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Fox (*Vulpes vulpes*) involvement identified in a series of cat carcass mutilations

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Abstract

This study was designed to identify the cause of mutilation and death in 32 cats, part of a larger cohort found dead in Greater London, the United Kingdom, between 2016 and 2018. At the time, discussion in the media led to concerns of a human serial cat killer (dubbed The Croydon Cat Killer) pursuing domestic cats, causing a state of disquietude. Given the link between animal abuse and domestic violence, human intervention had to be ruled out. Using a combination of DNA testing, computed tomography imaging, and postmortem examination, no evidence was found to support any human involvement. Instead, a significant association between cat carcass mutilation and the presence of fox DNA was demonstrated. Gross examination identified shared characteristics including the pattern of mutilation, level of limb or vertebral disarticulation, wet fur, wound edges with shortened fur, and smooth or irregular contours, and marks in the skin, muscle, and bone consistent with damage from carnivore teeth. Together these findings supported the theory that the cause of mutilation was postmortem scavenging by red foxes (*Vulpes vulpes*). The probable cause of death was established in 26/32 (81%) carcasses: 10 were predated, 8 died from cardiorespiratory failure, 6 from blunt force trauma, one from ethylene glycol toxicity, and another from liver failure. In 6 carcasses a cause of death was not established due to autolysis and/or extensive mutilation. In summary, this study highlights the value of a multidisciplinary approach to fully investigate cases of suspected human-inflicted mutilation of animals.

Keywords

Felis catus, forensic pathology, mutilation, postmortem examination, scavenging patterns, predation, veterinary forensics, DNA analysis, *Vulpes vulpes*

Between 2014 and 2018, more than 300 dismembered cat carcasses were discovered by members of the public in and around London, the United Kingdom. There was a concern that a single person was responsible for the killing and mutilation of these animals, and that this behavior could progress to harm humans.[2,27] Cat owners felt specifically targeted, and media hype led to people keeping their cats indoors for fear of attack.[29] Cat carcasses were found in conspicuous locations with various combinations of missing heads, tails, or limbs. Wounds were described as being post mortem with smooth edges, but interpretation of these findings varied.[8] Some thought them to be "surgical" suggesting human foul play or intervention, while others considered carnivore scavenging more likely.[3,13,14]

This is not the first time that there has been a need to differentiate between the signs of animal carcass mutilation performed by humans or wild animal scavenging. In 1979, in Alberta, Canada, numerous cattle were found dead with their genital organs or portions of the face and head missing.[23] Tissue edges surrounding the mutilation sites were reported to be "remarkably smooth," and initial blame lay with deranged persons, satanic cults, or visitors from outer space. However, further research concluded that these animals had died from natural causes and scavengers were responsible for the mutilations. More recently in Edmonton, investigations into a spate of dismembered cats found the pattern of injury to be consistent with coyote scavenging.[20] In neither situation was DNA analysis performed on swabs from mutilated carcasses.

The act of scavenging involves investigation of a carcass followed by tearing and removal of soft tissue and bone using teeth and possibly claws.[34] Scavenger DNA can be extracted from transferred saliva that is usually present at the wound margin, providing blood contamination from the host does not inundate small amounts of scavenger DNA. Identifying

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predator or scavenger DNA from saliva deposits on animal carcasses is becoming more regularly used in the context of ecology and wildlife management.[4,12,24] For example, where there is conflict between livestock owners and wild predator species, these methods can confirm or refute allegations relating to particular species. One recent case identified wild boar (*Sus scrofa*) as the killer of a hunting dog where wolves (*Canis lupus*) were first suspected of being responsible.[20] Chances of recovering DNA are higher if the carcass is fresh and the scavenger or predator spends more contact time with it, and decreases with time, excessive decomposition, or extreme weather conditions.[5,12,21]

In the United Kingdom, two of the most common wild scavenger species are the red fox (*Vulpes vulpes*) and Eurasian badger (*Meles meles*). Until now, interest in their scavenging behavior has been driven by their tendency to modify crime scenes by dispersing human remains. However, much of the knowledge in this area is anecdotal, and relevant published literature is limited to a single study that closely monitors the scavenging behavior and patterns of mutilation of the fox and badger on deer remains.[34]

The aim of this study was to identify the cause of death and mutilation of dismembered cats in which there was a suspicion of human foul play.

Materials and Methods

Sample Collection and Storage

The carcasses of 32 mutilated domestic cats (*Felis catus*) were submitted to the Hertfordshire and Metropolitan Police by members of the public between January 2016 and March 2018. Carcasses were individually sealed in police evidence bags, labelled with an identification tag, and frozen at −20 °C for up to 2 years before being delivered to the Department of Pathobiology and Population Sciences at the Royal Veterinary College (RVC), Hawkshead campus. Carcasses were defrosted at room temperature for 1 to 3 days prior to further examination.

Carcass Signalment and Hair Coat Characteristics

For each carcass, approximate age, sex, length of hair coat, and presence of moisture on hair coat were recorded when possible. The age was estimated using carcass size and presence/absence of thymus and recorded as kitten, juvenile (thymus), and adult (no thymus). Males and females were recorded as entire, neutered, male/female of unknown neutering status, or unknown. The length of hair coat was recorded as domestic short haired (DSH) or domestic long haired (DLH). The presence of moisture on the coat was recorded as being diffuse, multifocal, localized to wound (<2 cm diameter from edge of mutilation site) or dry.

DNA Testing

Sampling. Prior to carcass sampling, necropsy tables and boards were disinfected by covering the table in a 1% solution of Virkon-S, scrubbing with a brush using circular motions for 30 seconds, rinsing with Virkon-S, scrubbing for a further 30 seconds, and wiping dry with a clean paper towel. Appropriate PPE was worn and swabs taken before removing the carcass from the bag. Swabs were rolled 10 times with moderate pressure on the fur in the sampling region. If the fur to be sampled was wet, dry swabs were used. If the sampling site was dry, swabs were dampened with sterile water before use. Negative control swabs, either exposed to the air or dampened with sterile water as appropriate, were taken for each case.

