	11–50 m	Yes (one site)	Yes	Bi-monthly	No	Yes
Keyes et al.[56]	2021	Natural	Unclear	No	No	Unclear	Both	11–50 m	No	Yes	Daily	No	Yes
King[57]	2014	Termination	Cooling	No	Both	Unclear	No	11–50 m	Yes	Video	Second day	ADD	Yes
King et al.[58]	2016	Shot, natural	Cooling	No	Both	Unclear	No	Unclear	Yes	Video	Second day, decr.	ADD+TBS	Yes
Kjorlien et al.[7]	2009	Unclear	Unclear	Yes	No	Yes	No	Unclear	Possible	Yes	Daily	No	Yes
Klippel and Synstelien[59]	2007	Natural	Unclear	Unclear	No	Yes	No	Unclear	Yes	Yes	Unclear	No	Yes
Komar and Beattie[60]	1998	Unclear	Unclear	Yes	No	Unclear	No	11–50 m	Yes	No	Daily	No	Yes
Labanowski[61]	2017	Unclear	Unclear	Yes	No	Unclear	No	1501–2000 m	No	Yes	Unclear	No	Yes
Lewis[62]	2018	Natural	Unclear	Both	No	Yes	No	11–50 m	Yes	Yes	Daily	ADD+TBS	Yes
Lira et al.[63]	2020	Unclear	Unclear	No	Yes	Unclear	No	Unclear	Unclear	Yes	Daily	No	Yes
Marshall et al.[64]	2009	Unclear	Unclear	Yes	Unclear	Unclear	Unclear	Unclear	Possible	Yes	Twice daily	No	Unclear
Martin[65]	2012	Unclear	Unclear	No	No	Unclear	No	Unclear	No	Yes	Unclear	No	Unclear
Martin and Johnston[66]	2014	Unclear	Unclear	Unclear	Unclear	Yes	Unclear	Unclear	Yes	Yes	Unclear	No	Unclear
Meckel et al.[67]	2018	Natural	Unclear	No	No	Yes	No	Sample size 1	Yes	Yes	Unclear	No	Yes
Miranker et al.[68]	2020	Natural	Fresh	No	No	Yes	No	11–50 m	Yes	Yes	After events	ADD	Yes
Morton and Lord[69]	2006	Unclear	Unclear	No	No	Unclear	No	Unclear	Possible	Video	Weekly	No	Yes

(continued on next page)

Table 4 (*continued*)

		Treatment			Setup					Documentation			
Author	Year	Cause of death	Treatment	Clothing	Cage	Fence	Tethering	Distance	Habituation	Camera trap	Site visits	Parameters	Species ID
Moss[70]	2012	Natural, accident, unclear	Five autopsied	Both	Both	Yes	No	Unclear	Yes	Yes	Unclear	No	Yes
O'Brien et al.[71]	2007	Shot	Fresh	No	No	Yes	No	Unclear	Unclear	Video	Unclear	No	Yes
O'Brien et al.[72]	2010	Shot	Unclear	No	Both	Yes	No	Unclear	Unclear	Video	Unclear	No	Yes
O'Brien et al.[73]	2017	Unclear	Fresh	No	Both	Yes	Yes	Unclear	Unclear	Video	Unclear	ADD	Yes
Petersen[74]	2013	Exsanguination	Surgeries	No	No	Yes	No	0–10 m	No	Yes	Daily	TBS	Yes
Pharr[75]	2017	Unclear	Fresh	No	No	Yes	No	1001–1500 m	Yes	Yes	Unclear	No	Yes
Pharr[76]	2014	Unclear	Unclear	No	No	Yes	No	Unclear	Yes	Unclear	Unclear	Unclear	Yes
Pharr[77]	2012	Unclear	Unclear	No	No	Yes	No	1001–1500 m	Yes	Yes	Unclear	Unclear	Yes
Pharr et al.[78]	2015	Unclear	Unclear	No	No	Yes	No	501–1000 m	Yes	Yes	Unclear	ADM	Yes
Pokines[79]	2022	Butcher	Defleshing	No	No	No	No	Unclear	No	Yes	Twice (start/ end)	No	Yes
Pokines and Pollock[80]	2018	Unclear	Defleshing	No	Yes	Unclear	Yes	51–100 m	Yes	Yes	Unclear	No	Yes
Pokines et al.[81]	2021	Unclear	Decomposition	No	No	Unclear	No	Unclear	Yes	Yes	Weekly	No	Yes
Potmesil[82]	2005	Natural	Unclear	No	No	Unclear	No	Unclear	Unclear	No	Once	No	No
Reeves[83]	2009	Unclear	Fresh	No	Both	Yes	No	Unclear	Yes	Yes	Daily	No	Yes
Ricketts[84]	2010	Shot	Fresh	No	Both	Unclear	No	Unclear	Yes	Yes	Twice a week	No	Yes
Rippley et al.[85]	2012	Natural	Autopsied	No	Yes	Yes	No	Sample size 1	Yes	Yes	Daily	No	Yes
Robinson and Blake[86]	2016	Unclear	Unclear	No	No	Yes	No	Unclear	Yes	Yes	Unclear	Unclear	Yes
Schultz and Mitchell[87]	2018	Shot	Fresh	No	No	Yes	No	11–50 m	No	Yes	Unclear	ADD+TBS	Yes
Séguin et al.[88]	2021	Shot	Fresh	No	No	Unclear	No	101–500 m	No	Yes	Daily	TBS	Yes
Smith[89]	2021	Natural	Autopsied	No	No	Yes	No	Unclear	Yes	Yes	Daily, de-/ incr.	ADD+TBS+TBDS	Yes
Smith[90]	2015	Natural	Cooling	No	No	Yes	No	Unclear	Yes	No	Daily	ADD+TBS	Yes
Sorg et al.[91]	2012	Unclear	Unclear	Yes	No	Unclear	No	1501–2000 m	No	Yes	Weekly	No	Unclear
Spies et al.[92]	2020	Shot	Fresh	Yes	No	Unclear	No	11–50 m	No	Yes	Daily	ADD	Yes
Spies et al.[93]	2018	Shot	Fresh	No	Both	Unclear	No	11–50 m	No	Yes	Weekly, incr.	No	Yes
Spies et al.[18]	2018	Shot	Fresh	No	Both	Unclear	No	11–50 m	No	Yes	Unclear	No	Yes
Spradley et al.[11]	2012	Natural	Autopsied	No	No	Yes	No	Sample size 1	Yes	Yes	Daily	ADD	Yes
Stamper et al.[94]	2020	Termination	Freezing, burning, trauma	No	Yes	Yes	No	Unclear	No	No	Daily	No	Yes
Starkie et al.[95]	2013	Natural	Unclear	No	No	Yes	No	Unclear	No	No	Daily	No	Yes
Steadman et al.[96]	2018	Termination	Unclear	No	Both	Yes	No	0–10 m	Yes	Yes	Twice daily	ADD+TBS	Yes
Suckling[97]	2011	Unclear	Unclear	Unclear	Both	Yes	No	Unclear	Yes	Yes	Daily	Yes	Yes
Synstelien[98]	2009	Unclear	Unclear	Unclear	No	Yes	No	Unclear	Yes	Unclear	Near daily	Unclear	Yes
Synstelien and Klippel[99]	2005	Unclear	Unclear	Unclear	No	Yes	No	Unclear	Yes	Unclear	Unclear	Unclear	Yes
Vanlaerhoven and Hughes [100]	2008	Shot	Fresh	No	No	No	No	11–50 m	No	No	Daily	ADD	No
Wescott et al.[101]	2013	Unclear	Unclear	Unclear	Both	Yes	Unclear	Unclear	Yes	Unclear	Unclear	Unclear	Unclear
White[102]	2013	Shot	Fresh	No	Yes	No	No	0–10 m	Possible	Yes	Twice daily, decr.	ADD+TBS	Yes
Willey and Snyder[10]	1989	Roadkill	Fresh	No	No	Yes	No	Unclear	Yes	Unclear	Unclear	No	Yes
Young et al.[19]	2014	Shot	Fresh	No	No	No	No	baits 11–50 m, full bodies 51–100 m	Possible	Yes	Weekly	No	Yes
Young et al.[103]	2014	Shot	Fresh	No	No	No	No	baits 11–50 m, full bodies 51–100 m	Yes	Yes	Weekly	No	Yes

