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The effect of clothing on decomposition and vertebrate scavengers in the cooler months of the temperate southwestern Cape, South Africa

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Abstract:	With research providing conflicting results from different habitats across the globe, the effect of clothing on decomposition is unclear; some studies indicating clothing increases decomposition rate by facilitating increased insect activity, and others concluding clothing prolongs the decay process. In South Africa, such research is lacking, with no data for the Western Cape Province, which suffers from a high murder rate with many unclaimed, unidentified bodies. Improving post-mortem interval (PMI) estimates will increase chances of correct forensic identification of decedents by narrowing the search window for police. Since no current PMI estimation method accounts for the possible influence of clothing, this study was designed to examine the effect of seasonally appropriate common clothing on decomposition rate in the thicketed Cape Flats Dune Strandveld, Cape Town, a forensically significant region. Four ~60 kg domestic pig carcasses (Sus scrofa domesticus) were used as proxies for human decomposition, two were clothed and two unclothed. The clothing, altered by a seamstress to ensure an appropriate fit, caused a notable decrease in decay rate in this initial sample. Daily weight loss was used as a quantitative measure of decomposition progression, as the clothing prevented the use of visual decomposition scoring systems. Weight loss was closely associated with scavenging activity by the Cape grey mongoose (Galerella pulverulenta), with a clear scavenger preference for unclothed carcasses. This suggests that the effect of clothing on decomposition may be better assessed in this environment by examining how scavengers interact with only a single clothed carcass.
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Title Page (with authors and addresses)

Dear Professor Cristina Cattaneo,

We wish to submit the following paper "The effect of clothing on decomposition and vertebrate scavengers in cooler months in the temperate southwestern Cape, South Africa" for publication as an Original Research Article in *Forensic Science International*. This work was completed at the University of Cape Town. It has not been published anywhere else nor is it being considered elsewhere for publication, nor do any of the authors have a vested or conflict of interest.

Abbreviated Title: Effect of clothing on decomposition in the Western Cape, South Africa

KEY WORDS: Post-mortem interval, Decomposition, Porcine models, Cape Flats Dune Strandveld, Cape Town

Proofs to: Dr. Victoria Gibbon, Department of Human Biology, Anatomy Building, level 5, room 5.14, Faculty of Health Sciences, University of Cape Town, Anzio Rd, Observatory 7925 Cape Town, South Africa. Tel: +27 021-650-4431 E-mail: Victoria.Gibbon@uct.ac.za

Grant declaration:

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Sincerely,

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Highlights

Decrease in porcine decomposition rate due to clothing

Cape grey mongoose (*Galerella pulverulenta*) only observed scavenger

Clear scavenger preference for unclothed carcasses

Influence of multiple carcasses may skew results

Effect of clothing may be better assessed with only one clothed carcass

Title: The effect of clothing on decomposition and vertebrate scavengers in cooler months of the temperate southwestern Cape, South Africa

KEY WORDS: Post-mortem interval, Taphonomy, Porcine models, Cape Flats Dune Strandveld, Cape Town

Abstract:

With research providing conflicting results from different habitats across the globe, the effect of clothing on decomposition is unclear; some studies indicating clothing increases decomposition rate by facilitating increased insect activity, and others concluding clothing prolongs the decay process. In South Africa, such research is lacking, with no data for the Western Cape Province, which suffers from a high murder rate with many unclaimed, unidentified bodies. Improving post-mortem interval (PMI) estimates will increase chances of correct forensic identification of decedents by narrowing the search window for police. Since no current PMI estimation method accounts for the possible influence of clothing, this study was designed to examine the effect of seasonally appropriate common clothing on decomposition rate in the thicketed Cape Flats Dune Strandveld, Cape Town, a forensically significant region. Four ~60 kg domestic pig carcasses (*Sus scrofa domesticus*) were used as proxies for human decomposition, two were clothed and two unclothed. The clothing, altered by a seamstress to ensure an appropriate fit, caused a notable decrease in decay rate in this initial sample. Daily weight loss was used as a quantitative measure of decomposition progression, as the clothing prevented the use of visual decomposition scoring systems. Weight loss was closely associated with scavenging activity by the Cape grey mongoose (*Galerella pulverulenta*), with a clear scavenger preference for unclothed carcasses. This suggests that the effect of clothing on decomposition may be better assessed in this environment by examining how scavengers interact with only a single clothed carcass.

1 Introduction

Estimation of the post-mortem interval (PMI) is a crucial element of forensic death investigations. An accurate estimate of PMI reduces the potential pool of individuals that the remains may belong to, thereby increasing the chances of correct identification [1]. It also assists with understanding the context of a criminal case (for example, when a crime may have occurred), narrowing the search window for police. In the case of a homicide, this can

be used to exclude possible perpetrators or corroborate witness testimony [2]. The estimation of PMI relies heavily on interpreting the state of decomposition, a continuous process influenced by multiple environmental factors, along with insect activity and vertebrate scavenging [1,3–6]. Since these factors can vary significantly by geographic area, local data is crucial for forensic validity [3,7]. Recent research has established the base rate of terrestrial decomposition for the locally relevant Cape Flats area in Cape Town, Western Cape Province, South Africa, using unclothed pigs (a median time to 75% weight loss of 83.5 days, and mean ADD of 1126.06) [8]. However, this is not necessarily the most appropriate model for decomposition, given that most recovered individuals in forensic cases are clothed to some degree [9,10]. Therefore, the assessment of how clothing affects decomposition is essential for developing improved PMI estimation methods in our relevant biogeographical area.

Internationally, the effect of clothing on decomposition remains unclear; research has shown the presence of clothing on surface depositions may slow or accelerate decomposition, depending on other factors. These include the trapping of moisture, increasing temperature, slowing cooling to promote putrefaction, inhibiting scavenging and entomological processes essential in the natural decomposition cycle, allowing for new areas of increased oviposition for insects, or simply protecting larvae from the elements [11–14]. Some researchers have maintained that although the effect of clothing is measurable, it is only statistically significant when comparing winter and summer months or simply that the statistical significance does not equate to a practical affect [13,15,16]. Different fibre types can degrade at different rates and can affect decomposition to varying degrees in both summer and winter settings [17]. With respect to scavenging, clothing has been suggested to be comparable to deer hide [18], but research has shown scavenging patterns to differ, with foxes failing to successfully scavenge clothed lower limbs of recovered human remains, suggesting that clothing can inhibit scavenging activity [19]. However, clothing does not appear to inhibit large scavengers such as bears [20]. This highlights the inconsistencies observed regarding the impact of clothing on decomposition and scavenging, as well as the importance of regional data due to the significant effect of climate and environment on the decay process.

Although the effect of clothing on the rate of decomposition has been well-studied and reported in forensic cases [21–23], no studies to date have attempted to quantify the effect

of this barrier on the rate of decomposition where scavengers are the principle agents of decay. To the best of the authors' knowledge, only one experimental taphonomic research project where clothed carcasses (human) were used has explicitly investigated scavenging [24]. However, the effect of clothing on scavenging was not the focus of their research and observations on the effect of clothing on scavenging were limited and entirely qualitative. Similar limited qualitative observations were made in earlier related research at the same facility [11,12].