Swabs were taken from 20/32 of the most intact mutilated carcasses. For all 20 carcasses, a swab was taken from fur adjacent to a mutilation site, avoiding blood from the carcass. A second swab (wet or dry as detailed above) was taken from fur distant to the mutilation site on the left flank in 12/20 carcasses. Swabs were stored in individual rigid plastic vials in the freezer at −20 °C immediately after sampling. Each swab was tested once, together with appropriate positive and negative controls. Swabs were sent for DNA analysis within 12 months of the postmortem examination.

DNA Analysis. All DNA extractions included a DNA-template-free extraction control (also known as a reagent blank) to monitor for reagent contamination. DNA was extracted from each swab using the QIAmp DNA Investigator kit (Qiagen), and 3 polymerase chain reaction (PCR) tests were applied which targeted dog, fox, and badger DNA (Supplemental Material S1). These PCR tests target regions of the mitochondrial genome and, by design, are specific to the species of interest.[32] The targets were mitochondrial DNA sequences that can be used to identify these 3 species in the United Kingdom. All PCR tests included negative and positive controls. Products were visualized using a 1% agarose gel stained with Gel Red (Biotium), and visible amplicons, plus all controls, were sequenced using BigDye Terminator v3.1(Thermofisher Scientific) chemistry on a Genetic Analyzer 3500xL (Applied Biosystems). DNA sequences were analyzed using Geneious software package 11.1.5 (https://www.geneious.com), and compared to respective validated reference sequences from each species to confirm homology of the results (98% to 100% sequence match). A "positive" result was defined by 1 or 2 swabs from a case providing a DNA sequence that matched the target species.

Control Cats. To determine the background level of fox/dog/badger DNA on nonmutilated cats, samples were taken from 8 live outdoor cats, 5 of which lived with dogs. For each cat, a single swab was taken from the base of the neck and tested for fox, dog, and badger DNA.

Statistical Analyses

Fisher's exact test was used to compare proportions of cases positive for fox or dog DNA between mutilated cats and living

Table 1. Postmortem examination protocol to look for evidence of red fox scavenging in mutilated cat carcasses.

Tissue examined	Location	Features
Skin	All over carcass	Puncture wounds: number, shape, length
	Around MW edge	Reflection: yes/no
		Contour: % irregular/smooth
Hair	All over carcass	Wet: localized to wound, multifocal, diffuse
	Around MW edge	Natural length or shortened
Muscle	All over carcass	Puncture wounds: number, shape, length
	MW surface	Ragged with tags of muscles and nerves or straight edges
		Blood: yes/no
		Adherent organic matter: grass, leaves, grit, debris
	Neck/thorax/pelvis	Tissue bridging[a]
Viscera	Thoracic/abdominal	Present/absent
		Puncture wounds or perforating wounds
Bone	Mutilation site	Fracture or disarticulation
	Mutilation site	Teeth marks: puncture, pit, score, furrow, ragged edge, or stellate cracking

Abbreviation: MW, mutilation wound.

[a]Tissue bridging is characterized by partial tearing of subcutaneous structures or muscle with remaining bridges of nerves, vessels, or connective tissue.

outdoor cats. The McNemar test was used to evaluate whether there was a higher proportion of positive fox or dog results within a group. Fisher's exact test was also used to compare positive dog DNA results from outdoor cats that shared a house with dogs with those that did not live with dogs.

Computed Tomography (CT) Imaging

All carcasses were CT scanned in left lateral recumbency, using a multislice CT scanner (Aquilion ONE/GENESIS Edition 320-slice, Canon Medical Systems). CT DICOM images were reviewed using an imaging processing software (OsiriX Imaging Software). Multiplanar reconstructions were used as needed. A summary report was provided by an ECVDI-certified radiologist.

Postmortem Examination

A standardized protocol to identify and record characteristic features of the carcass and mutilation site was developed (Table 1). Specialized techniques were used to examine skin and bone.

Skin Examination. To visualize skin puncture wounds, hair was removed by hand plucking. If the carcass was fresh and hair was resistant to hand plucking, the skin was removed entirely and sealed in a plastic bag at room temperature to autolyze for around a week until the hair was easily removed. External and internal skin surfaces were examined and small puncture wounds were detected by holding the skin up to the light. The underlying muscle was examined for puncture wounds and tissue bridging (tearing of subcutaneous structures).

Bone Examination. Bones associated with mutilation sites were removed, and soft tissues gently dissected away taking care not to score underlying bone with the knife. Bones were placed in undiluted thick household bleach at room temperature, until soft tissues were easily removed (1–24 hours). Bones were examined and photographed in tangential light to look for signs of teeth marks. Marks were recorded as puncture, pit, score, furrow, ragged edge, or stellate cracking as defined by Andres and colleagues.[1] All postmortem fractures and luxations were recorded using a combination of CT scan reports and gross dissection.

Carcass Preservation

The state of decomposition was recorded for each carcass and graded as follows:

- *Mild:* minimal autolysis of internal organs, +/- maggots
- *Moderate:* hair adherent to skin, internal organs moderately friable, +/- maggots
- *Marked:* skin or hair sloughing, internal organs markedly friable, +/- maggots
- *Mummified:* diffusely brown, leathery and dry

Cause of Death

Routine gross and microscopic examination of tissues were performed to establish the most likely cause of death for each carcass where possible. The following criteria were used to diagnose cardiorespiratory disease as the most likely cause of death: (1) heart weighing over 21 g, (2) significant fibrofatty replacement of myocardium, or (3) significant interstitial fibrosis in combination with one or more of myofiber disarray, intra-alveolar hemosiderophages, or increased pericardial fluid.