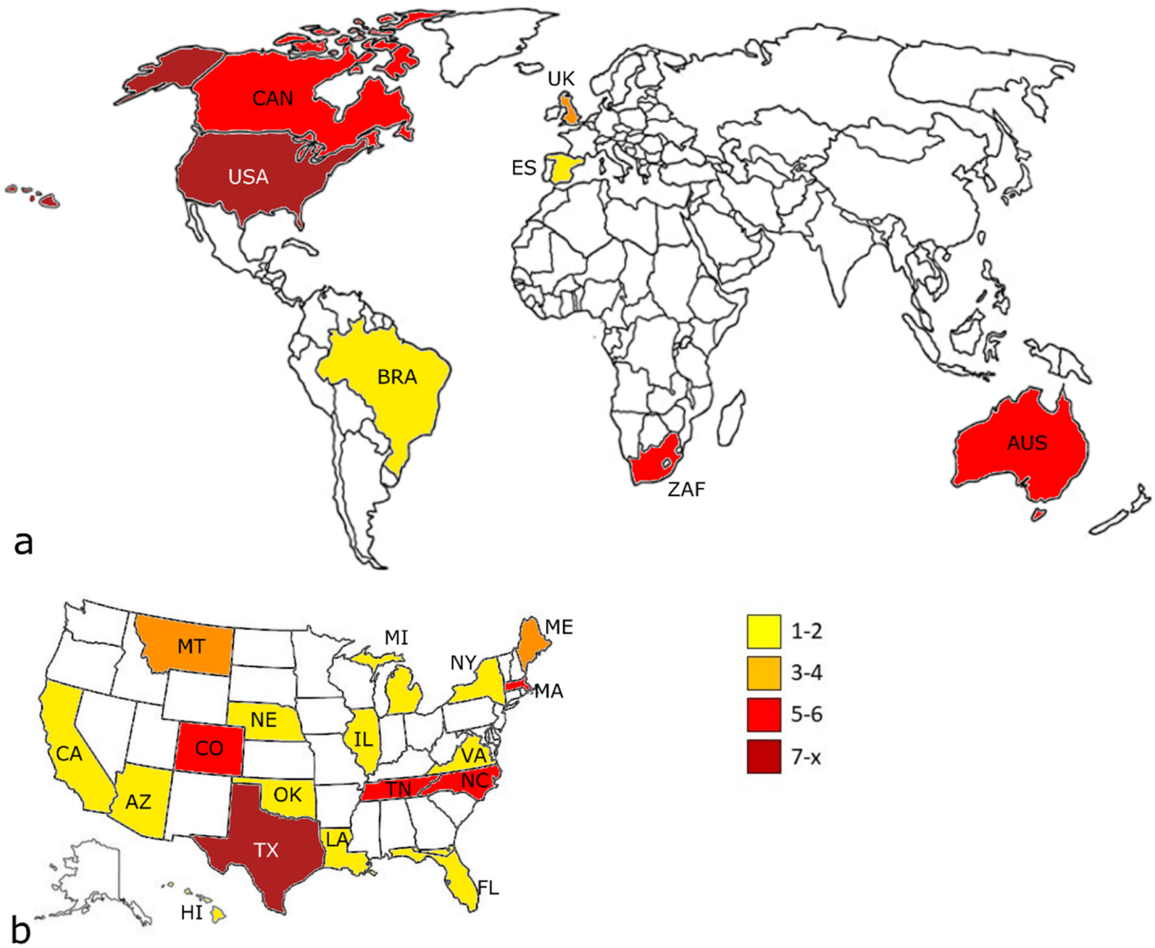

Fig. 2. Heat map showing the geographical distribution of the reviewed experiments on scavenging and/or scattering worldwide (a) and in the USA (b).