Review of the relevant literature focuses mostly on international studies due to the relative lack of local data – only one decomposition study incorporating clothing has been conducted in South Africa [15]. This took place in the central Free State Province, which is categorised by the Köppen-Geiger climate type system as BSk: arid, steppe, hot [25]. Cape Town, by contrast, is type Csb, characterised by a temperate climate with dry and warm summers. Cape Town also has the highest murder rate for any metropolitan region in South Africa, ranking 11th overall worldwide [26,27]. The Salt River Forensic Pathology Laboratory, one of the primary mortuaries in the city, receives over 3500 cases per year of suspected unnatural death, ~9% remaining unidentified [28]. Solving these cases is made considerably more difficult when bodies are decomposed or skeletonised – forensic anthropologists are usually consulted to assist in these cases, with accurate PMI estimations helping to identify the decedent. This follow-up study was designed to answer questions that have arisen from previous local PMI investigations, and from the apparent inconclusive effect of clothing on decomposition internationally. The aim of this study is to examine the effect of clothing on the process of surface decomposition in a forensically significant habitat in Cape Town, and how it influences small mammal scavenging activity and PMI. Herewith, are the results from the first trial conducted in the winter months.

2 Materials and Methods

2.1 Experimental Location

The study was conducted at the South African Medical Research Council's secure research facility in Delft, Cape Town, South Africa. The facility is adjacent the Driftsands Nature Reserve, home to one of the largest intact remnants of the Cape Flats Dune Strandveld and Cape Flats Sand Fynbos vegetation subtypes [29]. This biogeoclimatic area, along with the

reserve and research facility, coincide with a densely populated and forensically significant area of the City of Cape Town Metropole, the Cape Flats (Figure 1) [5,6,30]. This habitat is easily colonised by the invasive tree species Rooikrans (*Acacia cyclops*) and Port Jackson (*Acacia saligna*) [31], forming dense thickets across the region, providing optimal locations for the disposal and concealment of human remains. Therefore, the chosen portion of the research site is covered by a dense thicket of these tree species. Four locations within the tree cover were chosen for deposition with similar dappled shade conditions, approximately 20-30m away from each other. In January (summer), Cape Town has an average high temperature of 29 °C and low of 17 °C, and in July (winter) an average high of 20 °C and low of 11 °C, with winter rainfall averaging 853 mm annually.

2.2 Materials

2.2.1 Study Design

Four male domestic pig (*Sus scrofa domesticus*) carcasses of approximately 60 kg in weight were used as proxies for adult human decomposition. The carcasses were euthanised early in the morning to ensure minimal blow fly activity. Immediately after euthanasia, the carcasses were washed with water, sealed in individual body bags and transported to the research facility in the back of a utility truck, without refrigeration or freezing. They were deployed within 2-3 hours of euthanasia, as soon as the treatment group was clothed upon reaching the research site. The project was designed in duplicate to mitigate the effect of possible outliers, with two unclothed controls (UC1 and UC2) and two clothed experimental treatments (C1 and C2). Previous research in the area has demonstrated a vast difference in decomposition rate between scavenged carcasses and a non-scavenged caged control, therefore the present study did not incorporate a control for scavenging activity [6]. All were deployed in a standard position lying on the right side with limbs outstretched, to maintain consistency. To prevent overlap of ground-dwelling insect populations, new deployment locations, unused in previous decomposition cycles, were chosen within the tree-covered horse paddock used for this study, at least 20 m away from the nearest neighbouring carcass. Each carcass was deployed on a steel weighing grid (10 cm x 10 cm squares), modified with wire mesh designed to hinder vertebrates burrowing and scavenging from beneath; a previously documented behaviour of the local Cape grey mongoose (*Galerella pulverulenta*) [6,8]. This behaviour is undesirable, as it unnaturally limits carcass contact with the ground,

and promotes mummification. The mesh also served to prevent any small bony elements from falling through the grid when weighing, which could disturb the carcass further, and confound the rate of weight loss towards the end of the cycle.

2.2.2 Pigs

Domestic pigs, particularly those approximating human size and weight, are widely considered acceptable and appropriate proxies for establishing general trends and baseline decomposition data, despite recent reported differences between pig and human decomposition [32,33]. When human cadavers are unavailable, the domestic pig is still viewed as the best analogue for taphonomic studies, due to various similarities to humans [34–38]. Currently in South Africa, the use of donated human cadavers for taphonomic research is not permitted, therefore, domestic pigs are the best alternative [39].

The carcasses were purchased from Mariendahl Experimental Farm, Stellenbosch University, and euthanised by 0.22 calibre 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 form of euthanasia that meets the needs of this project; the small calibre bullet ensuring little physical damage is done to the carcass, unlike conventional exsanguination methods, and no potential contaminants of unknown effect are introduced such as with methods involving lethal injection. Additionally, the small entry wound is quickly clogged with clotted blood and does not form a site of attraction to accelerate oviposition of blowflies [6].

2.2.3 Clothing

The choice of the clothes used in this study was based on anecdotal evidence from senior members of our local service provider, Forensic Anthropology Cape Town (FACT), as well as a thorough retrospective analysis of all FACT case files. Both support the choice of inexpensive, seasonally appropriate, primarily cotton-type clothing. The analysis confirmed that a notable proportion of cases conducted by FACT involved clothed remains (70% when cases with no clothing information were excluded), and that a local investigation into the impact of clothing on the decomposition process is needed.

Each treatment carcass was clothed with typical clothing worn during colder weather defined as underwear, denim jeans with a leather belt, a cotton T-shirt, pull-over jersey, socks

and shoes. The clothes were identical and newly purchased at the same time from Pep Stores, an inexpensive clothing retailer that is widespread and popular across the Western Cape, due to its affordability. The exact percentages of fibre types for the chosen clothes are as follows: underwear (65% polyester, 35% cotton), T-shirt (100% cotton), jersey (100% acrylic), denim jeans (60% cotton, 30% polyester, 10% viscose), socks (97% polyester, 3% elastane), shoes (sole: synthetic, lining: textile), and belt (bonded leather).

To ensure the clothes fit the pigs as they would a human, some alterations were required. The clothes were first washed, and a seamstress employed to make alterations to the clothing to ensure a reasonable fit, accounting for the difference in human and pig anatomy. The alterations were made prior to the deployments using measurements taken from a live 60 kg pig to use as a guide. These included shortening and tapering of the trouser legs, jersey and T-shirt arms. Large sized clothes were purchased to account for the planned alterations, particularly the trousers, which required a deep in-seam to accommodate the relatively elongated pelvis of pigs compared to humans. Additionally, the rear seam of each pair of denim trousers was opened to facilitate dressing the pigs on site, and to ensure an appropriately tight fit, as the seams were securely sewn closed by hand once the pig carcasses were dressed.