Results

Sample Signalment and Hair Coat

The study included 20 adults, 7 juveniles, and 5 kittens of varying sexes and hair lengths. Two had moisture localized to the wound, 23 were multifocally wet, 6 were diffusely wet, and 1 was dry. Details of age, sex, hair length, and amount of

Table 2. Identification of fox, dog, or badger DNA in swabs from 20 mutilated cat carcasses and 8 live outdoor control cats with and without known dog contact.

	Fox	Fox and dog	Dog	Badger	None[a]	Total tested
Mutilated cat carcasses	17	2	0	0	1	20
Control, no dog contact	1	0	0	0	2	3
Control, with dog contact	0	0	3	0	2	5

[a]None: no fox, dog, or badger DNA was identified.

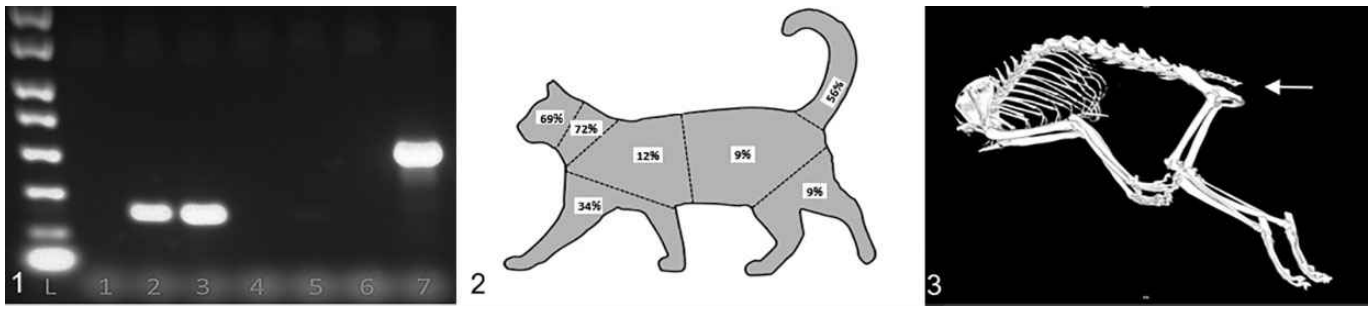


Figure 1. Identification of fox DNA in swabs of the coat of mutilated cat carcasses. PCR amplicons were separated on agarose gels. L = DNA ladder, 1 = extraction control, 2 and 3 = swabs from mutilated cat carcasses, 4 = control swab from live cat, 5 = faint product visible from swab taken from a live cat, 6 = negative control, 7 = positive control (synthetic DNA).[32] DNA sequences identical to reference sequences from foxes were subsequently produced from the products in lanes 2, 3, and 5. **Figure 2.** Frequency of missing body parts in 32 cat carcasses identified by postmortem examination. The most commonly mutilated parts were the head, neck, and tail. **Figure 3.** Postmortem scavenging, cat, case 18. CT image. The head and neck are missing at the level of the seventh cervical vertebra and the tail is absent distal to the fourth caudal vertebra (arrow).

coat moisture in the examined cats are provided in Supplemental Material S2.

DNA Results

Of the 20 carcasses swabbed for DNA, fox DNA was detected in 19/20, and 2 of those had dog DNA also present (Table 2). Badger DNA was not detected on any carcass. No results were produced from any negative control swab taken during this study or laboratory controls.

From the 8 control cats sampled, dog DNA was detected on 3 out of 5 cats that were living with dogs. No dog DNA was identified on any of the 3 control cats that did not live with dogs. Although this result would indicate that cats living with dogs are more likely to have dog DNA present, the difference was not significant ($P = .196$, Fisher's exact test, $n = 8$). Fox DNA was detected in samples from 1 of the 3 control cats that did not live with dogs, although this result was qualitatively weaker than for the mutilated cats (Fig. 1). No control cat tested positive for both fox and dog DNA.