3.8% (3/79), the sample consisted of body parts only.

Weight. 45.6% (36/79) of the publications, including most human model studies, did not specify carcass weight. The mean weight of the 343 pig carcass is at 37.1 kg, the distribution is shown in Fig. 5a. Weight differences between any specimens of the same publication (not of the same trial) ranged from 0 to 259 kg (mean of 47.2 kg ± 69.9 kg).

Sample size. The sample size distributions are shown in Fig. 5b-c. 8.9% (7/79) of the publications were single-specimen studies, and 5.1% (4/79) did not specify their total sample size [72,73,98,99]. For human specimens, it was not possible to establish trial-specific samples sizes because of the study designs.

Biomass availability. We could extract biomass per trial in 50.6% (40/79) of the publications. None of these 40 papers include human specimens, because human specimen studies did not inform about additional bodies present in the facility during the trials that would add to the overall biomass availability. The average biomass per trial, not separated by species, ranged from 1.1 to 2000 kg (n = 84, mean of 143.1 ± 228.6 kg).

3.6. Treatment

Cause of death. Specimens died naturally in 21.5% (17/79), or were shot (sometimes following illness [41,49,58]) in 21.5% (17/79). Further causes were drug-induced termination (6.3%, n = 5), exsanguination (2.5%, n = 2), traffic accidents (1.3%, n = 1), and butchery (1.3%, n = 1). In 5.1% (4/79) of the studies, more than one of the above methods was applied to the different specimens. 40.5% (32/79) of the publications did not detail the specimen's cause of death, 78.1% (25/32) of these studied pigs. 3.8% (3/79) of the studies mention stunning methods such as electricity [18,74,93].

Handling. Handlings involve cooling (5.1%, n = 4) and surgery or autopsy (5.1%, n = 4). In 34.2% (27/79) of the publications, the carcasses were deposited "fresh" and in 48.1% (38/79), handling between death and deposition was not detailed. Three publications included different handlings, e.g. autopsy and fresh [70], cooling and freezing [53], and freezing, burning and wounds [94]. Where bones were deployed, these were all defleshed or decomposed prior to deposition.

Clothing. Of the studies with full bodies (n = 76), 76.3% (58/76) conducted research on non-clothed carcasses, 13.2% used clothed bodies or both (10/76), and 10.5% (8/76) did not specify.

3.7. Setup

Cage. The 79 experiments studied caged individuals (7.6%, n = 6), uncaged ones (65.8%, n = 52) or both (24.1%, n = 19), while it remains unclear in 2.5% (2/79) [64,66]. One study with uncaged human cadavers mentions nets covering hands and feet [51]. We show an example of a caged pig carcass in Fig. 6.

Enclosures. Enclosures were present in 54.4% (43/79), while absent in 13.9% (11/79), and comprised chain-link fences, hardware cloth covering, razor wire tops, and electric or barbed wires. In 31.7% (25/79) of the publications, the use of enclosures remains unclear.

Tethering. Tethering of the carcass was mentioned in 16.5% (13/79), with four of these studies also including non-tethered individuals. No tethering was present in 81.0% (64/79), while it remained unclear in 7.6% (6/79).

Inter-carcass distance. 84.8% (69/79) of the publications studied more than one carcass simultaneously. In 43.0% (34/69) of these, inter-

Fig. 3. Two examples of scavenging experiments in different environments: a) a experimental setup in a temperate forest in Switzerland, and b) a steppe environment in the outskirts of Arivaca, Arizona.
(reproduced with permission from Beck et al. [9], published by John Wiley & Sons Ltd, 2014).

carcass distance was given. It ranged between 0 and 10 m (8.7%, n = 6), 11–50 m (21.7%, n = 15), 51–100 m (2.9%, n = 2), 101–500 m (2.9%, n = 2), 501–1000 m (1.3%, n = 1) and > 1000 m (6.3%, n = 5). One study combined different distances between 150 m and 50 km [47] and two studies looked at baits (11–50 m) and full bodies (51–100 m) [19, 103].

Scavenger habituation. We determined the potential of scavenger habituation as present in 54.4% (43/79), possibly present in 10.1% (8/79), not present in 27.8% (22/79), and unclear in 7.6% (6/79). In 1.3% (1/79), we defined habituation as present for the baits (repeated deposition) and possible for the full bodies [103], one publication compared a habituation-context to a non-habituation [55].

3.8. Documentation

Camera trap photography/ videography. 76.0% (60/79) of the studies used camera traps, 2.5% (2/79) additionally used 24 h video recording. No video/photographic recording devices were used in 13.9% (11/79), and in 7.6% (6/79) it remains unclear.

Site visit frequency. Daily site visits were performed in 34.2% (27/79). In five publications, the frequency decreased from daily (6.3%, n = 5) to less frequent. In 3.8% (3/79) of the publications, the visit frequency increased after scavenging or dispersal occurred [68,89,93]. Regular visit schedules were every second day or "near daily" (2.5%, n = 2), two or three times a week (3.8%, n = 3), weekly (6.3%, n = 5), biweekly (1.3%, n = 1), bimonthly (1.3%, n = 1), once each at the start and end of the trial (1.3%, n = 1), once only at the end (2.5%, n = 2). We found no details about site visits in 35.4% (28/79) of the studies. Constant observation occurred during one feeding experiment [82]. Site visits range from non-invasive (e.g. photographs and measurements) to invasive, e.g. including carcass weighing [92] and insect collection [64].