2.3 Data Collection and Analysis

2.3.1 Weather

A Davis Vantage Pro 2 weather station was used on site, in the vicinity of the carcasses, to track ambient temperature, humidity, rainfall, wind velocity, and solar radiation within the habitat, as using weather data generated from near-by national weather service stations has been shown to be potentially unreliable [40]. Accumulated degree days (ADD) were calculated using 0°C as the minimum developmental threshold [2].

2.3.2 Photographs

Each carcass was monitored by a motion-activated, infrared-capable time-lapse wildlife camera (Primos Proofcam model 3), set to capture three photos per motion trigger, along with a time-lapse sequence comprising one photo in hourly intervals. The time-lapse mode was limited by the hardware to daylight hours only, but the motion-activated burst mode was still triggered at night. Each camera was fitted with an 8-gigabyte standard secure digital (SD)

memory card and mounted directly above its carcass onto a specially built four-legged wooden structure.

Photographs captured by the cameras were downloaded daily from the SD cards, and scavenger activity processed using freely available software, Timelapse2 [41]. The photographs captured the presence of scavenger species, along with the time and area of scavenging. Daily analysis of the photographs facilitated digitally marking the presence of each scavenger and noting any distinctive features, such as when disarticulation occurred. The software generated spreadsheets populated with scavenger-related data for each image, used to calculate the number of visits per day by a given species, length of visit and accumulated duration of visits. Individual scavenger visits were defined by an absence of at least 10 minutes between visits, *i.e.* any activity in frame on/around the carcass was included in the duration of a visit.

2.3.3 Decomposition

The methods of scoring decomposition in the literature, such as the method developed by Megyesi *et al.* [2] or the version adapted for use on pigs by Keough *et al.* [42], rely on the observation and scoring of visual changes to the carcass as decomposition progresses. This is difficult when the subject is covered with clothing, doubly so when certain parts of the carcass are rapidly eaten by mammalian scavengers; both factors are not accounted for currently in any decomposition scoring methodology known to the authors. Short of removing the clothing on a regular basis to visually assess the progression of decomposition, which would impact the results, there is no viable means to visually score decomposition. Although this has been done in previous studies, by altering clothing to include long slits with velcro hook-and-loop-fasteners to facilitate opening and closing of the clothing for decomposition scoring purposes [43], the unknown effect of this frequent interference is difficult to quantify and was, therefore, avoided.

To track decomposition via a non-visual quantitative method, less prone to researcher bias, daily site visits were conducted to measure weight loss manually every day, approximately 24 hours apart (±30min). Weighing of each carcass was facilitated by a block and tackle and analogue scale mounted to a steel tripod. Although labour intensive and time-consuming, the frequency of visits ensures an even and reliable spread of data with equal intervals separating data points to facilitate statistical analysis. The date and time of each

weighing event was recorded, together with comments on the visual state of decomposition where visible and presence of insects.

Decomposition was deemed to be in a condition of stasis and the collection of data was terminated when at least two of the following criteria were met by all carcasses in a given decomposition cycle:

- Skeletonisation was reached [44];
    - Obvious loss of internal abdominal structure, only spine and ribs remaining underneath dried skin;
    - Substantial unweathered/greasy bone exposed (>50% of carcass) and no wet decomposition when observed underneath the carcass (facilitated by lifting the grid with block and tackle);
    - Significant areas (>30% of carcass) of bleached or weathered bone exposed.
- The weekly accumulated weight loss declined to below 5% of the original weight value for three consecutive weeks;
- Minimal insect appearance/activity.

2.3.4 Data Analysis

The weight loss, scavenger and weather data were all processed using Microsoft Excel and further analysed using the statistical analysis programme IBM SPSS Statistics 25. Due to the low sample size, the interpretation of these initial results will be informed via graphical observation and comparison to assess baseline patterns.

3 Results

The carcasses were deployed on 24 August 2018, traditionally falling more within spring than winter (Spring Equinox: 23 September 2018). However, since Cape Town does not experience clearly defined seasons, the initial period still falls within the cooler months of the year and provides sufficient seasonal difference compared to the high local summer temperatures [8,45]. Maximum, mean and minimum daily temperatures over the 140 days were 37.80°C, 17.95°C and 3.40°C respectively, and 108.60 mm of rain fell over the study period. The trial was terminated after 140 days on 10 January 2019, although daily weight readings were no longer possible from day 113, 14 December 2018. The camera traps and weather station remained active on site over the final period and continued to record data, with a final weight

reading taken on the last day. Carcass characteristic measurements were taken using ImageJ [46] from photographs captured on day 1 (Table 1).

Table 1: A list of sample characteristics; length, height and weight, along with means for each variable.

Carcass ID	Snout-tail Length (cm)	Shoulder Height (cm)	Starting Weight (kg)
Clothed 1	114.36	59.37	61.00
Clothed 2	116.66	59.62	60.50
Unclothed 1	115.11	59.51	60.50
Unclothed 2	114.31	60.39	60.00
Mean	115.11	59.72	60.50
(cm = centimetres; kg = kilograms)			

A noteworthy difference was observed between the clothed and unclothed carcasses, with respect to weight loss, with unclothed carcasses reaching 25%, 50% and 75% weight loss quicker than the clothed carcasses (Table 2). On average, the clothed carcasses took 51 days (ADD 724.98) to reach 25% weight loss, compared to 30 days (ADD 379.12) for the unclothed. This pattern continued throughout the duration of the cycle, with clothed carcasses reaching 50% loss by day 80 (ADD 1275.64), compared to 49.5 days (ADD 694.57) for the unclothed controls. Additionally, the clothed carcasses never reached 75% weight loss, even after the additional month left on site after daily weight recordings were terminated, totalling 140 days (ADD 2512.45). By contrast, the unclothed carcasses lost 75% of their weight by 86.5 days (ADD 1399.48) on average. Unclothed 2 (UC2) was the quickest to reach 25%, 50% and 75% weight loss and lost the most weight overall, totalling 85% compared to 81.82% for UC1. The clothed carcasses experienced less total weight loss, ending at 68.03% for C1 and 70.25% for C2 on day 140. Over the final 26-day period when daily weight readings were not possible, the clothed carcasses lost 3.5 kg and 3 kg for C1 and C2 respectively, compared with 2.5 kg for UC1 and 1 kg for UC2.

Table 2: Measures of both time in days and associated heat energy in ADD to reach weight loss percentages for clothed and unclothed carcasses, as well as comparative data from Finaughty [8].