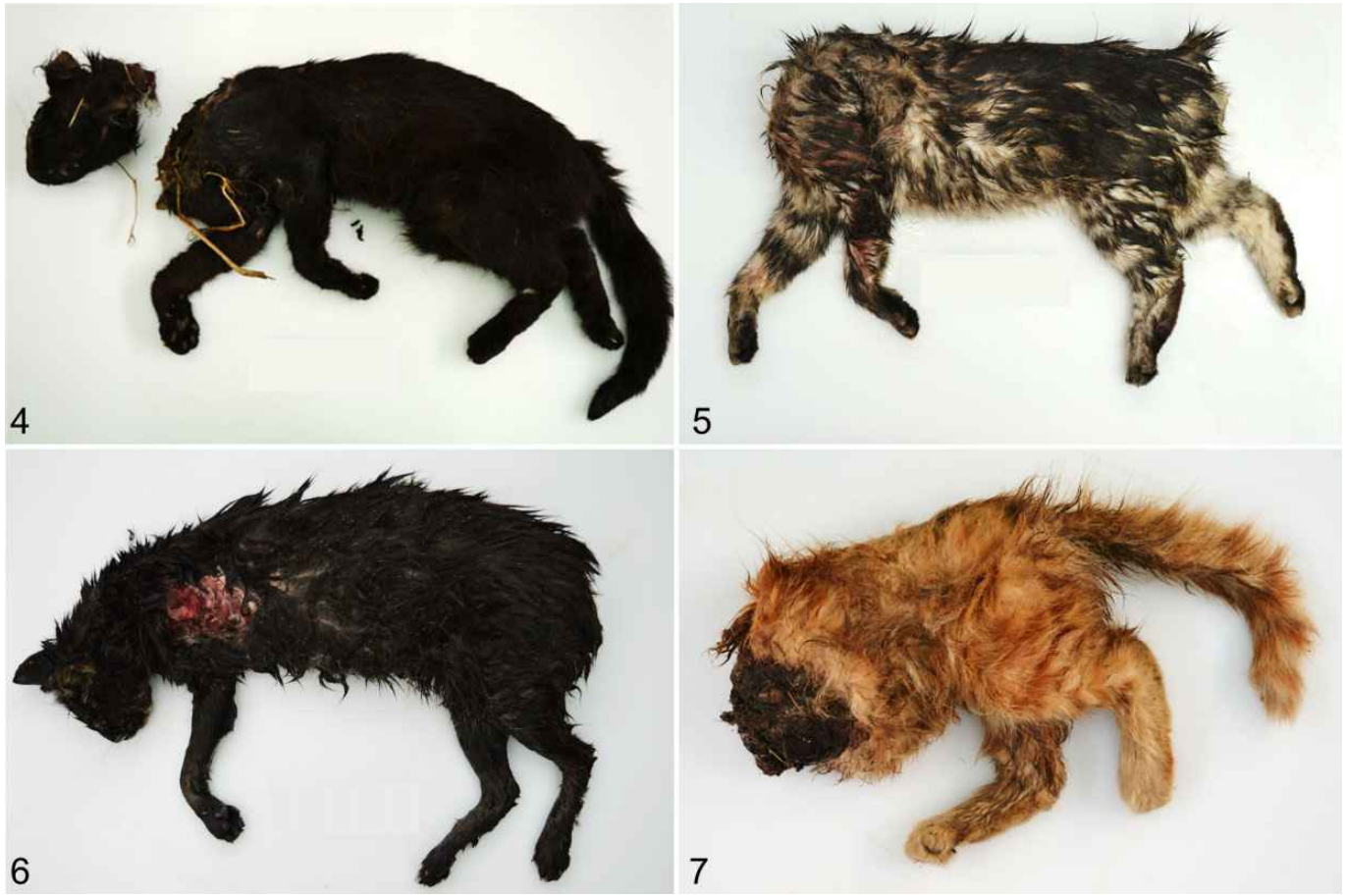
Mutilated cats were more likely to have fox DNA detected on coat swabs than live control cats ($P < .0001$, Fisher's exact test, $n = 20$). There was no significant difference between mutilated and live groups for detection of dog DNA ($P = .123$, Fisher's exact test, $n = 28$). Among scavenged carcasses, more were positive for fox DNA compared to dog DNA ($P = .0001$, McNemar test, $n = 20$); there was no difference in detection of fox and dog DNA among the control cats ($P = .617$, McNemar test, $n = 8$).

Postmortem Examination

Mutilation Sites. There were 40 individual bony mutilations in 32 carcasses. Individual body parts missing were head, neck, tail, forelimb (scapula only or entire limb), cranial half of the carcass (head, neck, and both scapulae, with or without distal forelimb and thorax), or caudal half of carcass (pelvis and sacrum with or without tail and hind limb(s)). Of the 32 carcasses, heads were missing in 22 (69%), necks were missing in 23 (72%), tails were missing in 18 (56%), and scapula or entire forelimb in 11 (34%). The thorax was missing in 4/32 (12%), and the pelvis and hind limbs were missing in 3/32 (9%; Fig. 2). Hind limbs were always missing in combination with the abdomen/pelvis. One carcass only included forelimb parts.

Mutilation Disarticulation Levels. Precise disarticulation levels were assessed with CT imaging (Fig. 3) and details are shown in Supplemental Material S3.

Head and neck. In the single case (case 26) with a missing head only, it was disarticulated at the atlanto-occipital joint. In the 14 carcasses with a missing head and neck, the proximal level of neck disarticulation varied between cervical vertebrae (C)3 and C8. In carcasses 7 and 22, where the heads were present but fully disarticulated, missing cervical vertebrae were between C4-C7 and C1-C5 respectively.



Figures 4–7. Postmortem scavenging by foxes, cat carcasses. Variation in mutilation pattern. **Figure 4.** Case 7. Decapitation and absence of C4–C7 vertebrae. **Figure 5.** Case 4. Absence of head, neck and tail. **Figure 6.** Case 19. Absence of thoracic limb and tail, and diffusely wet fur. **Figure 7.** Case 12. Absence of cranial half of the carcass, multifocal areas of wet fur.

Tail. All tails were disarticulated proximal to coccygeal vertebrae (Cd) 6. One was removed at the base, with the majority occurring caudal to Cd2, Cd3, and Cd4.

Fore and hind limbs. In all 11 forelimb mutilations there was separation of the scapula from the body wall. Of these, 3 were missing the scapulae only, with the remaining humerus and distal forelimb attached by skin and soft tissues. Hind limb mutilations were present in 3 carcasses, and all occurred distal to the femur. In one, tibia and fibula were fractured and distal to these fractures the limb was absent. In the second, mid to distal metatarsals were missing bilaterally. In the third, all that remained of the hind limbs distal to the femur was a separated fragment of distal tibia and fibula.

Transected carcasses. Six carcasses were transected at multiple levels including cervical (C4 and C6), thoracic (T3 and T4), and lumbar vertebrae (L5 and L7).

Mutilation Patterns and Wound Characteristics. There were 13 different combinations of missing body parts, and one collection of individual forelimb parts (Figs. 4–7). The most frequently recorded combinations were a missing head and neck (7/32), a missing tail (5/32), missing head, neck, and thoracic limb(s) 5/32, or missing head, neck, and tail (4/32). Three carcasses had a missing cranial half and tail. Individual carcasses had the following missing: head and tail, cranial half, neck and tail, neck only, caudal half, head and neck and caudal half, caudal half and forelimb, tail and forelimb. Overall, apart from the tail it was more common to find parts of the cranial carcass missing, including individual forelimbs or scapula, with the proximal hind limbs remaining attached to the pelvis with no disarticulation.