Decomposition parameters. We found that 36.7% (29/79) of the studies report at least one concept. ADD and/ or TBS were the most frequent recorded ones, followed by Total Body Desiccation Score (TBDS) [48,89], Kelvin scale ADD (KADD) [42], and Accumulated Degree Minutes (ADM) [78]. In 54.4% (43/79) of the publications, they did not use any decomposition parameters, and in 8.9% (7/79), it remains unclear.

Species identification. 86.1% (68/79) of the papers report identification of the vertebrate scavenger species. The remaining studies without species identification were mainly scattering-based.

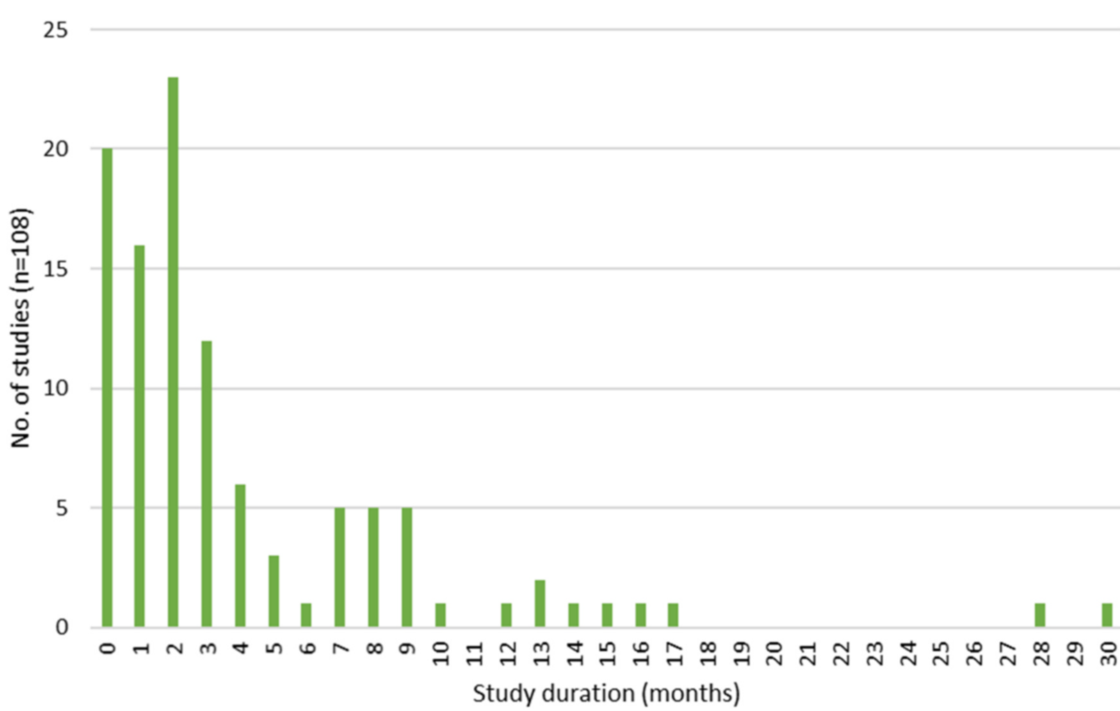

Fig. 4. The 108 trials and their study duration in months. "0 months" includes all studies lasting less than one month. 27 publications did not specify the study duration.