Weight loss Stages	Clothed			Unclothed			Total			Finaughty [8]
	1	2	Mean	1	2	Mean	Min	Max	Mean	Mean
Days to 25%	57.00	45.00	51.00	34.00	26.00	30.00	26.00	57.00	40.50	27.00
Days to 50%	84.00	76.00	80.00	57.00	42.00	49.50	42.00	84.00	64.75	56.50
Days to 75%	-	-	-	97.00	76.00	86.50	76.00	97.00	86.50	83.50
ADD to 25%	831.66	618.29	724.98	431.38	326.86	379.12	326.86	831.66	552.05	333.24
ADD to 50%	1357.28	1194.00	1275.64	831.66	557.48	694.57	557.48	1357.28	985.11	686.63
ADD to 75%	-	-	-	1604.95	1194.00	1399.48	1194.00	1604.95	1399.48	1126.06
%Weight Loss	68.03	70.25	69.14	81.82	85.00	83.41	68.03	85.00	76.27	-
(ADD = accumulated degree days)										

3.1 Did clothing impact scavenging?

Initially, all carcasses showed similar patterns of scavenging by the Cape grey mongoose (*G. pulverulenta*) with activity beginning near the mouth and head. After a few days the abdomens of both clothed carcasses were quickly opened, with the jersey and T-shirt pulled up towards the head and out of the way. Subsequent activity was largely focused on the unclothed carcasses. The feeding on unclothed carcass 1 (UC1) began at the mouth and then continued down the neck and parts of the forelegs, before the abdomen was opened, and the ribs exposed. Unclothed carcass 2 (UC2) also showed initial signs of scavenging at the mouth, but then scavenging began anew near the anal region and continuing up to the hind legs and abdomen, before exposing the ribs and parts of the forelimbs. Across all carcasses, typical mongoose feeding behaviour involved stripping out subcutaneous fat and muscle from beneath the skin, leaving it relatively intact.

Both the clothed carcasses experienced a substantial decrease in mongoose activity after approximately two weeks whilst the unclothed carcasses were visited with greater frequency and duration over many more days; UC1 saw a drop-off in scavenging activity around week 4/5 and scavenging of UC2 continued at substantial levels until week 7 (Figures 2 and 3). Due to this differential scavenging across the sample, the clothed carcasses experienced notable bloat, whereas the unclothed carcasses showed very little bloating.

Less than 1% of the total number of scavenging hours of clothed carcasses was attributable to simultaneous feeding by multiple mongooses, whereas 5.52% of visits to UC1 were by more than one mongoose, and 9.14% for UC2 (Table 3). UC2 also experienced the most visits (1501) and scavenging time (97:41:41), which are substantially higher than those of both clothed carcasses, as well as for UC1 which was visited 446 times, with a total accumulated duration of 41:43:37 (Table 3). Figure 4 depicts this graphically.

Table 3: Accumulated scavenging activity per carcass grouped by weight loss quartiles

Carcass	%Weight Loss	Day	ADD	Weight	Visit Duration	No. of Visits	Multi-Visit Duration
Clothed 1	0%	1	0	61	0:00:00	0	0:00:00
	25%	57	831.66	45.5	14:30:32	214	0:01:02
	50%	84	1357.28	30.5	15:01:06	270	0:01:02
	75%	-	-	-	-	-	-
	End (62.30%)	113	1920.01	23	15:07:31	287	0:06:49
	Final Weight (68.03%)	140	2512.45	19.5	15:17:10	298	00:06:49 (0.74%)
Carcass	**%Weight Loss**	**Day**	**ADD**	**Weight**	**Visit Duration**	**No. of Visits**	**Multi-Visit Duration**
Clothed 2	0%	1	0	60.50	0:00:00	0	0:00:00
	25%	45	618.29	45.00	38:22:55	281	1:31:28
	50%	76	1194	29.00	41:07:50	385	1:31:28
	75%	-	-	-	-	-	-
	End (65.29%)	113	1920.01	21.00	41:36:08	444	2:18:15
	Final Weight (70.25%)	140	2512.45	18.00	41:43:37	446	02:18:15 (5.52%)
Carcass	**%Weight Loss**	**Day**	**ADD**	**Weight**	**Visit Duration**	**No. of Visits**	**Multi-Visit Duration**
Unclothed 1	0%	1	0	60.50	0:00:00	0	0:00:00
	25%	34	431.38	44.50	27:06:53	238	0:11:18
	50%	57	831.66	30.00	29:22:23	364	0:11:18
	75%	97	1605	15.00	NA	364	0:11:18
	End (77.69%)	113	1920.01	13.50	29:22:23	397	0:11:18
	Final Weight (81.82%)	140	2512.45	11.00	29:22:26	404	00:11:18 (0.63%)
Carcass	**%Weight Loss**	**Day**	**ADD**	**Weight**	**Visit Duration**	**No. of Visits**	**Multi-Visit Duration**
Unclothed 2	0%	1	0	60.00	0:00:00	0	0:00:00
	25%	26	326.86	45.00	48:46:17	338	4:48:59
	50%	42	557.48	30.00	90:52:40	564	8:52:39
	75%	76	1194	14.00	97:27:33	1435	8:55:28
	End (83.33%)	113	1920.01	10.00	97:36:57	1486	8:55:28
	Final Weight (85%)	140	2512.45	9.00	97:41:41	1501	08:55:28 (9.14%)
(ADD = accumulated degree days)							

4 Discussion

This study assessed the impact of clothing on decomposition in a forensically significant local region, the Cape Flats, where a large proportion of Forensic Anthropology Cape Town (FACT) cases originate. These results indicate clothing caused a reduction in decay rate, primarily by altering scavenger behaviour, along with additional potential mechanisms. The small sample size of this initial trial is acknowledged, limiting any robust statistical analysis of the results.

The sequence of weight loss for unclothed carcasses remained consistent with previous research by Finaughty in the same environment at a similar time of year: 25% weight loss was reached in 30 days (ADD 379.12) on average compared to 27 days (ADD 333.24); 50% weight loss by day 49.5 (ADD 694.57) vs day 56.5 (ADD 686.63); and 75% weight loss by day 86.5 (ADD 1399.48) vs day 83.5 (ADD 1126.06) [8]. This pattern was not followed by the clothed carcasses, with weight loss milestones reached more slowly than unclothed carcasses (measured in number of 24-hour days) and associated with more thermal energy (measured in accumulated degree days or ADD). Clothed carcasses did not reach 75% weight loss after 140 days (ADD 2512.45), when the trial had to be terminated. This data suggests that clothing decreased the decomposition rate in this habitat, like studies in Arizona and Tennessee, USA [9,12], but unlike others in Western Poland and North West England [13,16]. Given enough time, the clothed carcasses would eventually skeletonise and presumably reach a similar weight and visual appearance to the unclothed carcasses, appearing to be at the same state of decay, having simply been exposed to the same ADD. This could mask the accelerative effect of increased scavenging of the unclothed carcasses in the early stages of decomposition. However, such a coincidence point would likely only occur late in the cycle at complete skeletonisation and may be overcome by assessing skeletal damage, the presence of scat and other identifiable signs of scavenger activity.

Since different fibre types can influence decomposition in different ways, the choice of clothing used in this study was informed from case files and anecdotal evidence and was an example of typical warmer clothing worn during colder months in Cape Town, South Africa, found on decedents during casework. The clothing prevented easy access for the vertebrate scavengers, reducing visit number and duration and subsequently the rate of weight loss, but did not seem to noticeably impact insect activity, unlike the increased insect activity due to clothing observed by some researchers [11,15,47]. Clothing may also alter the rate of decay

by creating a microhabitat around the carcass, either acting as insulation to limit thermal exposure or prevent thermal loss. Clothing became soaked with rain, artificially elevating the recordings of carcass weight, which may have unexplored consequences on the decomposition process. Future studies should investigate internal and surface temperature differences between clothed and unclothed carcasses, along with the influence of clothing on invertebrate activity in this environment.