In the 32 carcasses, there were 52 wounds, with 1 or maximum 3 in each carcass (Table 3). Of these, 40 were associated with bony mutilations, and 12 involved soft tissue loss only. Soft tissue wounds were present over the carpus, tail base, neck, ear tip, thorax, and abdomen. For 51/52 wounds, there was a degree of skin reflection around the wound and the exposed surface was irregular with tags of muscle, nerves, and connective tissue. The missing ear tip (case 25) was the only exception as the skin was not reflected and the exposed surface was smooth.

The contour of the wound edge varied within a single wound, between wounds on the same carcass and between

Table 3. Gross characteristics of 52 wounds (40 of bone and 12 of soft tissue) on 32 mutilated cat carcasses. Autolysis hindered interpretation of hair length in 7 wounds.

Wound characteristic		Number
Skin contour of wound edge	Irregular	22 (42%)
	≥50% smooth	23 (44%)
Hair length at wound edge	Shortened	36 (69%)
	Natural length	10 (19%)
Presence of dirt in wound	Mud, gravel, grass	37 (71%)
	Clean	15 (29%)

carcasses. Overall, 22/52 (42%) wounds had irregular edges (Fig. 8) and 23/52 (44%) had a smooth contour for half or more of the wound circumference (Fig. 9). The hair length around the wound was shortened in 36 (69%) wounds and was a natural length in 10 (19%; Figs. 8, 9). For 7 wounds, autolysis hindered interpretation of hair length. Thirty-seven (71%) wounds had adherent mud and/or gravel and/or grass and 9 (29%) were clean. One of the tail wounds (case 18) was focally associated with blood.

Soft Tissue Injury

Skin. Of 32 carcasses, 31 showed evidence of full-thickness puncture wounds in the skin. These wounds were sometimes very subtle and hard to visualize. Puncture wounds were variably distributed all over the carcass, and not just localized to the mutilation site (Figs. 10–14). Puncture wounds were oval or rhomboid and varied in diameter from approximately 3 to 20 mm. The total number per carcass varied from 3 to 113.

Skeletal muscle. All 32 carcasses showed puncture wounds in the underlying muscle (Fig. 15). These were generally larger (longer and wider) and more numerous than those in the skin. Tissue bridging was seen in skeletal muscle in one or more of the thorax, pelvis, and neck region in 20/32 carcasses (Fig. 16).

Viscera. In the 20 carcasses with a missing head and neck, the remaining trachea length ranged from 2 to 9 cm length. Eight of these tracheas showed a well-circumscribed punched out notch in the tracheal cartilage or muscle at the transection site and variable perforating wounds distally (Fig. 17).

Penetrating and perforating puncture wounds were found in the liver (16/32), and less frequently in the lung and kidney. Complete or partial evisceration of intestines was seen in 3 carcasses. In one, the intestine had been removed through the anus and the other two via a perforating abdominal wound.

Bony Injury. Teeth marks characterized by pits, scores, punctures, stellate cracking, and furrows were detected in flat (scapula and pelvis), long (humerus, femur and rib), short (metatarsals), and irregular (vertebrae) bones (Figs. 18–21 and Suppl. Figs. S1, S2). Fractures, identified as post mortem by an absence of hemorrhage in surrounding soft tissues, were detected in the scapula, ribs, vertebrae, pelvis, and skull. Cats that had been predated showed a higher percentage of bony injuries toward the front of the body, while those dying from blunt force trauma showed a higher percentage of bone injuries caudally (Supplemental Material 4). The latter is more commonly associated with accidental injury (eg, road traffic accident) rather than nonaccidental injury.[18]

Carcass Preservation. Carcasses were variably preserved. Autolysis was mild in 11 carcasses, moderate in 14, and marked in 6; one was mummified.

Cause of Death (Supplemental Material 5). Of the 32 cats, 10 were suspected to have died from predation. All of these were kittens or juvenile cats, and characteristic findings included missing cervical vertebrae and surrounding soft tissues with associated hemorrhage and puncture wounds. Cardiorespiratory failure was the presumed cause of death in 8 cats. Of these, 2 cases (18 and 24) had hypertrophic cardiomyopathy as the hearts weighed over 30 g and had significant interstitial fibrosis. Four cases (17, 23, 28, and 32) had normal heart weights but significant interstitial fibrosis and an increase in pericardial fluid suggesting cardiac disease as a cause of death. For case 7, the heart only weighed 8.2 g but there was significant interstitial fibrosis, pulmonary hemosiderophages, and an increase in pericardial fluid. In case 2, the heart showed a multifocal fibrofatty infiltrate, consistent with arrhythmogenic cardiomyopathy. Case 31 showed fibrofatty replacement of the myocardium suggestive of arrhythmogenic cardiomyopathy, but also had significant lesions of blunt force trauma, which was identified as the cause of death.

Six cats died from blunt force trauma (assumed road traffic accident), and showed severe blunting of claws together with subcutaneous bruising and variable soft tissue and bone injury. One cat died from ethylene glycol toxicity and one from suspected liver failure. All of these were adult cats. It was not possible to establish the cause of death in 6/32 cats due to a combination of marked autolysis and extent of mutilation.