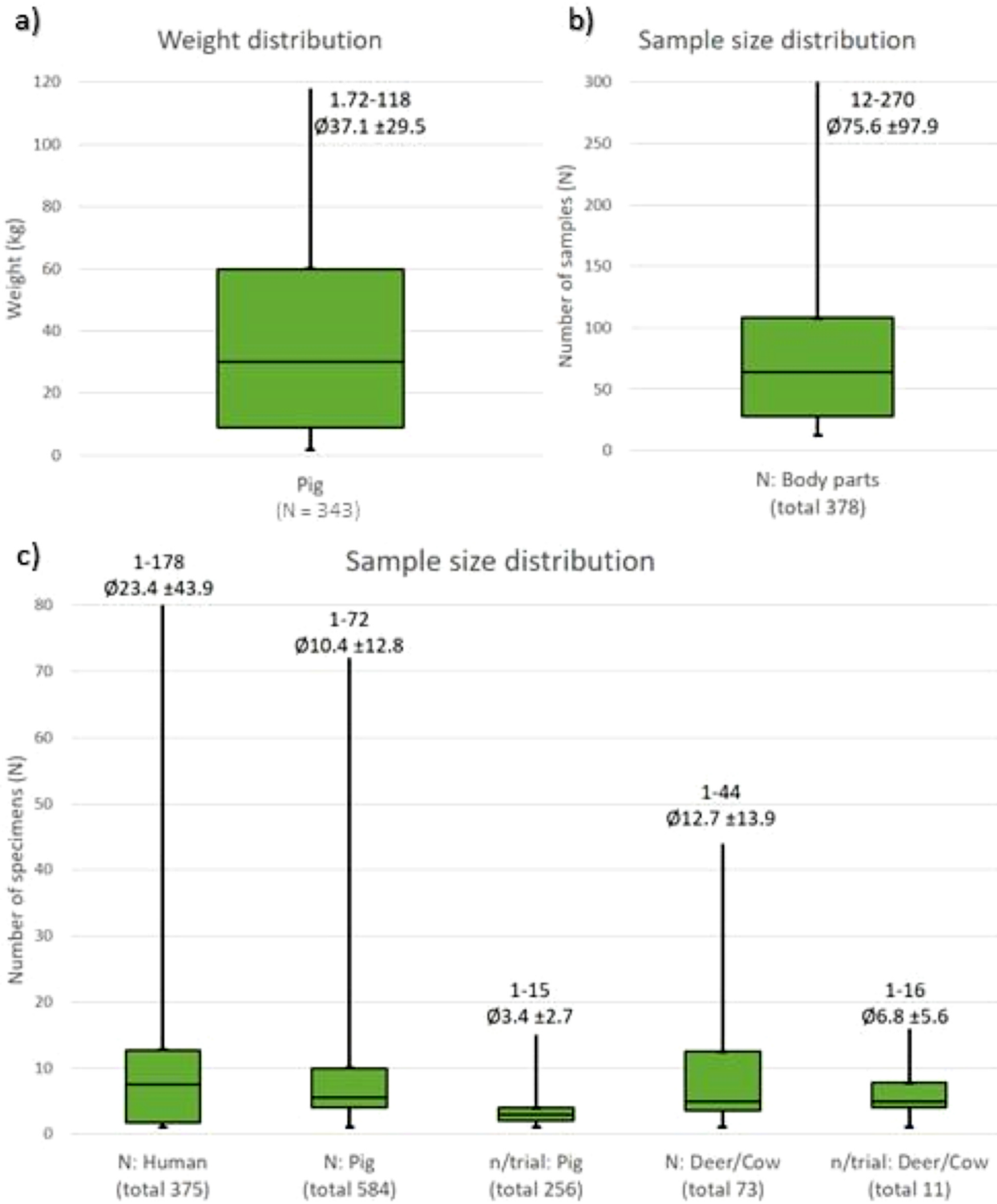

Fig. 5. a) Weight distribution of pig carcasses and b) sample size distribution of b) body part and c) full body specimens with total number, minimum and maximum, mean (ø) and standard deviation. N = overall sample size per publication, n/trial= sample size per trial.

4. Discussion

We found a promisingly large number of experiment publications on vertebrate scavenging and scattering; the increase of works over time mirrors the growing recognition of the topic's relevance in forensic practice. However, the challenge unveiled by our review is the poor standardisation in design for experimental research on scavenging and scattering, the subsequent inconsistency of methodology, the variable quality of published data, and the unequal geographical distribution of the studies. In the following, we discuss our findings in detail.

4.1. *Type*

Type. Our review shows that master's theses and abstracts often do

Fig. 6. A caged pig carcass to prevent access for large scavengers in a scavenging experiment by the authors (not reviewed here). The mesh size is 5 × 5 cm.

not result in international publications, leaving the information they contain less available and less detectable, especially considering that the major databases (i.e., Web of Science™, Scopus, and PubMed) do not index theses. Furthermore, abstracts are limited in scope and the ones reviewed often missed important data, especially regarding methodology. However, theses are more extensive than articles, containing information needed to reproduce or compare the studies. Also, they are well suited for e.g. exemplary baseline taphonomy research of selected geographical areas [8]. Nevertheless, we would like to stress that the researchers pursue publication as articles in indexed international, peer-reviewed journals to ensure better detectability.

Publication year. It becomes apparent from our review that vertebrate scavenging and scattering gained growing attention in forensics over the past decades. This comes with a general increase of teaching, research, and specialisation in forensic sciences and anthropology, particularly in the USA and the UK [104–107]. Furthermore, the first taphonomy research facilities were established since the early 1980's and comprehensive textbooks on forensic taphonomy were published since the late 1990's [108–111].

4.2. Topic

Our review shows that scavenging is about ten times more prominent than scattering in experimental research. This is surprising, because failure to recover the entire skeleton due to taphonomic variables is a common issue in forensic casework [4,5,107,112,113]. Furthermore, it was shown that knowledge on the specific faunal agent and its scavenging behaviour can increase the recovery success in a forensic case [112,114,115]. Possible explanations for the low scattering occurrence are that scavenging experiments are easier to perform, e.g. with a carcass and camera traps. On the other hand, scattering research is usually long-term (several months to years) and requires ways to trace the removed skeletal elements. Nevertheless, we would like to point out the necessity to do more research on scavenger-typical scattering.

4.3. Location

Country. The majority of experiments were conducted in the USA. We explain this by the high availability of taphonomy research facilities, particularly where the study of human remains is concerned. Currently, eleven of thirteen human taphonomy facilities are based in the USA [116]. In addition, forensic science has a longer history in the USA and is established in the education and criminal justice system [107,117]. Subsequently, there might be more funding available for education and research in forensics. Other countries and continents are clearly underrepresented in our review, Asia being conspicuously absent. Moreover, apart from the UK and Hawaii, no experiments were conducted on islands, despite them often bearing distinctive flora and fauna. Based on our data, we recommend greater focus on so far neglected geographic regions, as also stressed by Ubelaker and DeGaglia [2].

Köppen-Geiger Climate Classification System. The reviewed experiments cover most climates and only neglect those where the forensic need is low, such as polar regions. To have direct comparisons of equal setups, we deem it valuable in future studies to conduct simultaneous experiments in different climate zones, following the example of O'Brien et al. [73] for warm temperate and snow climate, and Baigent et al. [35] for arid and snow climate.

Environment. Almost half of the reviewed experiments were conducted in wooded or open-wooded areas, environments where human remains are frequently recovered in forensic practice [4,103,106,112, 118–121]. High altitude environments are underrepresented, only three conference abstracts having described scavengers in a research facility at almost 2900 m AMSL [33–35]. However, the frequency of finds in mountainous regions ("orobiomes") is expected to increase due to proceeding glacial melt and shorter periods of snow cover [4,122,123]. Thus, more research would be useful, e.g. to better differentiate scavenger-induced from geologically/glacially caused dispersal patterns. Details on the environment were only included in about half of the publications. We propose the inclusion of relevant information such as weather data, the presence of dense vegetation or leaf litter, and distances to the next settlement in future published works. The rationale for this suggestion is henceforth illustrated: for instance, certain vegetation impairs visibility of the remains, decreasing activity of visually-oriented scavengers [53,88,124]. For example, leaf litter negatively affects the search and recovery of the remains [125]. Furthermore, some animals might avoid places in close proximity to settlements [73] or, conversely, be more likely to scavenge in settlements given larger populations in urban compared to rural settings (e.g. the European red fox in the UK [126]).