The clothed carcasses took notably longer, with more associated thermal energy to reach the weight loss quartiles and lost less total weight overall. The minimal weight lost by all four carcasses over the additional 26-day period (ranging from 1 – 3.5 kg) is indicative of the carcasses having already reached a state of stasis prior to the termination of daily weighing on day 113 due to the facility closing. Weight loss in this environment is strongly linked with scavenging activity, which is discussed below.

4.1 Scavenging

As expected from previous studies in this region, the Cape grey mongoose (*G. pulverulenta*) was the only vertebrate scavenger species observed, as the Cape lacks many larger vertebrate obligate or facultative scavenger species, and the fence surrounding the study site precludes access by feral domestic dogs and cats. Some avian species, such as the Cape robin-chat (*Cossypha caffra*), common starling (*Sturnus vulgaris*), Hadeda ibis (*Bostrychia hagedash*) and Cape francolin (*Pternistis capensis*), along with an unconfirmed species of field mouse and a domestic cat (*Felis catus*), were observed to briefly and infrequently visit the carcasses. No discernible scavenging activity was attributable to any of these animals, whereas video and photographic evidence clearly depicts mongooses feeding on carcasses. The cameras were sensitive enough to be triggered by fly movement and small field mice even in dark conditions, therefore, any other scavengers present would have been photographed. In addition, no discernible feeding lesions of other animals were observed during site visits or when examining photographs.

The mongoose visits occurred diurnally, in-line with behaviour previously documented in this area [6]. Individual visits were defined by an absence of at least 10 minutes between visits. Visits of more than one mongoose occurred, with a maximum of three at once, but were infrequent and short. The observed pattern of scavenging on UC2, beginning near the anus and continuing up to the abdomen and ribs, was similar to that observed previously

[6,8]. This behaviour of using natural orifices to access pig carcasses is similar to the Virginia opossum (*Didelphis virginiana*), a nocturnal North American marsupial, comparable in size to the mongoose [48]. The northern racoon (*Procyon lotor*), another nocturnal North American mammal of approximate size, has been observed to effectively pierce the skin of human cadavers to access the underlying tissues via small openings, targeting mostly the limbs [49]. Both racoons and mongooses were able to push or pull clothing away from the feeding site. Like the raccoon, the mongoose would predominantly target skeletal muscle and fat leaving most of the skin intact, whereas the opossum would largely target viscera [24,48–50]. At this stage it is not possible to validate these observations on human remains as experimental human taphonomic research is not presently permitted in South Africa. Moreover, despite the similarities between the Cape grey mongoose and other scavengers internationally, as highlighted above, no other species has been described to exhibit the same suite of scavenging behaviours as the mongoose. Thus, no validation by proxy could take place at an internationally located human taphonomy facility. However, it may be possible to assess patterns of scavenging by this species on human remains through prospective analysis of local forensic cases. This would require definitive identification of scavenging by this species either through the presence of species-specific soft-tissue lesions and/or hard-tissue artefacts, or DNA analysis of swabs of the same. However, both approaches would require future research, specifically the establishment of this species' genetic profile and an appropriate extraction and processing methodology for forensic casework and/or the development of a delineation protocol for this species' scavenging artefacts (if they are sufficiently unique to allow this).

4.2 Was scavenging impacted by clothing?

In general, the rapid and substantial scavenging observed across both unclothed carcasses, causing them to essentially bypass the bloat phase, has also been described [6]. This is indicative of scavenger preference for unclothed carcasses, similar to canid scavenging behaviour observed in Alberta, Canada [51], as the clothed carcasses experienced notably less scavenging overall, and did not progress as rapidly through the decomposition cycle. Interesting to note, however, is that clothing may have facilitated the opening of the abdomen, as this occurred much earlier in the clothed than unclothed carcasses and could be due to the leather belt restricting bloating and allowing scavengers to easily break through the taught skin. This behaviour has not been observed in previous research conducted on

unclothed pig carcasses in this area [8,52], nor has it been described in the international literature to the best of the authors' knowledge.

The rapid decline in scavenger activity at the clothed carcasses after two weeks – strongly contrasted against that of the unclothed carcasses, which continued to experience scavenging – is likely attributable to the presence of clothing. Although the precise mechanism is difficult to identify, it is most probable that the palatable tissue was depleted more rapidly on the clothed carcasses due to lower amounts of accessible tissue. One potential reason for a reduction in palatable tissue is due to precocious natural mummification, previously documented in this research habitat [8, 53]. However, although some desiccation of soft tissue was observed later in the cycle, precocious natural mummification is unlikely for two reasons: firstly, it has not been observed in the region during winter months in any previous research where it was assessed [8]. Secondly, the clothed carcasses would be less likely to experience precocious natural mummification given the propensity for clothing to retain moisture following rainfall events, which were plentiful during the winter months where this study was conducted. The unclothed carcasses did not undergo mummification, evidenced – in part – by continued scavenging activity after cessation at the clothed carcasses. It is not possible to conclusively prove this as the decomposition was not qualitatively assessed during this study for reasons stated in the methodology. This limitation does, however, present an opportunity for future research. Specifically, for the development of a quantitative measure of soft-tissue desiccation, informative for assessing the onset of states such as precocious mummification. This would be especially useful in circumstances with clothed carcasses where traditional long-term continuous qualitative assessment is not possible.

The extent of scavenging activity by the Cape grey mongoose contrasts strongly with that of the small Indian mongoose (*Herpestes javanicus*), which was only recorded to feed on porcine carcasses in two distinct events, with no discernible impact on weight loss, in Oahu, Hawaii [54]. The present study clearly shows increased weight loss correlates with increased scavenging activity in this environment, possibly mediated by the presence of clothing as patterns were seen to differ between clothed and unclothed carcasses. One important aspect to note from the results of this study is the clear focus of scavenging activity on one particular unclothed carcass, UC2. This increased scavenging activity on UC2 may reflect mongoose preference for unclothed over clothed carcasses, and may also be associated with position,

as it was closest to the facility's boundary fence with Driftsands Nature Reserve. Despite all carcasses being approximately 20-30m apart, the mongooses may have chosen the carcass closest to dens possibly located in the reserve to the east, to predominantly feed on. More research should be done on the mongooses' behaviour and ranging patterns.

Although the mongoose is a small, facultative scavenger, and is unable to cause large scale disarticulation and scatter like the patterns observed with larger canid scavengers internationally [18,22,55], no skeletal elements were disarticulated and scattered during the study period, unlike previous observations in this area [5], for both clothed and unclothed carcasses. Possible explanations for this include: the older, larger pig carcasses used in the present study may have more well developed joints and epiphyses which are more difficult to disarticulate compared to those of the younger carcasses used previously; the increased mass (~60kg vs ~20kg) could allow scavengers to focus on the available soft tissue, reducing the need to target skeletal elements and increasing the chances of desiccation occurring on the tissue surrounding bones, preventing easy disarticulation by small scavengers like the mongoose. In addition, the increased number of available carcasses could have contributed to the factors mentioned above – further possible consequences of increased carrion biomass are briefly discussed below.