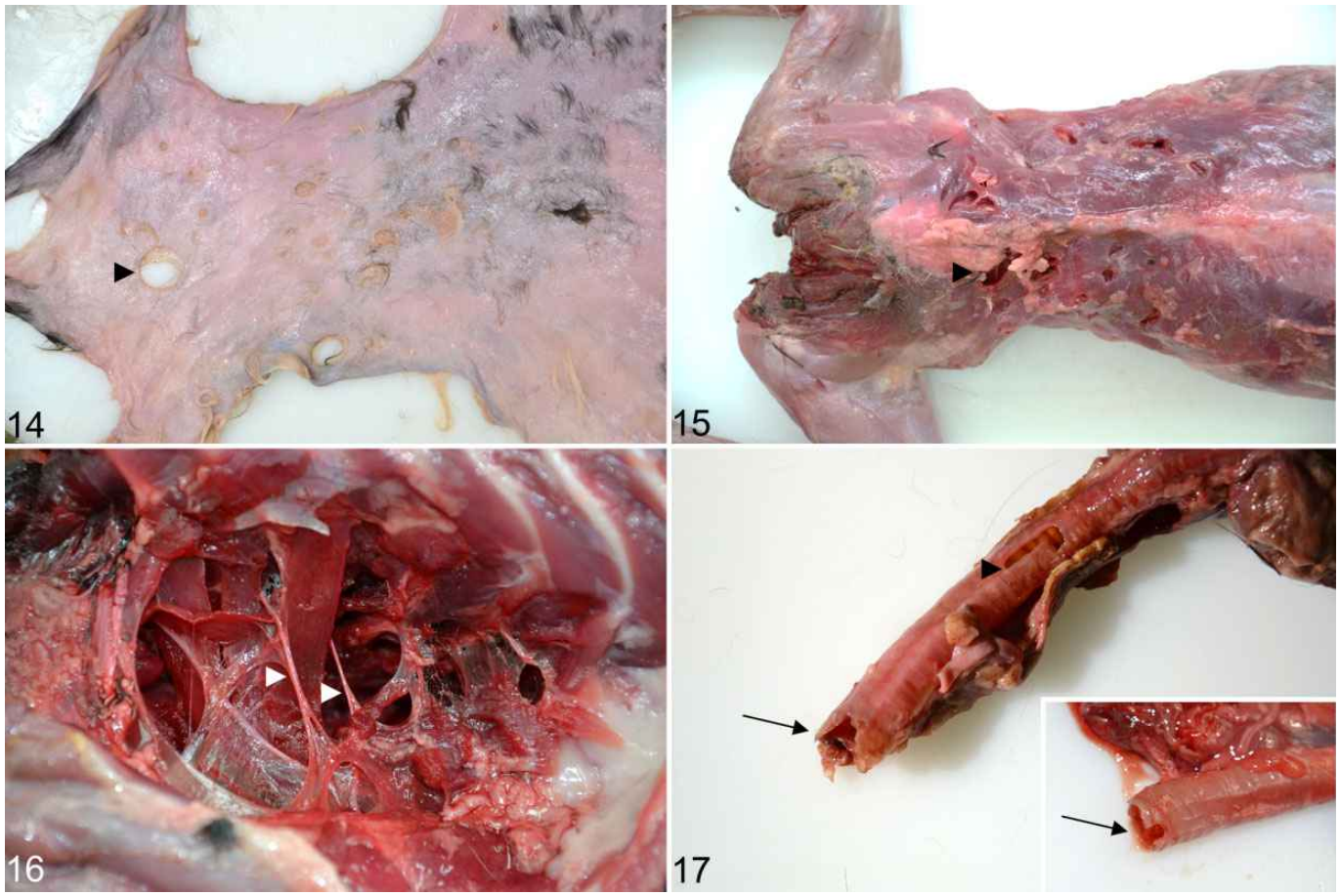
Discussion

This study investigated the causes of cat mutilation and death where there was a suspicion of human foul play. A scientific approach was prompted by the publication of numerous sensational and speculative articles which lacked credibility and scientific rigor. Each of the 32 carcasses were subject to CT scans and a detailed postmortem examination, and swabs for analysis of fox, badger, and dog DNA were gathered from 20 carcasses. Postmortem scavenging by red foxes was found to be the cause of the mutilation in all the carcasses examined. The causes of death were variable, and included fox predation, cardiorespiratory failure, blunt force trauma, and poisoning.

A similar investigation in Canada relied on gross post mortem examinations only to identify coyotes (*Canis latrans*) as the cat mutilator.[20] In our study, in addition to postmortem examination, DNA analysis was carried out on swabs taken from the fur of mutilated cats, and fox DNA was recovered from almost all of them, even though all carcasses had been frozen and thawed and some were in an advanced state of

Figures 8–9. Postmortem scavenging by foxes, cat carcasses. Mutilation wound characteristics. **Figure 8.** Neck wound from decapitated carcass, case 5. The wound edge has an irregular contour and shortened fur (arrow). **Figure 9.** Flank wound, case 20. The wound edge has a smooth contour and shortened fur (arrow). The skin is reflected from the wound edge, and grass is adherent to the wound.

