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Anthropology

Portion size matters: Carrion ecology lessons for medicolegal death investigations—A study in Cape Town, South Africa

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Abstract

Forensic taphonomic studies are regionally specific and improve time since death estimates for medico-legal casework. Within forensic taphonomy and carrion ecology, vertebrate scavengers are under-researched with many studies conducted using multiple, unclothed carcasses. This is a forensically unrealistic experimental design choice with unknown impact. The effect of variation in carrion biomass on the decomposition ecosystem, particularly where vertebrate scavengers are concerned, requires clarification. To assess the effect of carrion biomass load on vertebrate scavenging and decomposition rate, seasonal baseline data for single, clothed ~60 kg porcine carcasses were compared to clothed multiple-carcass deployments, in a forensically relevant habitat of Cape Town, South Africa. Decomposition was tracked via weight loss and bloat progression and scavenging activity via motion-activated cameras. The single carcasses decayed more quickly, particularly during the cooler, wetter winter, strongly correlated with concentrated Cape gray mongoose (*Galerella pulverulenta*) scavenging activity. On average and across seasons, the single carcasses lost 68% of their mass by day 32 (567 accumulated degree days [ADD]), compared to 80 days (1477 ADD) for multi-carcass deployments. The single carcasses experienced substantially more scavenging activity, with longer visits by single and multiple mongooses, totaling 53 h on average compared to 20 h for the multi-carcass deployments. These differences in scavenging activity and decay rate demonstrate the impact of carrion biomass load on decomposition for forensic taphonomy research. These findings need corroboration. However, forensic realism requires consideration in taphonomic study design. Longitudinally examining many single carcasses may produce more forensically accurate, locally appropriate, and usable results.

KEYWORDS
Cape Flats Dune Strandveld, Cape Town, carrion ecology, decomposition, post-mortem interval, scavenging, taphonomy

This paper is based on research conducted for a PhD thesis: Spies MJ. The effect of clothing and carrion biomass load on decomposition and scavenging in a forensically significant thicketed habitat in Cape Town, South Africa. [PhD Thesis]. Cape Town: University of Cape Town; 2022. Available from: http://hdl.handle.net/11427/37810.

Highlights

- Vertebrate scavengers can impact decay rate and post-mortem interval estimates in medico-legal investigations.
- Taphonomic studies often employ multiple carcasses simultaneously.
- Increased carrion availability affects scavenger behavior and decay rate.
- Single individuals are more common in forensic casework.
- Longitudinal studies of multiple single, clothed carrion sources are advised.

1 | INTRODUCTION AND BACKGROUND

Forensic taphonomic research is increasingly focused on the quantification of methods for estimating the post-mortem interval (PMI). This shift was precipitated by precedent-setting court cases outlining the scientific evidence considered valid and admissible in court, leading to the creation of the 'Daubert Standards' in the USA [1]—standards that have been widely adopted, statutorily or in principle. These standards demand quantification of the experimental data that predictive models are based on to ensure statistical robusticity and demonstrate method reliability, precision, and the known/potential error rate [2]. Therefore, in forensic taphonomic research, it has been recommended (and is common practice) to deploy multiple carrion sources simultaneously, as replicates ensure repeatability and quantification [3]. In Cape Town, South Africa, like elsewhere, research conducted by Finaughty from 2014 to 2016 [4] utilized an unclothed multi-carcass experimental design for the establishment of baseline soft-tissue decay rates for this forensically relevant biogeoclimatic setting. This drive for statistical reliability and reproducibility meets scientific standards. However, are multiple unclothed bodies forensically realistic? Apart from disaster situations, large numbers of unclothed individuals are not common forensic scenarios. We turn to carrion ecological theory to help address this question.

The work of Baruzzi et al. [5] suggests that multi-carcass deployments (single or successive), commonly utilized in forensic taphonomy, may alter the ecosystem by increasing carrion biomass above baseline levels. Small, short-lived facultative vertebrate scavengers with restricted home ranges perceive carrion deposition as ephemeral nutrient pulses varying in temporal and spatial availability [6, 7]. Increased frequency or magnitude of carrion pulses often causes increased vertebrate scavenger activity and species variety [8]. Vertebrate scavengers are highly impactful biotic drivers of carrion decomposition [8–15]. Thus, knowing the local scavenger guild, its activity, and its influence on local decomposition patterns are all critical in a forensic context. Failure to account for their activity may skew estimates of PMI. Additionally, recovery efforts can be confounded by scavenger-induced skeletal scattering, and damage to soft and hard tissues can be misinterpreted as peri- or post-mortem trauma, hindering identification. As a result, forensic taphonomists have increasingly called for the consideration of the potential effects of vertebrate scavengers when evaluating decomposition [16–20]. Of importance is the increased incorporation of the knowledge and theory from carrion ecology into taphonomic experimental design and interpretation [21, 22].

Multi-carcass deployments, and the increased carrion biomass they represent, invariably provide scavengers with several carrion options and may influence the behavior of the local vertebrate scavenger assemblage. For example, the increased carrion availability may attract more scavengers than a single resource would, or scavengers may be 'swamped' by the abundant carrion, dividing their time between carcasses and not fully utilizing each individual carcass to the extent they might have otherwise [15, 23, 24]. Either scenario would inevitably alter the baseline decomposition rate and, thus, the experimental design and purpose of such forensic taphonomic studies.

In Cape Town, the incidence of single, clothed individuals found on the surface in forensic cases is the norm [25, 26]. Therefore, recent research has focused on the effect of seasonally appropriate, common, casework-derived clothing on decomposition in Cape Town [15]. The initial results of this study, using a multi-carcass, clothed versus unclothed deployment, demonstrated that scavengers had an overwhelming preference for unclothed carrion, ostensibly due to greater tissue access. This led to some pressing questions: would the pattern and extent of scavenger-driven decomposition change appreciably if a single, clothed carrion source were available, as would be realistic in most local circumstances? If so, would these patterns vary with the season? Answers would not only inform forensic research but also carrion ecology, given the uncertainty regarding the effect of varied carrion biomass loads (e.g., Ref. [27]). Therefore, this study was designed to assess the impact of carrion biomass load on decomposition and vertebrate scavenging by comparing single and multiple clothed carcasses in both summer and winter settings in Cape Town, South Africa.