Land use. About 40% of the studies were conducted at perennial decomposition research facilities, with the risk that local animals might become accustomed to this food source. To quantify scavenger habituation, an ecological baseline prior to the first carcasses being deployed is needed [14,26]. Finding places to conduct decomposition experiments is challenging and researchers often lack choice of suitable areas. Subsequently, the previous land functions are diverse as shown by our review. However, almost one third of the publications did not detail the land use. Nonetheless, we deem this information crucial to include and discuss, because it can greatly influence an experiment's outcome. For instance, the human activity before the experiment or nearby can influence animal presence, diversity and behaviour [73,127–129].

4.4. Temporal data

Study duration. Our review shows that short-term studies clearly predominate. They are well suited for student projects, education and the detection of general trends. However, longer experiments enhance knowledge on taphonomic processes over large time intervals, for instance, changes of bone over years [130]. They also take into account seasonal differences in species composition. It would also be beneficial to increase the study length in future experiments because a large proportion of forensic cases have a PMI of at least several years, as shown e.g. by [4,131].

Season. The reviewed experiments cover all seasons more or less equally; many publications deal with more than one season, but only few compare the influence of different seasons on similar trials. Seasons can greatly affect decomposition and vertebrate scavenging, e.g. due to differences in precipitation, temperature, or invertebrate colonisation rate [40,53,56,72,84,88]. Forensic anthropologists may encounter overlapping season-specific alterations. Being able to delineate these can be crucial when estimating PMI, for instance.

4.5. Specimen

Carcass type. Over three quarters of the reviewed literature studied animal specimens. The number of experiments with human bodies is low because of legal framework hurdles and ethical considerations present in many countries, regarding the use of human remains for decomposition research [132,133], while non-humans are easier to acquire, even in large numbers and with homogenous properties [28]. Nevertheless, animal experiments must still follow ethical standards, guidelines and laws [134–137]. Because the carcass type can affect decomposition [138–140] and scavenging [96,141], the study of human analogues and the variability of species is a challenge for forensic research. Experiments on domestic pig carcasses were predominant in our review. This is not surprising, because they are considered the most suitable human analogue for taphonomy studies, in particular for the identification of trends, the initial validation of forensic methods, or in "proof-of-concept" studies [28]. However, results from animal studies need validation on humans and should not be directly transferred to forensic (anthropological) cases, as stressed in several publications [27,28,138,142].

Carcass parts. Nearly all reviewed publications studied full bodies, which probably is the most common forensic scenario. However, depending on the research question, body parts or bones may be more suitable. For instance, they are sufficient for capturing local scavenger guilds, or the reproduction of scenarios with dismembered and mutilated remains [5], while bones can be used to study dry-bone-scavengers such as squirrels [81,143]. By using body parts, the sample size could be enhanced without needing additional specimens, and bones could even be re-used after a full-body decomposition experiment, thus embracing the 4 R's principles of ethical animal research [144].

Weight. The weight information was absent in almost half of the reviewed literature, a surprisingly high number given that body size seems to affect decomposition in various ways [145–149]. Interestingly, weight information was missing for most human cadavers. Because the effects of body size and weight on decomposition are not fully understood [29], it is important to document these data from forensic taphonomic experiments. Furthermore, we found that the variability between carcasses within and between studies with respect to weight is vast, impeding comparability. To reduce this bias, we strongly recommend using similarly sized carcasses within experiments. For pigs as human analogues, Matuszewski and colleagues recommend a minimum weight of 30 kg in forensic entomology [28]. Nevertheless, we would recommend a higher weight nearer to (adult) humans in casework, e.g. 50–100 kg [146].

Sample size. Almost 10% of the reviewed publications observed only one specimen. However, effects observed on only one or two samples might be random, and statistical power of a study increases with number of replicates, among other factors [26]. Therefore, Simmons recommended a minimum sample size of three per treatment (e.g. clothing, caging) [13]. However, single-carcass-experiments better reflect the typical forensic case [29]. Furthermore, controls unaffected by the investigated variables (positive controls) and controls without carcasses (negative controls) should be included in equal numbers to allow for a statistical robusticity of the subsequent evaluation. In addition, it facilitates the comparative analysis and the description of effects influenced by scavengers, e.g. decomposition rate and pattern, trauma alteration and scatter patterns. It should be noted, however, that ecological principles should still be borne in mind when undertaking such work (e.g. observing appropriate inter-carcass distances to prevent overlap of attendant carrion entomofauna). Avoidance of simple pseudo-replication in experimental design with multiple carcasses should also be a research imperative [26].

Biomass availability. We were unable to calculate biomass in more than half of the reviewed studies because of missing data about weight and/or sample size. This despite increasing biomass changes activity and species of scavengers at a carcass across trophic levels [150]. Furthermore, Finaughty et al. [151] compared a single- to a multi-carcass-deployment. They found that the single carcass decomposes faster and scavengers visited it more often and longer than in the higher biomass scenario. We think that the impact of increased biomass availability on decomposition and scavenging requires more attention in future taphonomic studies.

4.6. Treatment

Cause of death. We found that trauma is often mentioned in the reviewed literature, for example, road accidents or gunshots. This reflects forensic casework, where trauma is common, e.g. [5]. Some previous studies state that penetrating trauma affects decomposition rate and/or pattern [152–155], but also influences vertebrate scavenger behaviour by luring them and by facilitating access to internal structures [19,154]. Termination was mentioned in three publications without further specification on the drug. Sodium pentobarbital is a common termination drug but should be avoided in scavenging experiments because it can cause secondary poisoning in scavenging wildlife [156], resulting in scavenger death or behavioural changes. Ante- or perimortem medical treatment and illnesses are often not covered in the literature. Nevertheless, it can alter decomposition rates, e.g. through bacterial growth inhibition (antibiotics) or by elevating body temperature [157–159]. The notation "natural death" as given in a fifth of the studies is problematic because the actual cause and the effect on scavengers remain unknown. However, natural causes probably remain the most ethical deaths for taphonomy experiments, although they present challenges, too. We propose to note the most likely causes of death and discuss potential bias in future research.