The way the trial was designed enabled the local scavenger species to choose from multiple carrion options. However, this is not a true reflection of the local forensic scenario, where a single clothed individual is most commonly found, and groups of decedents are exceedingly rare [56,57]. Globally, these types of studies are done in duplicate for statistical validity and to ensure findings are repeatable. However, having multiple carcasses at a given time may impact the decay rate by providing carrion options to the decomposers in the environment [58]. At a local scale, the ephemeral occurrence of carrion in a given environment may be considered a nutrient (resource) pulse [59]. An increase in the frequency or magnitude of such pulses can change the ecological dynamics, structure, and composition of the local facultative scavenger assemblage (inclusive of true and meso-carnivores) [58,59]. Therefore, the effect of clothing on decay might be better assessed by looking at how scavengers respond when only one carrion source is available. If only one carcass was present, it is expected to decay quicker through increased scavenging, influencing the estimated post-mortem interval.

5 Conclusion

This research was designed to investigate the influence of clothing on decomposition in the thicketed Cape Flats Dune Strandveld habitat of the Cape Town metropole. The results from the initial trial conducted in the cooler months indicated that clothing prolongs decay, primarily by altering behaviour (inhibiting carcass access) of the vertebrate scavenger, the Cape grey mongoose (*Galerella pulverulenta*). This suggests that current models of estimating PMI, which do not consider the impact of clothing, may be inaccurate in environments where scavengers are known to be the major agents of decay, such as the habitat currently under study [5,6]. The present study, therefore, is the first worldwide to quantifiably link the effect of clothing on decomposition to scavenging. Since most recovered individuals are clothed, scavenger studies that do not involve clothing may be inaccurate, as scavenging behaviour was clearly altered by the presence of clothing. This suggests that previous studies investigating scavenging activity may need to be interpreted with greater caution, and study designs re-evaluated for future research to include clothed remains, enabling better understanding of the variance in the decay process, as feeding patterns may differ between clothed and unclothed carrion. However, since mongooses in the present study exhibited a preference for unclothed over clothed pig carcasses, further research on local scavenger behaviour is required with a single clothed carrion option, more representative of real-world forensic scenarios, to validate this pattern. Finally, the results of this study suggest that future research is necessary to develop robust PMI estimation methods which account for the influence of both clothing and scavenging.

6 References

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Figure captions

Figure 1: a) Population density of the City of Cape Town Metropole, measured by inhabitants/square kilometre (inh/km^2) [30]. Legend and location of Driftsands Nature Reserve is indicated. **b)**. Heat map of the City of Cape Town Metropole indicating quintiles of contact crimes (murders) per police precinct. Precincts within the fifth quintile (top 20%) in terms of number of murders are indicated in red. Legend is indicated [27].

Figure 2: Mongoose visits occurring between civil dawn and dusk for Clothed 1 and Unclothed 2 as examples for comparison, plotted against date with the longest and most visits occurring early in the cycle, tapering off rapidly. Scavenging activity continued for longer with unclothed compared to clothed carcasses.

Figure 3: Number and mean duration of mongoose visits and weight loss of Clothed 1 and Unclothed 2 per day, as examples for comparison. A greater number and duration of visits observed in unclothed carcasses, correlating with greater weight loss. Maximum, mean and minimum daily temperatures in degrees Celsius and rainfall measured in millimetres are also depicted.

Figure 4: Daily weight loss and accumulated mongoose visit duration for each carcass over the 140-day research period. Unclothed 2 clearly experienced substantially more scavenging activity.

Figure 1

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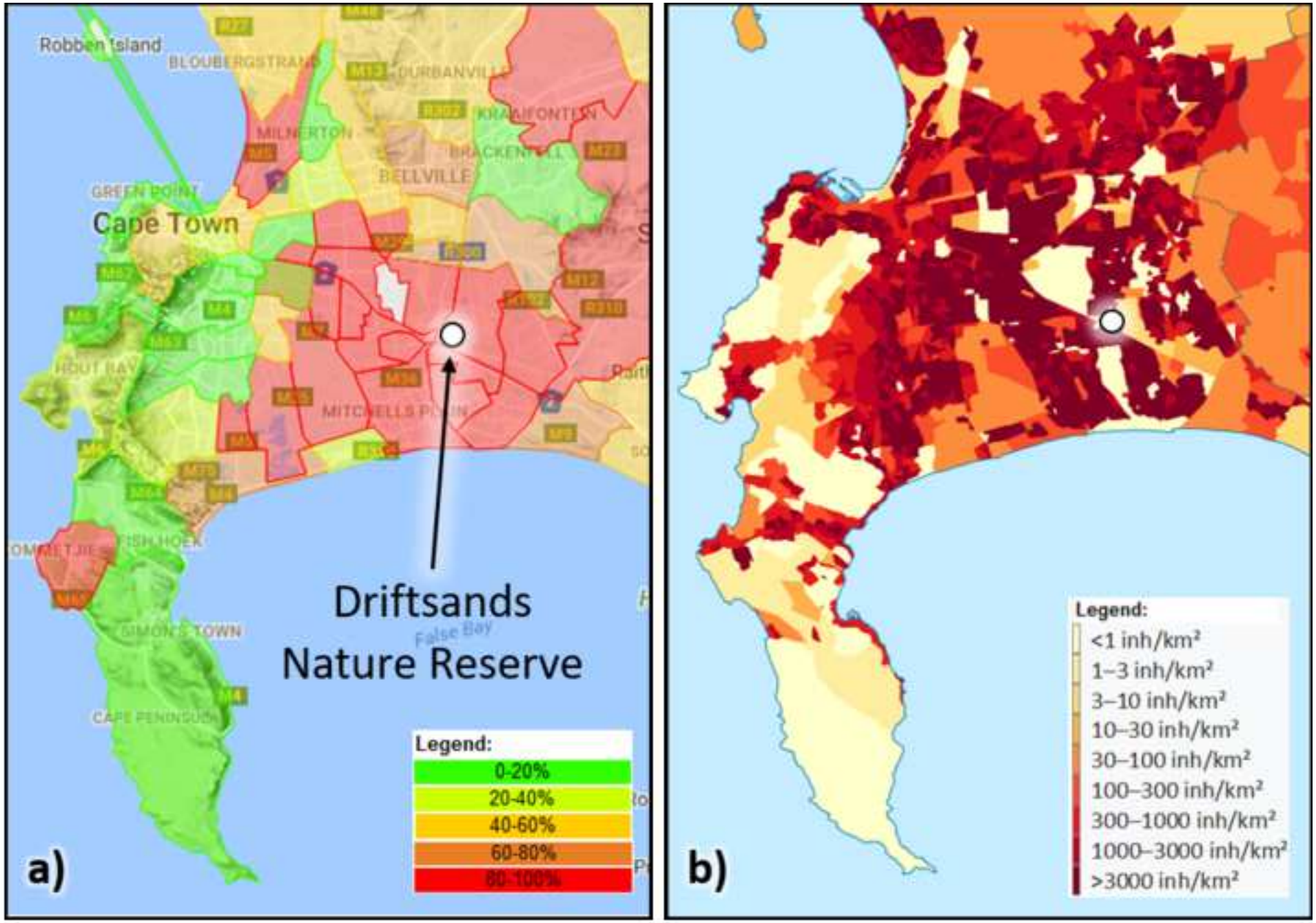