2 | MATERIALS AND METHODS

This research had four deployments with a total of 10 domestic pig carcasses (*Sus scrofa domesticus*), ~60 kg each. These were conducted from 2018 to 2020. The first two deployments had four carcasses each (two clothed and two unclothed). Only the clothed carcass data are analyzed here. The second two deployments consisted of a single clothed carcass each and were conducted to provide seasonal comparisons to assess the possible impact of varying carrion biomass on decomposition rate. The first and third deployments were carried out during the colder and wetter winter months (June–September), continuing into spring, whereas the second and fourth deployments began in the hotter and drier summer months (November–February), continuing into autumn. Additional comparative data were used, derived from an unpublished pilot study of a single, clothed winter carcass conducted by Du Toit [28] under the same conditions.

All deployments were carried out in the thicketed environment within the South African Medical Research Council's secure research facility in Delft, Cape Town, South Africa. This region is densely populated, with crime-ridden pockets, and is forensically relevant: a considerable proportion of forensic cases originate from this general area, as the dense thickets are used for the disposal and concealment of human remains [26]. Carrion was placed ~20–30 m away from other carcasses or previously used locations, under similar dappled shade conditions. The carcasses were clothed in inexpensive, seasonally appropriate, primarily cotton-type clothing specifically tailored to ensure an appropriate fit. The clothing choice was informed by local forensic casework, serving as a forensically realistic barrier for vertebrate and invertebrate activity. In the winter deployments, this comprised underwear, denim jeans with a leather belt, a cotton T-shirt, a pull-over jersey, socks, and shoes. In summer, the jersey, socks, and shoes were omitted. Further details on the choice of research location, the choice of clothing, and the tailoring methodology can be found in Spies et al. [15].

The pigs were terminated by a 0.22 caliber long rifle gunshot to the base of the brain (Faculty of Health Sciences Animal Ethics Committee, University of Cape Town: AEC 018_023). This is a rapid and humane method of life termination, which met the study needs; the small caliber bullet ensured little physical damage to the carcass, and no potential contaminants of unknown impact were introduced such as with a lethal injection. Additionally, the small entry wound is quickly clogged with clotted blood and does not form an orifice of attraction to accelerate the oviposition of blowflies [13].

2.1 | Data collection

Weather data were recorded via the on-site Davis Vantage Pro 2 weather station, and accumulated degree days (ADD) were calculated based on daily ambient temperatures. Scavenger activity was monitored via motion-activated infrared trail cameras (camera traps; models Primos ProofCam 3, Bushnell Trophy Cam 119436, and Foxelli Oak's Eye 2). In addition to the standard fixed overhead camera capturing static photography, auxiliary camera traps were deployed adjacent to the carrion to record video footage, to ensure data redundancy. Camera trap data were processed using Timelapse2 [29]. Measurements of the starting weight, snout-to-tail length, and shoulder height were taken for each of the carcasses.

Qualitative visual decomposition scoring was used to estimate the onset and end of bloating in the head and neck of each carcass from photographs, using the method developed by Keough et al. [30] as a guide. Evidence of bloat onset was confirmed via an increase in the width of the neck (not obscured by clothing) by at least 1 cm compared to day 1, measuring from approximately the middle of the throat perpendicularly to the back of the neck. This was done digitally, using freely available software, ImageJ, with the 10 × 10 cm metal grid used to calibrate the pixels per centimeter factor for each photograph.

Quantitative tracking of decomposition progression was achieved via measurement of daily carcass weight loss. In the first two cycles, this was accomplished by the manual use of a block and tackle, as described in Spies et al. [15], but replaced with an automated weighing apparatus in the latter two cycles [31–33]. Decomposition was deemed static, and data collection was terminated when all carcasses reached skeletonization [34] or the weekly accumulated carcass weight loss declined to below 5% of the original weight value for three consecutive weeks.

2.2 | Data analysis

Individual scavenging visits were defined by an absence of at least 10 min between visits. Analyses included *t*-tests to assess differences in weather variables and Kruskal–Wallis tests to identify possible sample confounders. Data on weight loss and scavenger activity and behavior were numerically and graphically compared. Inferential statistical analyses were conducted, and graphs were generated using RStudio v1.4.1106.

3 | RESULTS

An integrative approach was applied to assess the impact of carrion biomass load on vertebrate scavenging and decay rate in seasonally appropriate clothing, commonly found in local casework and tailored to fit appropriately. These results are divided into four sections: seasonality, decomposition, scavenging, and a comparison of two single carrion deployments under similar conditions.

3.1 | Seasonality

The first winter deployment (#1) began on August 24, 2018, and was terminated on January 10, 2019, lasting 140 days. The first summer deployment (#2) began on January 14, 2019, terminating on April 14, 2019, lasting 91 days. The subsequent cycles followed a similar pattern as close in date as logistically feasible. The second winter deployment (#3) began on September 2, 2019, ending on December 9, 2019, after 100 days. The second summer deployment (#4) began on January 13, 2020, and was terminated after 71 days on April 23rd, 2020. The average weather variables are available in Table S1.

The winter deployments were, on average, significantly colder by 3°C with a 24-h mean temperature of 18°C compared to 21°C for the summer deployments ($p = 0.000$). Deployment 2 recorded the highest maximum ambient air temperature of 38.60°C, and Deployment 1 had the lowest ambient air temperature of 3.40°C.

The seasonal difference in precipitation was statistically significant; the average sum of winter rainfall over 24h was 0.5mm more than in summer ($p=0.001$). In winter, the mean cumulative rainfall was 71mm compared to a mean of 11mm in summer.

Comparing interannual variation in weather variables between deployments in the same season revealed differences. In winter, the first deployment had a significantly higher 24-h maximum temperature ($p=0.020$) and accumulated rainfall ($p=0.021$) compared to the second winter deployment. The first winter deployment also had a significantly lower windspeed ($p=0.000$), but greater daytime solar radiation ($p=0.000$) and night-time rainfall ($p=0.004$). In contrast, the first summer deployment had a significantly lower 24-h minimum temperature ($p=0.002$) and windspeed ($p=0.000$), and greater daytime solar radiation ($p=0.000$) compared to the second summer deployment.