Handling. About half of the reviewed studies did not entail information on the carcass handling between death and deposition. We assumed that the authors would mention "heavy treatment" such as autopsy, burning or freezing because it is known that, for instance, frozen or autopsied carcass decomposition differs from fresh carcasses [160,161]. Nevertheless, seemingly less invasive treatments should be published as well, including the use, duration and type of storage between death and deposition. Furthermore, we strongly recommend uniform handling within an experiment, ideally reflecting real forensic scenarios.

Clothing. Most publications report bare carcasses and only 12% studied clothed ones. Clothed carcasses better reflect forensic casework [29] and while the use of garments depends on the research question or scenario examined, it is necessary to be aware of the impact of clothing on taphonomic processes. For instance, it seems to slow down decomposition and alter insect colonisation patterns [64,92,162,163], taint animal bodies with human scent [50,61,91], and delay vertebrate scavenging by restricting access [7,92,103]. However, other studies found no significant impact on decomposition [164] or on vulture feeding pattern and scattering [62]. Nevertheless, we recommend the use of clothed specimens and an equal number of bare controls.

4.7. Setup

Cage, Enclosures, Tethering. About two thirds of the publications studied uncaged specimens only. On the other hand, about half of all studies report some kind of enclosure, most probably preventing certain vertebrate species (especially those that cannot fly and climb or do not dig into ground) from access. In particular, security fences are installed at human decomposition facilities and these may serve to exclude or impede natural scavenging activity to some extent. While cages are an active part of the study design, enclosures such as fences are more passive, possibly explaining why a third of the reviewed publications do not detail that topic. The variety of cage or enclosure types and materials is vast. This is problematic because different vertebrates are prevented from accessing the carcasses, biasing comparisons of scavenger communities observed. For instance, several studies report a reduction in scavenging efficiency when larger facultative scavengers are excluded [165–167]. Tethering was not often present in the reviewed studies and while it might prevent losing the carcass to larger vertebrates, it also compromises the outcome of scavenging and scattering studies. This has previously been shown for fences by Keyes and colleagues [54]. Full reporting of an experiment includes information on *any* restrictive measures, preferably with type, material and mesh size of constructions. Furthermore, it is necessary to discuss which vertebrates were denied access through these. The most forensically realistic approach for actualistic experiments is to exclude restrictive material around the carcass [29].

Inter-carcass distance. Only about half of the reviewed experiments with more than one specimen involved mention the inter-carcass distance. Distances should be adequately chosen to achieve sample independence, because, for instance, Slater [168] showed that scavengers removed baits faster with shorter inter-carcass distances. For taphonomy studies, a distance of at least 30–50 m were found to be sufficient to ensure sample independence [28,169]. Inter-carcass distances might need adjustments relative to certain scavenger's territory sizes, ensuring sample independence and lack of distributed feeding intensity among specimens. This is almost impossible to achieve in restricted areas, such as research facilities.

Scavenger habituation. We found habituation present in over half of the reviewed publications. However, repetitive deposition of carcasses at a site changes the behaviour of vertebrate scavengers, as ecological studies have shown [168,170–172]. Therefore, it is important to assess the potential of habituation [29] and minimise it in an experiment, e.g. by increased inter-carcass distances or larger time spans between deployments [168,172,173]. Habituation is a big issue in taphonomic research facilities, where more than half of the studies were conducted. The oldest facility has been in existence for about forty years, so generations of animals have had plenty of time to get used to the bodies as a food source. We recommend the exploration of new locations in future scavenging research wherever possible, rather than using stationary locations. New facilities should also endeavour to establish ecological baselines for at least one year prior to first carcass placement to enable quantification of potential habituation effects.

4.8. Documentation

Camera trap photography/ videography. Our review shows that recording devices are relatively well implemented in scavenging and scattering studies, with camera traps being the favourite choice. These are indeed well suited to document animal activity, especially in long-term studies with few site visits. There are numerous ecological publications about camera trap methods and analyses [174–178], and we recommend that these concepts are adopted in forensic taphonomy. We think that ideally, a combination of several and different devices should be used to ensure optimal spatial and temporal coverage of the studied area. However, most of the reviewed studies only used one type of recording device. If only camera traps are available, we recommend setting them to record images as well as videos to capture the greatest diversity and detail of animal activity. We further advise to report the camera settings for better reproducibility, e.g. sensitivity, recording duration, rearming interval.

Site visit frequency. The reviewed literature shows various frequencies of site visits, often decreasing with time. In-person site visits are necessary for some type of data collection (e.g. weight loss, scavenging lesion documentation, entomology). However, studies showed that repeated disturbances at carcasses slowed down carcass weight loss and elongated time to scavenging onset [74,179]. Furthermore, some vertebrate scavengers avoid carcasses tainted with human scent [127]. We therefore recommend to include undisturbed controls in taphonomic studies and to keep visits and invasive sampling to a minimum, see also previous works [13,74]. Another possibility would be the implementation of a fully automated sampling and documentation approach as suggested by Finaughty et al. [180].

Table 5
Frequency and number of missing variables in descending order.

Missing variables	Publications (N = 79)	
	(%)	**(n)**
Inter-carcass distance	52.2	36 (N = 69)*
Biomass	50.6	40
Detailed environment	48.1	38
Carcass weight	45.6	36
Cause of death	40.5	32
Study duration	34.2	27
Enclosures	31.7	25
Handling	48.1	38
Site visit frequency	35.4	28
Land use	29.1	23
Season	13.9	11
Decomposition parameters	8.9	7
Scavenger habituation	7.6	6
Sample size	5.1	4

* For the inter-carcass distance, only studies with more than one carcass were counted, thus the total number of 69.