Figure 2

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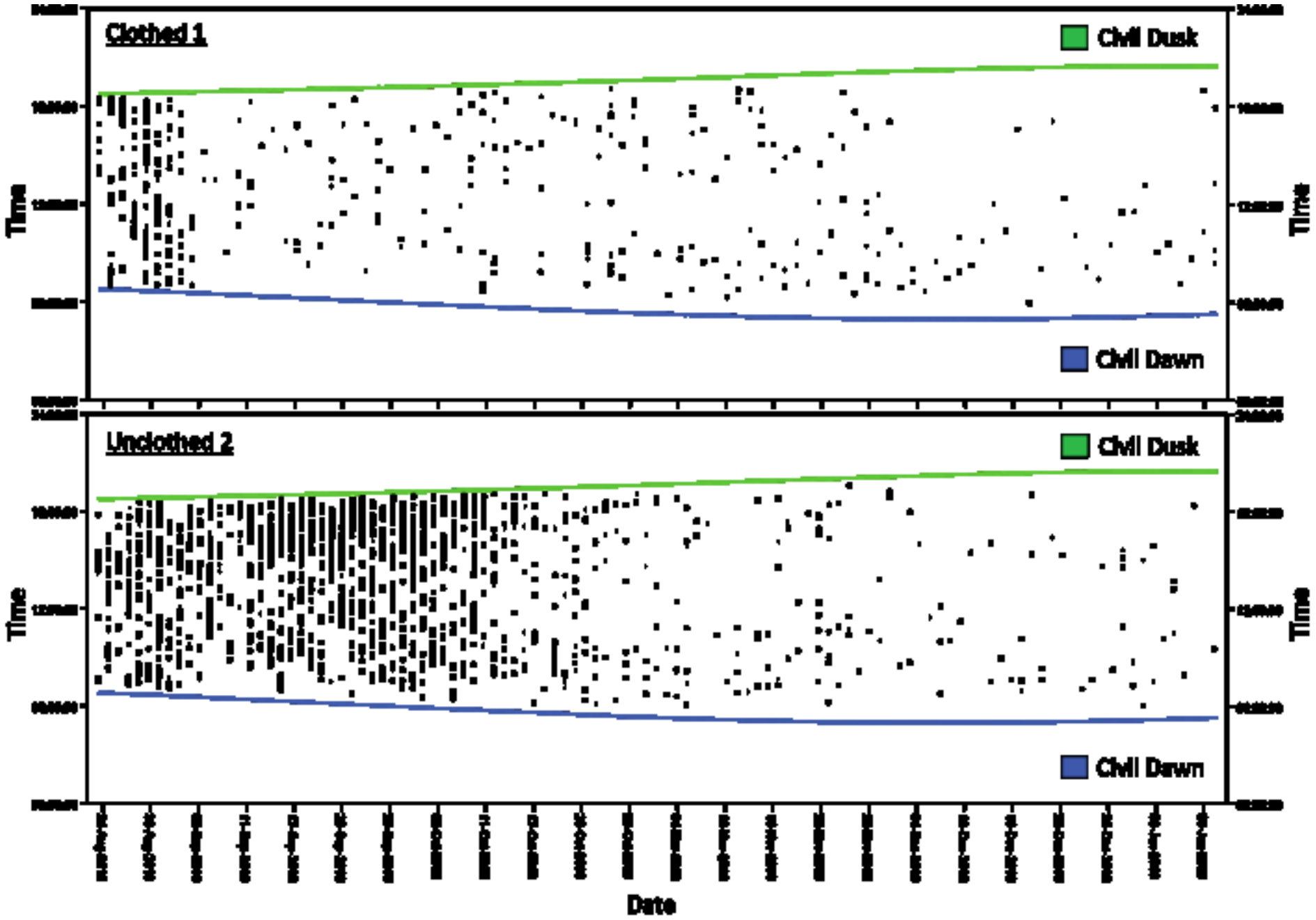

Figure 3

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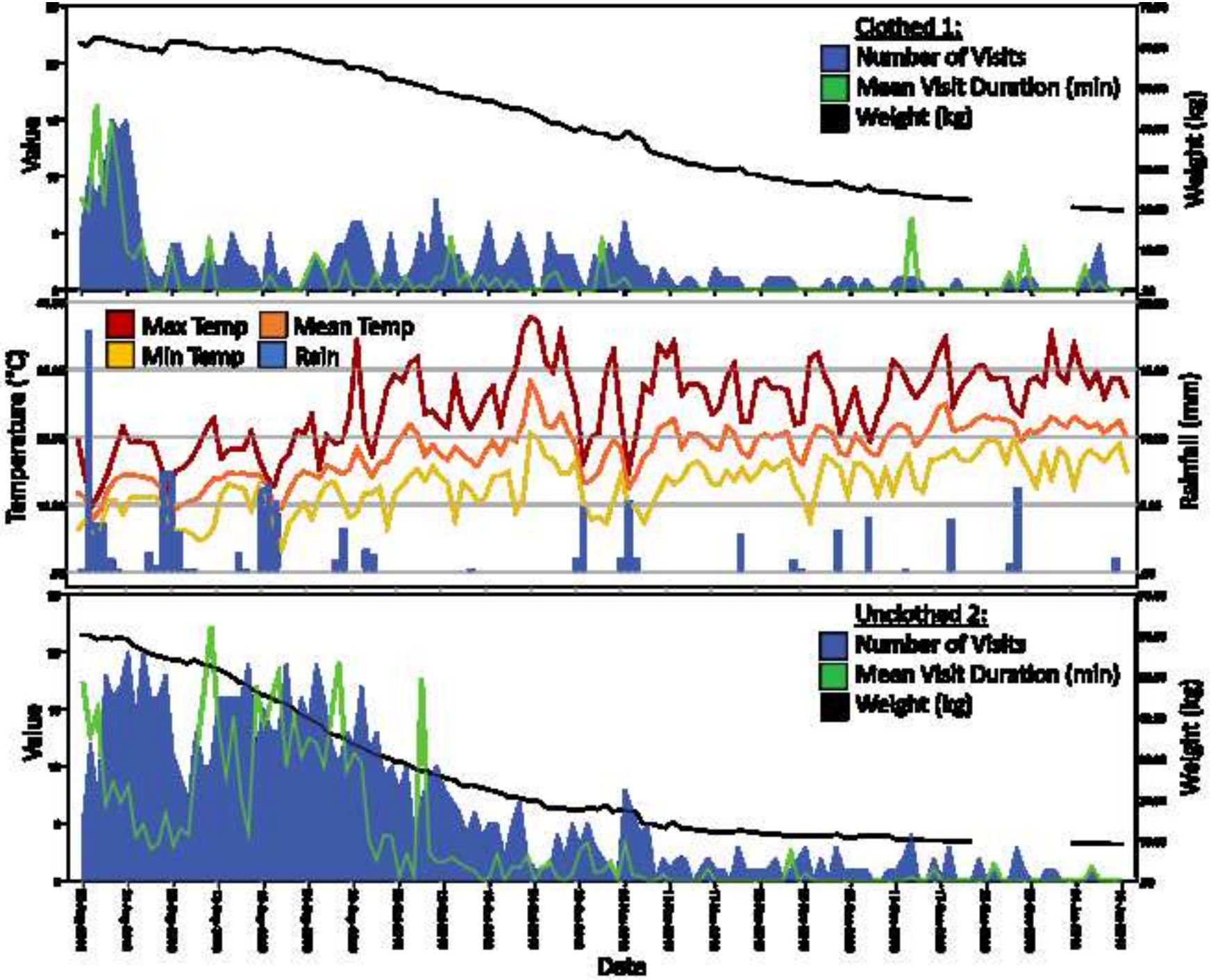