3.2 | Decomposition

Carcass dimensions were tested for significant differences across seasons, clothing, and both season and clothing, to identify any potential confounders (Table S2). All carcasses were similar in starting weight, height, and length indicating that, as a sample, carcass size and shape are unlikely to confound the results. To benchmark the rate of decomposition across the 10 different carcasses, mass loss milestones were defined: 17%, 34%, 51%, and 68%. These were decided upon as clothed cool-weather winter-deployed carrion failed to reach the 75% mass loss milestone. Therefore, a more conventional method of sectioning in quartiles was deemed inappropriate, and the highest possible mass loss percentage (68%) met by all individuals within the sample was used. To determine the effect that increasing carrion biomass availability may have on carcass mass loss, the analyses were completed using data only from clothed carcasses.

Regardless of the season, there was a noticeable overall difference in mean weight loss rate between the single and multi-carcass deployments (see Figure 1). In winter, the single carcass lost weight more rapidly with an appreciable difference in trajectory. The difference was less pronounced in summer, but the single carcass still showed an immediate sharp decline in weight, without the initial lag present in the multi-carcass summer mean. Both single, clothed carcasses plateaued earlier in the cycle, but with slightly more residual weight in summer, compared to the multi-carcass counterparts.

The onset and duration of bloat in the head and neck were influenced by carrion biomass load, with data presented in Table 1. The single carcasses began to bloat in the head and neck earlier on average, starting on day 4 with a shorter mean duration of 6days, compared to the multi-carrion deployments, which first showed evidence of bloat on day 10 and lasted 20days on average. In winter, this numerical difference was exaggerated, but in summer, the two groups were more similar.

Table 2 adds further detail to Figure 1. The two single carcasses took on average 8days to reach 17% mass loss, compared to an average of 25days for the multi-carcass deployments; 13days versus 36 to reach 34% loss; 17days versus 47 to reach 51% loss; and 32days versus 80days to reach 68% mass loss. Similarly, the single carcasses required less accumulated thermal energy, as measured by ADD, to reach each percentile, also presented in Table 2. Despite these differences, the average percentage of weight lost by the end of the cycle was very similar; 75% for the single carcasses compared to 76% in the multi-carcass deployments.

When split by season, the single winter carcass experienced 17% mass loss in 13days compared to an average of 41days for the multiple winter-deployed carcasses; 20days versus 60 to reach 34% loss; 24days versus 80 to reach 51% loss; and 45days versus 140 to lose 68% of their mass (Table 2). The comparison of accumulated thermal energy followed a similar pattern, with large differences in ADD values between the single and the multiple carrion sources in winter deployments. In summer, the number of days and ADD to reach mass loss percentiles were similar across deployments. However, the single carcass was still the quickest, with only 3days to reach 17% mass loss compared to 9 for the multi-carcass mean; 6days versus 11 to reach 34% loss; 10days versus 14 to reach 51% loss; and 18days compared to 20days to lose 68% mass. Similarly, in summer, the decomposition of the single carcass required less accumulated thermal energy than the multi-carcass deployment.

3.3 | Scavenging

Scavenging was observed in every deployment and on all carcasses: the Cape or small gray mongoose (*Galerella pulverulenta*) was the only vertebrate scavenger species observed. Some avian species, such as the Cape robin-chat (*Cossypha caffra*), common starling (*Sturnus vulgaris*), hadeda ibis (*Bostrychia hagedash*), Cape francolin (*Pternistis capensis*), red-eyed dove (*Streptopelia semitorquata*), and southern double-collared sunbird (*Cinnyris chalybeus*), along with an unconfirmed species of field mouse and a domestic cat (*Felis catus*), visited the carrion briefly and infrequently without discernible scavenging activity. Presumably, these animals were simply inquisitive or attracted to the concentrated insect populations and were not considered in further analyses. The Cape robin-chat was the most frequent avian species to visit the carrion and was photographed swooping above the remains to catch flies. Video and photographic evidence depict the mongoose as the only animal to feed on carrion. Photographs captured up to four mongooses simultaneously on and around one carcass.

The mongoose activity occurred diurnally (between civil dawn and civil dusk), with one exception: a short visit was observed in the early morning hours to clothed carcass 1 in the Winter 2019 deployment (C1-W19). The average pattern of scavenging was initially similar across all carrion, with activity beginning near the head, on the mouth, nose, eyes, or ears, usually occurring within a few hours on the first deployment day. Next, scavenging occurred anew at the abdomen with the clothing retracted up towards the head.

Across all carcasses, typical mongoose feeding behavior involved stripping out subcutaneous fat and muscle and fresh viscera from beneath the skin, often resulting in the tissue being pulled out of