Decomposition parameters. Decomposition parameters are less frequently implemented in scavenging and scattering studies as expected, with about half of the reviewed studies not using any of the parameters. For the almost 40% that did use these parameters, total body score (TBS) and accumulated degree days (ADD) were the most commonly applied ones. A combination of both was first provided by Megyesi et al. [181] to estimate PMI of humans based on decomposition stage and retrospective temperature. However, this method and subsequent validation studies do not account for animal scavenging. Therefore, we think there is a need for studies quantifying the effect of vertebrate scavenging on decomposition and PMI estimations. Furthermore, parameters like TBS and ADD aid a standardised study presentation and facilitate comparisons between experiments despite different climate conditions.

Species identification. While most papers report identification of animal species, we noted that those without mainly focussed on scattering. However, we want to stress that *ibidem* it is of utter importance to know the dispersing agents, especially when it comes to informing search strategies with species-specific behaviour. Compared to casework, it is relatively simple to document and identify scavengers in experiments and therefore, we strongly recommend to use that advantage more often.

4.9. Missing data

We present the variables that we could not extract from the publications in Table 5. However, depending on the study context, some of these variables are crucial to mention. For instance, as collated above, the inter-carcass distance, specimen weight and season affect the scavenging activity, while enclosure, duration and season influence the type of species at the carcass. Cause of death and handling might impact the scavenging sequence and enclosures manipulate the scatter pattern. We would like to highlight the variables that so far have not received sufficient attention in reporting taphonomy research.

4.10. Recommendations for future experimental research

The considerable variability of extrinsic and intrinsic parameters is one of the greatest challenges in forensic taphonomy research. The lack of standardisation is hampering comparisons between studies and compromising comprehensive conclusions relevant for casework [180]. Experiments and their publications should meet certain standards and qualities to be of use in forensic casework and should follow

Table 6
Recommendations on the use and specification of variables in forensic experiments on vertebrate scavenging and/or animal induced scattering.

Recommended variables	Details
Location	
Environment	Note the country with coordinates, and whether the area is e.g. forest, grassland, agricultural etc., give details on vegetation, animal species, nearby human infrastructure etc., or reference to a publication with the details
Climate	Express in abbreviations of Köppen-Geiger climate classification system
Land use	Note the land use before (and if applicable, during) the experiment
Temporal data	
Study duration	Express study length e.g. in days and/or months, include the starting and ending date
Season	Mention month, season, and hemisphere
Specimen	
Carcass type and parts	Be consistent with carcass type. Note the species and body parts
Weight	Stay within a small weight range for the specimens. Note weight for every carcass. Attempt to use carcasses of weights emulating adult humans (e.g. 50–100 kg)
Sample size	At least three specimens per trial, plus same amount of negative controls. Differentiate between total number and specimens per trial
Treatment	
Cause of death	Note in detail. For gunshots, note the location; for natural death, discuss the most likely causes; for termination, note the drug; for accidents, note sustained injuries etc.
Handling	Describe how and for how long the sample was handled between death and deposition, e.g. cooling, freezing, storage, autopsy, etc.
Clothing	Ideally use clothed and unclothed carcasses. Note the presence/absence and type of clothing. Tailor clothing to fit carcass
Setup	
Cage	Note the presence/absence and type of cages, including material and mesh size
Enclosure	Note the presence/absence and type of enclosure, including distance to carcass(es), material and mesh size
Inter-carcass distance	Keep at least 30 m distance between carcasses, ideally 50 m. Note distance between specimens
Scavenger habituation	Discuss whether there is potential scavenger habituation (e.g. previous experiments or subsequent trials at location) and its relevance for the outcome
Documentation	
Use of cameras	Note the use and type of recording material: photography and/or video. Motion-sensitive, time lapse, 24 h video, 12 h daylight video etc. If purpose-built camera traps are used, the settings should also be included (e.g. sensitivity setting, rearming interval, recording durations [for video], single/burst mode [for photography])
Site visits	Keep site visits to a minimum. Describe the frequency of in person visits, including number of persons and time spent per specimen. Describe if and why frequency was changed. Note invasive (e.g. weighing) and non-invasive (e.g. photographs) data collection; where the latter are employed, the frequency of site visitation for changing batteries and/or downloading memory cards should be stated
Decomposition parameters	Use ADD and TBS, and/or other methods if necessary other methods. Note parameters used and provide raw data
Species identification	Try to identify the species present at a carcass

standardised protocols where possible. According to Simmons [13], a robust experiment requires a reasonable sample size to ensure tenable statistical analysis, a design to test a single variable, controls, initially determined data collection protocols, and repeated trials under equivalent conditions. Albeit the lack of protocols in forensic taphonomy, researchers could employ recommendations of related research areas, such as ecology or medicine. For instance, Kilkenny et al. [137] provide the "ARRIVE guidelines" for reporting in vivo animal studies, which can well be applied to postmortem experiments.

Ecological literature is insufficiently incorporated in forensic taphonomy and we highly recommend to refer to related disciplines for concept ideas, study design or background information [182,183]. Although, carrion ecology experiments often study small specimens, their environment descriptions are more detailed, their sample sizes are generally larger and the emphasis frequently lies on the scavenger behaviour. We propose to draw upon these concepts for forensic purposes.

We have found that the presentation of raw data is unusual when reporting taphonomy experiments. Whenever possible and reasonable, authors should seek to include the raw (cleaned) data so that follow-up studies can extract the specifications needed. Different emphases require different data, and the needed information may not be displayed in a text-based study, preventing a proper synthesis. We present recommendations on experimental design and research reporting, specifically aimed at scavenging and scattering taphonomy experiments in Table 6.

CRediT authorship contribution statement

Lara Indra: Conceptualization, Investigation, Formal analysis, Methodology, Visualization, Writing - original draft. **Sandra Lösch:** Resources, Supervision, Writing - review & editing. **David Errickson:** Conceptualization, Supervision, Writing - review & editing. **Devin Finaughty:** Methodology, Supervision, Investigation, Visualization, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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