Figure 4

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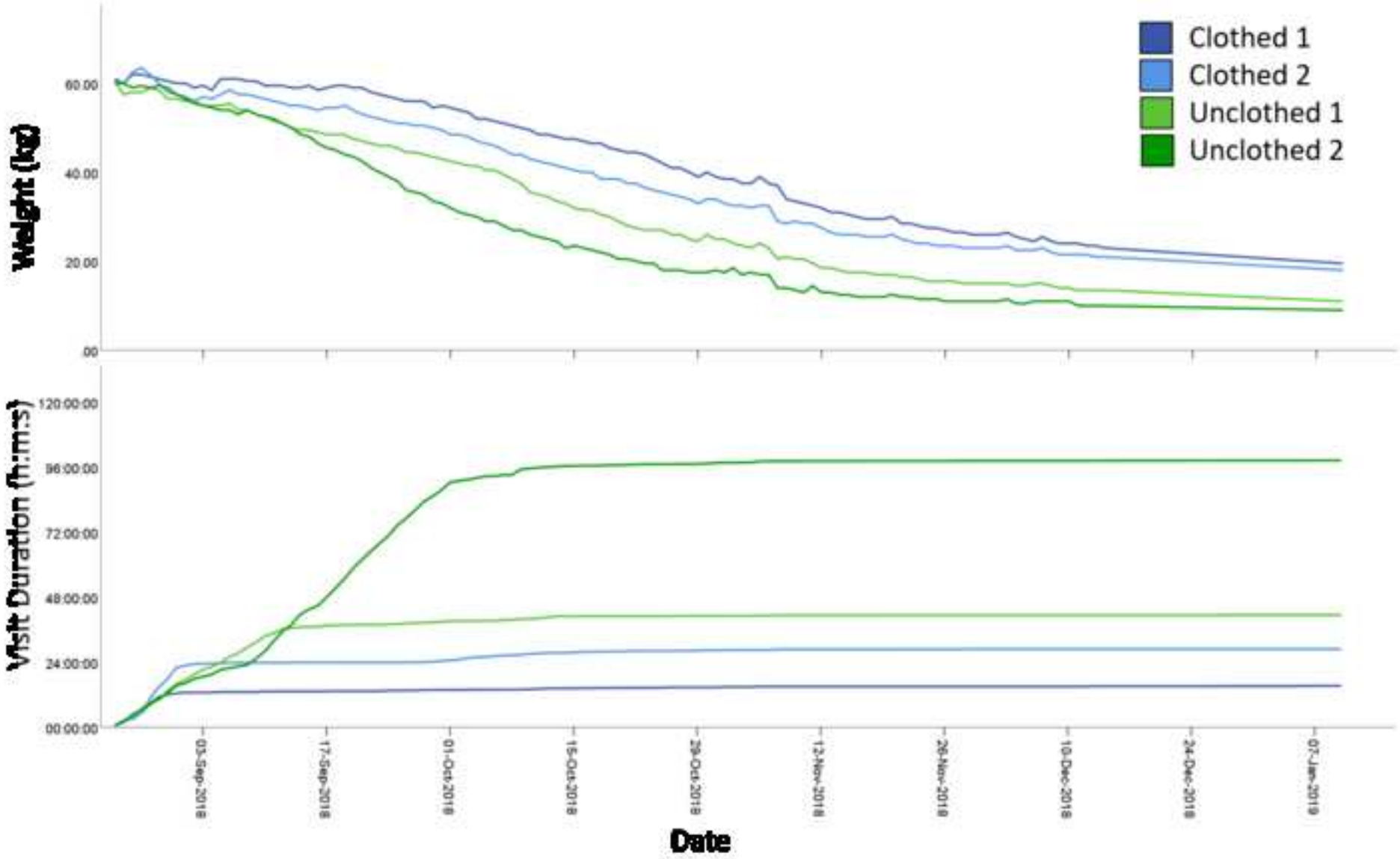

February 10, 2020

RE: Revision letter for Manuscript: FSI-D-19-00855R1

Dear Professor Christian Jackowski,

Thank you for the additional comments received via email on 21 January 2020 and the subsequent opportunity to revise our manuscript. We value the reviewers' feedback and wish to thank them once more. Their comments have been integrated to improve the manuscript.

We hope that we have sufficiently addressed the reviewer's comments.

December 17, 2018

RE: Revision letter for Manuscript: FSI-D-19-00855

Dear Professor Christian Jackowski,

Thank you for the comments received via email on 29 October 2019 and the subsequent opportunity to revise our manuscript. We value the reviewers' feedback and wish to thank them. The comments have been integrated to improve the manuscript except in the following cases, for reasons described below:

Not all the references suggested by reviewer 2 were included, as we did not deem them relevant to the focus of this manuscript, which was the impact of clothing on scavenging activity, not insect activity. Some of the suggested scavenger references have less comparative value than first anticipated, as Cape Town has fewer species of scavengers compared to some other previously studied habitats. We have included sections of text to address and clarify these points.

We hope that we have sufficiently addressed the reviewer's comments.

Credit Author Statement

AUTHOR DECLARATION

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property.

We further confirm that any aspect of the work covered in this manuscript that has involved either experimental animals or human patients has been conducted with the ethical approval of all relevant bodies and that such approvals are acknowledged within the manuscript.

We understand that the Corresponding Author is the sole contact for the Editorial process (including Editorial Manager and direct communications with the office). He/she is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs. We confirm that we have provided a current, correct email address which is accessible by the Corresponding Author and which has been configured to accept email from: Victoria.gibbon@uct.ac.za

Signed by all authors as follows:

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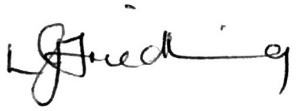

Victoria E. Gibbon