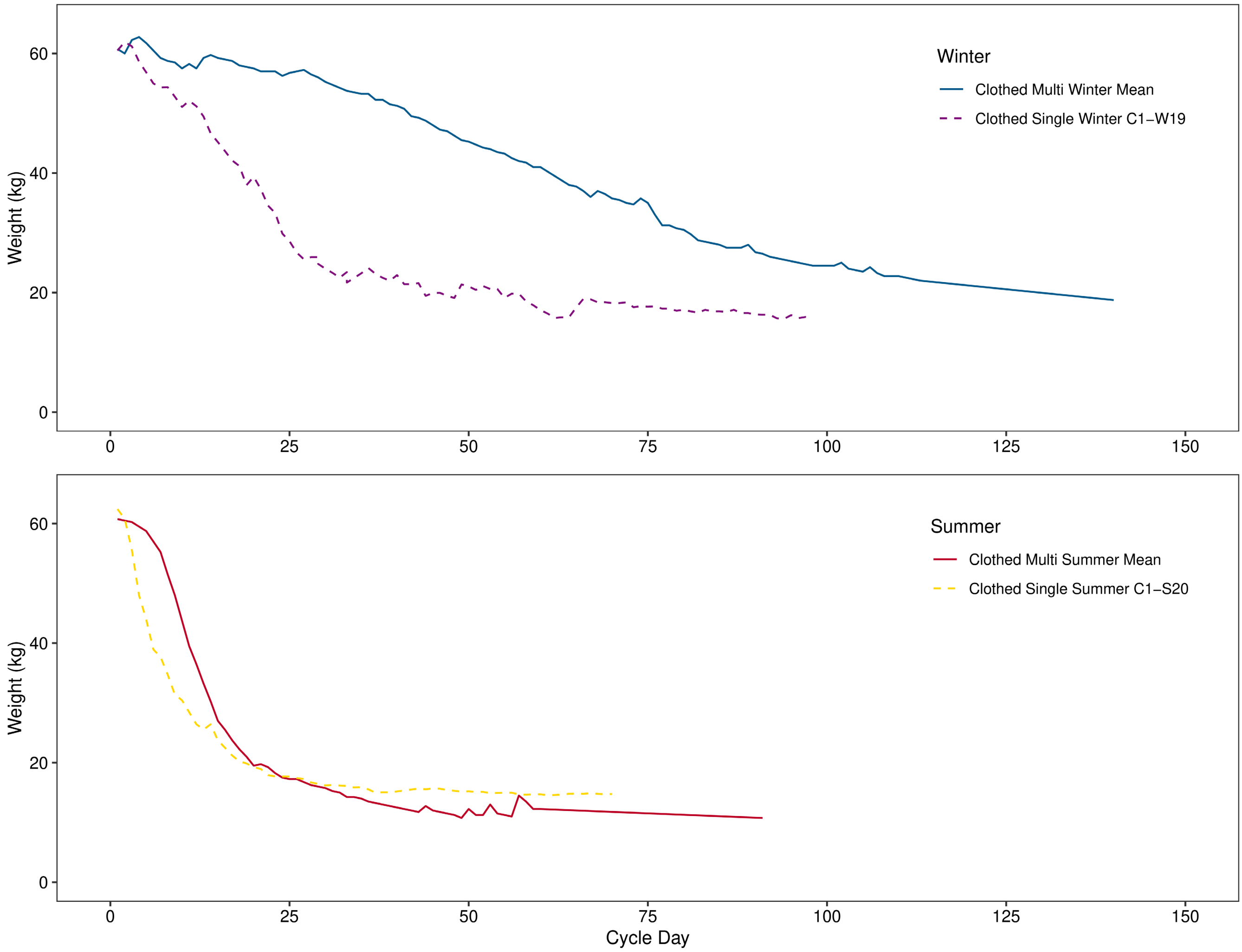

FIGURE 1 Weight loss plotted over time for clothed single carcasses and means for clothed multi-carcass deployments in winter (top panel) and summer (bottom panel). 19/20 = year of deployment; C, clothed; S, summer; W, winter.

TABLE 1 The start, end, and duration of bloat in the head and neck, measured in days, for clothed single and multiple carcass deployments per season.

Deployment	Measure	Bloat start	Bloat end	Duration
Single carcasses	Winter	5	15	10
	Summer	2	4	2
	Mean	4	10	6
Multi-carcass mean	Winter	17	52	35
	Summer	4	9	5
	Mean	10	30	20

the abdominal cavity. Although feeding on the skin itself did occur, it was often left comparatively intact and was either burrowed under or pulled with paws and mouth to widen an opening, resulting in sections of skin dehydrating and adhering to underlying skeletal tissue. Limited scattering of skeletal elements beyond the immediate vicinity of the carcasses was observed: C1-W19 was the only carcass that was scattered. Specifically, the hoof of the left hindlimb was removed and dragged ~7 m to the southeast into denser vegetation. The shoe was previously removed by mongoose activity, but the hoof remained within the sock.

Table 3 shows that single carcasses had an average total mongoose visit number of 384 compared to 320 visits for the multi-carcass mean. However, within individual mass loss percentiles, there was more variability, with a mean of 103 mongoose visits for the single carcasses before 17% mass loss compared to 142 visits for the multi-carcass mean; 64 versus 54 visits to reach 34% loss; 39 versus 33 visits to reach 51% loss; and 92 versus 26 visits to reach 68% mass loss. When assessed by season, the variation in mongoose visit number across the mass loss percentiles was similar between single and multiple carcasses in winter. In summer, the single carcass mongoose visits were more equally distributed across the mass loss percentiles than the multi-carcass deployment, which had a concentration of visits in the first 17% mass loss.

The total mean mongoose visit duration, also displayed in Table 3, shows mongooses spent over double the total time on

TABLE 2 Number of days and accumulated degree days (ADD) in parentheses to reach mass loss percentiles for clothed single and multiple carcass deployments per season.

Deployment	Season	17% Mass loss	34% Mass loss	51% Mass loss	68% Mass loss	Total	Final % mass loss
Single carcass	Winter	13 (204)	20 (319)	24 (380)	45 (741)	99 (1739)	73.81
	Summer	3 (74)	6 (144)	10 (227)	18 (393)	70 (1495)	76.61
	Mean	8 (139)	13 (231)	17 (304)	32 (567)	85 (1617)	75.21
Multi-carcass mean	Winter	42 (558)	60 (906)	81 (1285)	140 (2512)	140 (2512)	69.14
	Summer	9 (174)	11 (227)	14 (295)	20 (441)	91 (1886)	82.30
	Mean	25 (366)	36 (567)	47 (790)	80 (1477)	116 (2199)	75.72

TABLE 3 Mongoose visit number and duration (h:m:s) in parentheses by percentile for clothed single and multiple carcass deployments per season.