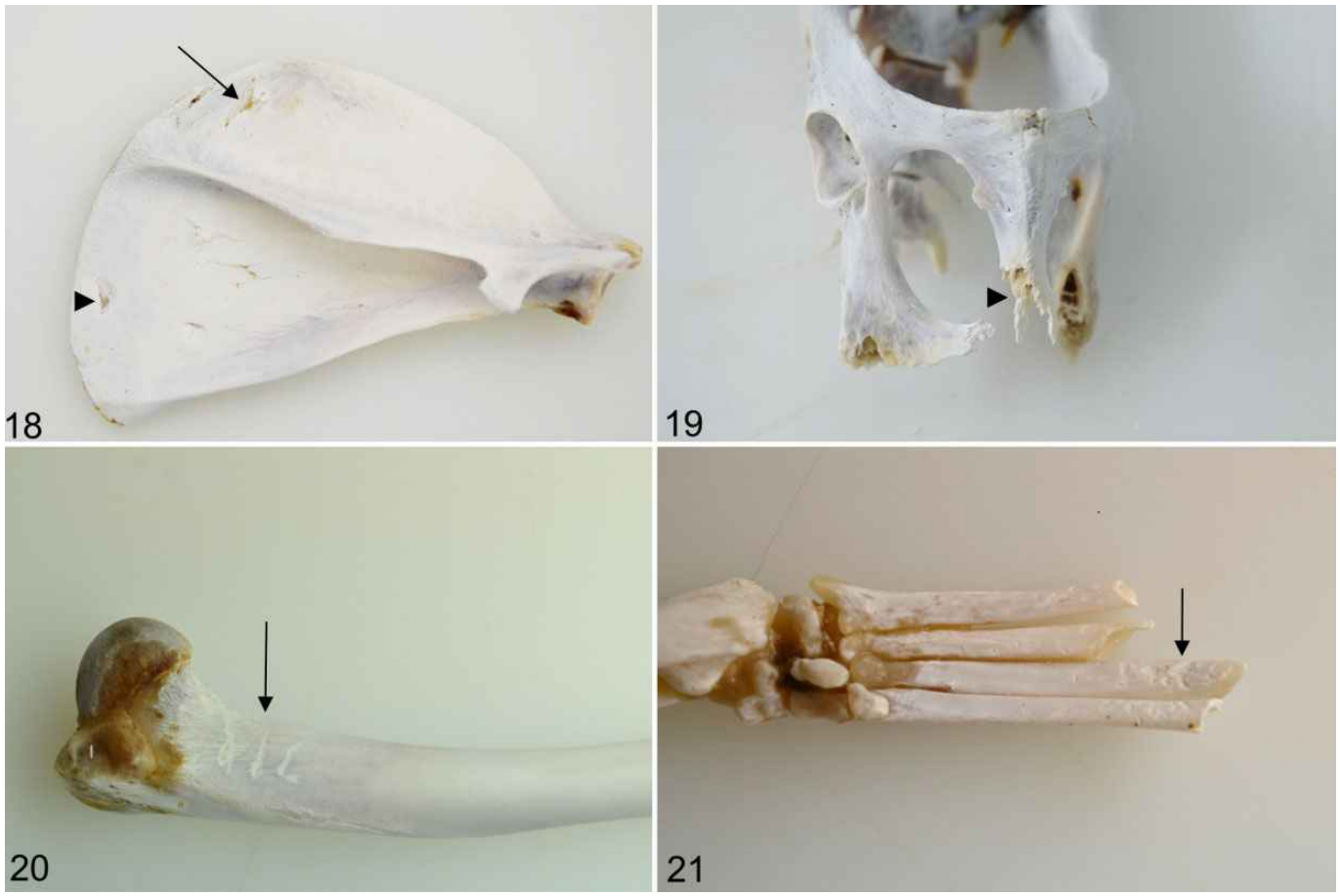
Figures 10–13. Postmortem scavenging by foxes, cat carcasses. Puncture wound appearance and distribution. **Figure 10.** Head and neck with skin partially removed; case 19. There are small indistinct puncture wounds in the skin (arrow) but larger and more frequent puncture wounds in the underlying muscle (arrowhead). **Figure 11.** Skin surface with hair removed by hand plucking, case 4. There are multiple, subtle, variably sized, full-thickness puncture wounds (arrowheads) around the mutilation site. **Figure 12.** Skin removed (subcutaneous aspect), case 6. There are multiple, obvious puncture wounds distant from the mutilation site. *, area of mutilated head and neck. **Figure 13.** Skin (external surface), case 8. After removal of the hair by autolysis, numerous variably sized puncture wounds are visible.



Figures 14–17. Postmortem scavenging by foxes, cat carcasses. Puncture wounds and common soft tissue injuries. **Figures 14–15.** Case 13. Corresponding puncture wounds (arrowheads) in the skin (Fig. 14, subcutaneous aspect) and musculature (Fig 15). **Figure 16.** Thoracic wall, case 26. Tissue bridging: tearing of subcutaneous tissues caused by shearing forces from shaking the carcass during scavenging, with remaining strands of nerves and fascia (arrowheads). **Figure 17.** Trachea, case 27 (inset: case 18). There is a characteristic notch at the mutilation site (arrows) and a puncture wound in the more distal trachea (arrowhead).

autolysis with wet fur. Dog DNA was recovered from 2 carcasses, but this was in addition to fox DNA. The recovery of dog DNA was not thought to be related to scavenger activity because some living cats were found to carry dog DNA in background levels, and few carcasses carried dog DNA compared to fox DNA. Fox DNA was identified from one living cat, although a qualitative assessment of the amount of fox DNA present suggested low levels compared to the mutilated carcasses. The risk of DNA contamination during the postmortem examination was considered negligible as strict precautions were taken to avoid the possibility of DNA contamination from the PM room environment, and appropriate negative controls were used throughout the DNA testing phase. Transfer of fox DNA onto this living cat may have been via secondary contact such as a shared rubbing post. Molecular identification of salivary DNA is widely used in wildlife management and investigation to identify a predator species,[15,24] and in some cases a specific animal or human,[4,5,20,21,25] but this study highlights the usefulness of DNA testing in cases of suspected human-inflicted mutilation on animals.

During the initial phases of the serial cat killer persona, there were certain features that raised particular concern for human involvement. One was the location of the mutilation, in that many of the carcasses had been "beheaded" or were missing tails. Our study confirmed that heads, necks, and tails were the most frequently mutilated body parts, but also detected forelimb mutilation at the scapula-body wall articulation, and less often complete carcass transection. These are similar to the scavenging patterns of foxes on lambs, where the nose, ears, tails, and heads are most often missing, but disarticulated limbs and transected spines are also detected.[16] In over half of the cat carcasses predated or scavenged by coyotes, carcass transection was also identified, but individual missing heads, necks, tails, or forelimbs were not.[22] These observations demonstrate clear differences in the mutilation pattern between the coyote and red fox when scavenging cat carcasses, but similarities in the scavenging patterns of the red fox on different but comparably sized species (ie, cats and lambs). Interestingly, when foxes scavenge larger carcasses such as deer they are seen to target extremities or the most decomposed areas in preference