Deployment	Season	17% Mass loss	34% Mass loss	51% Mass loss	68% Mass loss	End	Total
Single carcass	Winter	159 (43:35:44)	98 (12:32:11)	24 (1:01:21)	46 (1:57:12)	64 (1:08:45)	391 (60:15:13)
	Summer	46 (11:37:27)	29 (9:02:52)	53 (5:36:00)	138 (13:52:29)	111 (6:27:15)	377 (46:36:04)
	Mean	103 (27:36:35)	64 (10:47:31)	39 (3:18:41)	92 (7:54:50)	88 (3:48:00)	384 (53:25:38)
Multi-carcass mean	Winter	186 (19:33:00)	84 (2:04:18)	48 (0:34:26)	34 (0:12:50)	0 (0:00:00)	351 (22:24:34)
	Summer	99 (9:47:57)	24 (1:59:41)	19 (1:23:17)	19 (0:34:30)	129 (3:14:07)	288 (16:59:32)
	Mean	142 (14:40:29)	54 (2:02:00)	33 (0:58:51)	26 (0:23:40)	65 (1:37:03)	320 (19:42:03)

Abbreviation: h:m:s, hours:minutes:seconds.

the single carcasses with a mean of 53 h compared to 20 h for the multi-carcass deployments. Per weight loss percentile, single carcasses were visited consistently longer on average than the multi-carcass deployments. When examining mongoose visit duration by season, we see substantial differences between single and multi-carcass deployments in winter, again with longer durations for single carcasses. Although not as prominent as in winter, the single summer carcass similarly experienced a greater visit duration across all milestones than that for the multiple summer-deployed carcasses.

The mongoose activity data are visually depicted in Figure 2. This figure indicates the average visit number was somewhat similar between deployments, although considerably more time was spent on the single carcasses, regardless of the season. It also illustrates the distributed nature of mongoose activity to the single summer carcass throughout the decomposition cycle. More visits of longer duration continued later into the summer cycle compared to the single winter carcass or both multi-carcass deployments.

Simultaneous scavenging by multiple mongooses occurred for a longer duration and contributed a greater proportion of the total visit duration in single carcass deployments, as presented in Table 4, with the most simultaneous activity shortly after deployment. Single carcasses experienced a mean total multi-mongoose scavenging duration of 6 h (12% of total time) compared to a mean of only 49 min (5%) for the multi-carcass deployment. The summer cohort received more simultaneous attention from multiple mongooses; this was exaggerated for the single carcass, which received a total multi-mongoose visit duration of 10 h (22%) compared to a mean of 2 h (10%) for the summer multi-carcass deployment. In contrast, 2 h (3%) was recorded for the single winter carcass and a mean of only 4 min (<1%) for the multi-carcass winter deployment. A similar pattern of little to no activity by multiple mongooses was observed throughout the decomposition cycle for both winter groups, despite the single carcass receiving more activity in total.

3.4 | Comparative analysis

The single, clothed winter carcass data were compared with that collected by Du Toit [28]. In general, the weather experienced by the Du Toit carcass was significantly colder and more humid, with less solar radiation and wind but with greater atmospheric pressure. These differences and their significance values are presented in Table S3.

The line plots in Figure 3 provide a visual comparison of the rate of weight loss experienced by the various cohorts of winter carrion, including Du Toit's carcass, which lost weight more gradually, at a rate relatively like the multi-carcass deployment of the present study. In contrast, the single, clothed carcass from the current investigation (C1-W19) decayed more rapidly. The rate of weight loss for Du Toit's carcass is presented in Table 5. The single clothed winter carcass from the present study progressed more rapidly through the percentiles, requiring 13 days to lose 17% of its weight compared to 23 days for Du Toit's single carcass; 20 days versus 45 to reach 34% loss; 24 days versus 71 to reach 51% loss; and only 45 days compared to 85 to reach 68% mass loss. Similarly, less accumulated thermal energy was required to progress to each mass loss milestone.

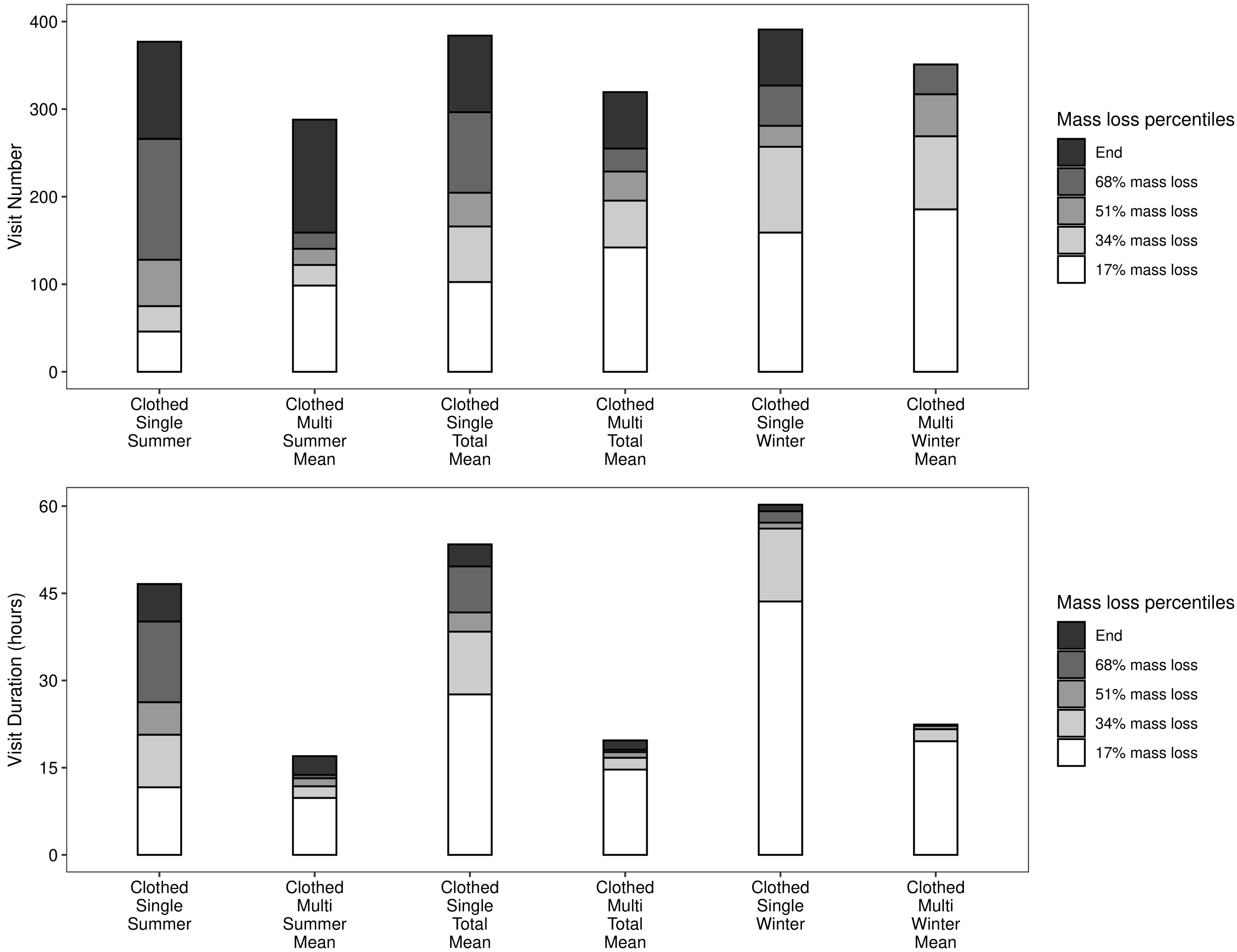

FIGURE 2 Number of mongoose visits (top panel) and visit duration (bottom panel) to reach mass loss percentiles for clothed single and multi-carcass deployments by season.

TABLE 4 Multi-mongoose visit duration (h:m:s) and percentage in parentheses by percentile for clothed single and multiple carcass deployments per season.

Deployment	Season	17% Mass loss	34% Mass loss	51% Mass loss	68% Mass loss	End	Total
Single carcass	Winter	01:21:25 (3%)	0:07:42 (1%)	0:00:00 (0%)	0:00:00 (0%)	0:02:49 (4%)	01:31:56 (3%)
	Summer	03:11:01 (27%)	01:38:37 (18%)	01:39:20 (30%)	02:41:27 (19%)	01:09:36 (18%)	10:20:01 (22%)
	Mean	02:16:13 (15%)	0:53:09 (10%)	0:49:40 (15%)	01:20:44 (10%)	0:36:13 (11%)	05:55:59 (12%)
Multi-carcass mean	Winter	0:01:05 (<1%)	0:00:00 (0%)	0:02:53 (17%)	0:00:00 (0%)	0:00:00 (0%)	0:03:58 (<1%)
	Summer	01:00:52 (11%)	0:17:05 (11%)	0:03:59 (5%)	0:02:35 (10%)	0:10:38 (8%)	01:35:09 (10%)
	Mean	00:30:58 (5%)	0:08:32 (5%)	0:03:26 (11%)	0:01:18 (5%)	0:05:19 (4%)	0:49:34 (5%)

Abbreviation: h:m:s, hours:minutes:seconds.

Regarding scavenging activity, the mongoose feeding pattern was similar, with some slight differences. Feeding began near the mouth and ears and then moved to the abdomen. The concealed flesh of the abdomen was exposed by retraction of the shirt and jersey, breaking the skin to feed on flesh and subcutaneous fat. Mongooses then fed on the visceral tissue, until the spinal column was exposed. Scavenging then began at the head region where, once largely skeletonized, feeding continued into the shoulder region by again pushing the clothing out of the way. The scavenging activity caused the dislocation of the right forelimb and hoof. The hind limbs remained mainly untouched, excluding the movement of a shoe and a disarticulated hoof. Most of the exposed skin was consumed.

There were, however, some stark differences in the frequency and duration of mongoose activity between C1-W19 and Du Toit's carcass.

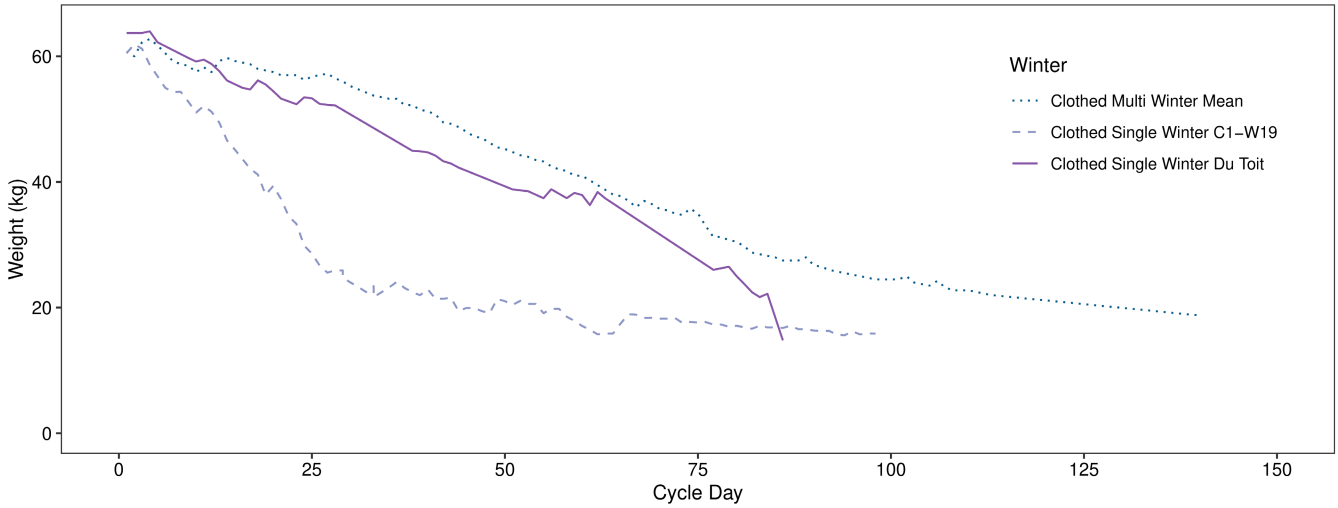

FIGURE 3 Weight loss plots over time for the winter clothed single carcass, comparative single clothed carcass studied by Du Toit [28], and means for the clothed multi-carcass deployment. 19, year of deployment; C, clothed; S, summer; W, winter.

TABLE 5 Number of days and accumulated degree days to reach mass loss percentiles for the single, winter carcass (C1-W19) and Du Toit's [28] comparative single, clothed carcass.

Measure	Deployment	17% Mass loss	34% Mass loss	51% Mass loss	68% Mass loss	Total	Final % mass loss
Days	C1-W19	13	20	24	45	99	73.81
	Du Toit	23	45	71	85	85	68.00
ADD	C1-W19	203.56	318.91	380.12	740.92	1738.58	73.81
	Du Toit	297.78	584.19	905.37	1096.65	1107.12	68.00

Note: 19 = year of deployment.
Abbreviations: C, clothed; W, winter.

Du Toit's was also only scavenged by the Cape gray mongoose, but it received comparatively more visits of longer duration. Table 6 provides the mongoose visit number and duration, along with the multi-mongoose visit duration and percentage. There were 159 mongoose visits to C1-W19 compared to 249 visits to Du Toit's carcass before 17% mass loss; 98 versus 274 visits to reach 34% loss; 24 versus 227 visits to reach 51% loss; 46 versus 51 visits to reach 68% loss; and a total of 391 mongoose visits to C1-W19 versus 802 visits to Du Toit's carcass across the study cycle. Visit duration was less for C1-W19, with a duration of 43 h compared to 59 h for Du Toit's until 17% mass loss; 12 versus 34 h to reach 34% loss; 1 versus 23 h to reach 51% loss; 2 h versus 1 h to reach 68% loss; and a total of 60 h for C1-W19 compared to 117 h Du Toit. The multi-mongoose visit duration for C1-W19 was 1 h (3%) compared to 8 h (13%) for Du Toit's carcass up to 17% mass loss; 8 min (1%) versus 5 h (15%) to reach 34% loss; 0 min (0%) versus 7 h (30%) to reach 51% loss; 0 min (0%) for both carcasses to reach 68%; for a total of 1.5 h (3%) versus 19.5 h (17%) over the total deployment.

4 | DISCUSSION AND CONCLUSION

Olea et al. [35] lamented the scant attention paid to the complexities of decomposing animal-derived organic material (carrion biomass), at both the local and ecosystem level. This is surprising as carrion is often the largest contributor to necromass in non-forested ecosystems [36]. In 2019, a unified framework for studying and interpreting the ecological interactions surrounding necromass was proposed [36], highlighting the disjointed and descriptive-heavy nature of the research enterprise to date—a disconnect that has hindered progress and the extension of the knowledge to applied disciplines such as forensic taphonomy. Although the use of large sample studies is a common and recommended practice in taphonomy studies to align with the standards of best practice established by the Daubert guidelines and those of Henssge and Madea [2], these appear, at first glance, to conflict with carrion ecological theory and forensic realism in experimental design. Specifically, many (if not most) forensic cases involve single, clothed decedents [25, 26], so large samples for taphonomic study do not accurately represent common forensic scenarios. Therefore, the objective of this research was to assess the impact of carrion biomass load on the behavior of vertebrate scavengers and the downstream effects on the rate and process of soft-tissue decomposition in a local forensically relevant habitat and context. This was achieved by comparing baseline data for single and multiple clothed pig carcasses in both summer and winter settings in a thicketed environment in Cape Town, South Africa. The discussion is separated into two parts, focusing on decomposition and

TABLE 6 Mongoose visit number and duration (h:m:s) by mass loss percentiles for the single, winter carcass (C1-W19) and Du Toit's [28] comparative single, clothed carcass.

Measure	Deployment	17% Mass loss	34% Mass loss	51% Mass loss	68% Mass loss	End	Total
Visit number	C1-W19	159	98	24	46	64	391
	Du Toit	249	274	227	51	1	802
Visit duration	C1-W19	43:35:44	12:32:11	1:01:21	1:57:12	1:08:45	60:15:13
	Du Toit	59:17:29	34:13:20	22:46:16	1:17:09	0:00:02	117:34:16
Multi-visit duration	C1-W19	1:21:25	0:07:42	0:00:00	0:00:00	0:02:49	1:31:56
	Du Toit	7:47:57	4:58:47	6:45:02	0:00:00	0:00:00	19:31:46
Multi-visit percentage	C1-W19	3	1	0	0	4	3
	Du Toit	13	15	30	0	0	17

Note: 19 = year of deployment.

Abbreviations: C, clothed; h:m:s, hours:minutes:seconds; W, winter.

scavenging, with comparisons of weather and season within each subsection. This is followed by the study's limitations and future recommendations.

4.1 | Decomposition

As observed previously, both the total body score (TBS)-ADD methods developed by Megyesi et al. [37] and Moffatt et al. [38] are potentially inaccurate for the Western Cape and other parts of South Africa [39, 40]. A correction for scavenger activity and TBS scoring for clothed individuals would be required to assess the decay rate via a visual scoring method. Therefore, decomposition was quantitatively assessed via daily weight loss. A considerable difference in decomposition rate was found, as measured by mass loss and the onset and duration of bloat, depending on the availability of carrion: in the same season, single carrion sources decomposed quicker than multiple sources deployed simultaneously. We argue this could be ascribed to the combined influence of vertebrate and invertebrate scavenging activity and was especially evident in the colder, wetter winter season. The single winter carcass decayed substantially faster despite the multi-carcass winter deployment experiencing a significantly higher maximum temperature and more solar radiation, along with other differences like more rain and less wind—all of which are typically associated with more rapid biotic agent-driven decay, leading one to assume the multi-carcass deployment should have decayed more quickly.

The weather differences between deployments may be the result of variations in interannual, within-season weather. This is highlighted by the comparison between the single winter carcass investigated in this study (C1-W19) and that of Du Toit [28]. Here, distinct differences in decomposition rate were observed—Du Toit's single, clothed carcass did not proceed as quickly through the mass loss milestones as C1-W19 and was more similar to the multi-carcass decay rate. However, Du Toit's carcass was deployed earlier in the colder part of the year, and experienced significantly colder and more humid weather, with less solar radiation and wind. Differences in weather are known to substantially alter the decomposition process, which likely contributed to the difference in decay rate between these two similar deployments. Therefore, although carrion biomass load impacts the decay rate, the current weather, not just the season, can modulate this effect. Both the timing of deployment and interannual seasonal differences in weather require careful consideration when comparing different deployments and designing experiments.

In the hotter and drier summer, the weight loss curves, measures of bloat, and the number of days and ADD to reach mass loss percentiles for both single and multiple carcasses were more similar, as summer decomposition progresses rapidly in this environment, regardless of the carrion biomass availability. However, the summer weight loss chart still demonstrates a noticeable difference between single and multi-carcass deployments: the single summer carcass experienced a rapid decline in weight from the first day of deployment, with no evident lag phase at the beginning like that experienced by the other carcasses. Similarly, the single summer carcass experienced quicker bloat onset and shorter duration than the multi-carcass summer deployment. Interannual differences in within-season summer weather may have also contributed to differences in single and multi-carcass decay rates and patterns, as the single-carcass summer deployment had a significantly higher minimum temperature and windspeed, but less solar radiation.

The across-season mean decay rate between single and multiple carcasses showed a stark difference of 32 versus 80 days (567.21 vs. 1476.55 ADD) to reach 68% mass loss. Although preliminary, these data suggest that forgoing forensic realism in vertebrate scavenger-based taphonomic research or deploying multiple carcasses simultaneously in close proximity without a means to control scavenger access, likely alters the decay rate and can inadvertently create forensically inaccurate data.

4.2 | Scavenging

The influence of vertebrate scavenging activity is integral to the analysis of the effect of carrion biomass load on the rate and process of decomposition. For many species and biogeographic settings, we lack a detailed understanding of the inter- and intra-specific interactions between vertebrate scavengers at carrion. Worse, the vertebrate scavenger assemblages for many ecosystems remain sparsely or entirely undescribed [35]. Given the ephemeral nature of carrion, altering the availability or quality of this precious nutrient resource could alter the structure and composition of the local scavenger assemblage and result in increased or decreased scavenger attendance and species variety, or scavenger swamping, altering the decay rate of carrion (including human remains) [5, 7, 9, 23, 24, 41–43]. Multiple carrion sources near each other may also be affected by adjacent invertebrate activity preventing assumptions of subject independence [44, 45].

Although the Cape gray mongoose was the only observed scavenger, this was not unexpected; exclusive scavenging by this species has been noted in this area before [4, 13–15, 46]. This mongoose, along with other species, has also been documented in other South African contexts [24, 47–49]. The single carcasses experienced more mongoose scavenging than the multiple carcasses for each season. The duration of visits to single carcasses was substantially and consistently more than the multi-carcass deployment means; mongooses spent more than double the amount of time at single carcasses. In addition, a noticeable pattern of prolonged feeding on single carcasses was evident, as the mongoose visit number and duration for these remained high late into the cycle, compared to the more rapid decline in mongoose activity after 17% mass loss observed in the multi-carcass deployments. Single carcasses were scavenged by multiple mongooses simultaneously for a greater duration and percentage of total scavenging time compared to the multi-carcass deployments. We argue this is evidence of scavenger swamping in multi-carcass deployments, indicative of mongooses splitting their time, feeding simultaneously on individual carcasses when multiple carrion sources are present, reducing the decay rate of the relatively unscavenged carrion, and reducing the forensic accuracy of the generated data [23, 24].

Du Toit's [28] carcass experienced similar scavenging behavior but with more mongoose visits of longer duration across most of the mass loss percentiles compared to C1-W19. The increased scavenging activity present at Du Toit's carcass may be due to factors such as the mongoose breeding season and resource availability, exaggerated based on the time of year of the Du Toit deployment in late autumn/early winter. This species of mongoose breeds between June and December, with litters of one to three born from August to February, which could account for the increased early winter activity [50]. Despite the increased scavenging activity, Du Toit's carcass did not decompose the quickest, suggesting that the number and duration of visits do not directly produce an increased decomposition rate and that weather variables still play a critical role, particularly in the cooler part of the year. Additionally, the currently used definitions for visit number and duration do not exclusively represent feeding time. To facilitate the delineation of behavior and more precise measures of feeding time, a refinement to the definition of a visit is suggested, like that used by Dibner et al. [51], paired with the joint roll-out of continuous videography and still camera trap photography as the standard for experimental design when investigating scavengers.

4.3 | Limitations and future recommendations

The small sample size, chosen for forensic realism, limited inferential statistical analyses. However, a small sample was necessary to examine a potential problem in traditional taphonomic study design. To overcome this shortcoming in future research, longitudinal studies of multiple single carrion sources in replicate habitats are recommended (see Ref. [52] for detailed experimental design recommendations).

In South Africa, the use of human cadavers for taphonomic research is not currently permitted. The decomposition of an animal analogue is acknowledged to differ from that of a human, and these results are not directly applicable to human PMI estimations [53–55]. Despite this, domestic pigs are considered acceptable proxies for establishing baseline general trends [45]. This is true when the carcass is of approximately human size and weight, as there are several anatomical and physiological similarities between pigs and humans [8, 56]. Recent analysis suggests pigs will likely remain the model organism for taphonomic research, as they offer various advantages compared to human subjects, such as the ability to control for factors like disease, pathology, and age [45]. That said, validation of this study's findings with human cadavers or casework is needed.

This study contributes insight into the necrobiome and has implications for forensic taphonomic research using multi-carcass experimental designs that permit scavenging. A balance between statistical robusticity and forensic realism is required when designing future forensic taphonomic studies, especially where vertebrate scavenging is prevalent. To validate our findings and generate more comprehensive statistical analyses and modeling, longitudinal studies in cooler and warmer seasons within the habitat, and replicates thereof, are needed. The same is required in other biogeoclimatic contexts where vertebrate scavengers are active. In addition, an assessment of the extent the observed differences in decay rate would impact PMI estimations is required. Establishing more robust definitions of different types of scavenging behavior that delineate feeding from other activities in the vicinity of a carcass would facilitate better comparisons across scavenging circumstances. Furthermore, it is recommended that the forensic taphonomic research community consider the inclusion of studies where the design takes cognizance of forensic realism and scavenger ecology as part of the investigative repertoire in actualistic taphonomic research. These should ideally use forensically and seasonally realistic clothing, limit ecological disturbance as much as possible (e.g., the use of an automated decomposition monitoring system, see Refs. [31–33]), and comprise repeated deployments of single subjects, not large samples, especially in environments where scavenger-driven decomposition has been observed. The value of the lessons from carrion ecology for forensic taphonomic research and its value for sociocriminal justice cannot be overstated. Both disciplines can mutually benefit from integrated, transdisciplinary research approaches going forward.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to declare.

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