Figures 18–21. Postmortem scavenging by foxes, cat carcasses. Bleach-digested preparations to show bone damage. **Figure 18.** Scapula, case 4. The supraspinatus fossa has stellate cracking (arrow) and puncture wounds (arrowhead). **Figure 19.** Pelvis, case 25. The ischium has ragged edges (arrowhead). **Figure 20.** Humerus, case 1. There is scoring of the proximal diaphysis (arrow). **Figure 21.** Metatarsals, case 16. The bone has scores and punctures (arrow).

to the head or neck,[34] and when cattle are targeted, lips, udders, or genitalia are removed first.[23] A possible explanation for these variations in scavenging patterns between the small and larger carcasses is the increased strength required to dismember larger carcasses. Adult foxes are solitary scavengers and dismantle carcasses on their own, in contrast to dogs and wolves that operate in groups and can tear carcasses apart together with more combined force.[34] Moreover, foxes are also reported to have relatively weak jaws, and thus may remove accessible soft tissues or disarticulate weaker joints that can be more easily gripped. In humans, joints that support more weight such as the knee or lumbar spine decompose more slowly and are more difficult to disarticulate than cervical vertebrae and the scapula, and studies have shown a clear link between the level of autolysis and disarticulation pattern from canine scavenging.[11] This study proposes that the same happens with cat carcasses, as there was frequent disarticulation of cervical vertebrae and scapula, with no evidence of hind limb disarticulation at the hip or stifle joint. Given that most tail disarticulations occurred between Cd2 and Cd5, these joints may either provide good leverage and/or be weaker and decompose more quickly.

Another feature raising suspicion of human involvement was the appearance of wound edges that were reported to be smooth with shortened fur, similar to wounds resulting from attack with a sharp implement. This study found 44% of wounds to have a smooth contour for over half of the wound circumference. Wounds in cattle carcasses scavenged by foxes have been described as being "surprisingly straight with knife-like cuts."[23] This has also been noted in a lamb carcass predated by a fox (H.M. Martineau, personal observation), and is thought to be due to the shearing force of the carnassial teeth, the main function of which is to slice and grind food.[30] However, this is the first time that shortened fur has been reported in any scavenged or predated carcass. We found shortened fur in 78% of wounds of variable size and location from mutilated long and short haired cats, but not in lamb or rabbit carcasses predated and scavenged by foxes. Interestingly, a study comparing the different viscoelastic properties of animal hair found cat hairs to behave differently when compared to 6 other domestic species including rabbit.[28] Cat hairs were shown to have the lowest overall ultimate strength, which could potentially predispose the cat hair to fracture when put under tension

during fox scavenging, although more research is required to confirm this theory.

Other characteristic features of fox-scavenged cat carcasses were wet coats, puncture wounds having shapes consistent with carnivore teeth all over the skin,[6] a well-circumscribed notch in the tracheal cartilage at the decapitation margin, tissue bridging in soft tissues, and teeth marks in bones. A study looking at the scavenging behavior of captive foxes on deer carcasses found that the foxes investigated food by sniffing and licking it first, and then biting and releasing the carcass before caching or scavenging.[34] This behavior has also been seen when foxes scavenge cattle[23] and porpoise carcasses,[17] providing a possible explanation for why almost all the cat carcasses had wet coats with skin puncture wounds everywhere. This contrasts with cat carcasses predated by coyotes, where there was no mention of wet coats, and puncture wounds were only recorded around mutilation sites.[20] This may reflect different behavior of the coyote, or that puncture wounds were not easily seen through the fur. In this study, coat hair was removed by purposefully autolyzing carcasses where necessary to facilitate fur removal, before ruling out the presence of skin puncture wounds. Interestingly, more puncture wounds were found in the underlying muscle than the skin. This is thought to be because skin is a malleable tissue that will sometimes stretch rather than split, but muscle autolyzes more quickly than skin making it softer for tooth impression when mutilated after death.[31] Puncture wounds from teeth were also considered to be the cause of the notch noted in the tracheal cartilage in 8 decapitated carcasses. This is a previously unreported finding in scavenged carcasses, and could represent another way of differentiating between decapitation caused by sharp-force injury and scavenging or predation. Tissue bridging (partial tearing of subcutaneous structures or muscle), that can arise from shearing forces associated with shaking of the carcass, was also present in over half of the fox-scavenged carcasses. This is similar to the coyote and may indicate that both species shake the carcass during dismemberment. Another difference between coyote and fox scavenging was the evisceration pattern. With coyotes, many cat carcasses showed trailing colon and missing intestines, whereas with fox scavenging, only 3 had their intestines removed, and other internal organs had puncture wounds but were mostly still present. The marks identified on multiple bones from mutilation sites included pits, punctures, furrows, and scores. These tooth/claw marks are reported to be common to the scavenging carnivore in general (ie, dog, fox and badger), but not specific to the red fox per se.[34]

Regarding the causes of death, where established, fox predation and heart failure were the most frequent. Foxes are well-recognized predators of other farmed and wild species,[10,25,26] but there are no published reports of foxes attacking cats. However, studies have shown that foxes are anthropogenic, with a large proportion eating scavenged meat including cat.[7,19] This raises the question regarding predatory behavior, and whether foxes have always preyed on cats, or changes in population densities of cats and foxes in urban areas or food availability have led to predatory behavior. In our study, all those predated were kittens or juveniles, which suggests small size or "inexperience" may be predisposing factors, although one might equally consider older animals weakened by debilitating diseases to appear equally vulnerable.

In conclusion, a multidisciplinary approach combining postmortem examination, CT imaging, and DNA analysis provided convincing evidence that the cause of mutilation in all 32 cat carcasses examined was scavenging by the red fox. The DNA testing was crucial to this work, as it not only allowed determination of the actual species causing mutilation but also ruled out involvement of the dog and badger, other commonly recognized scavenger species in the United Kingdom. With this information, CT imaging and postmortem examination could be interpreted to identify features specific to these carcasses, such as the mutilation pattern, limb and vertebral disarticulation levels, wound edge characteristics, dampness of the coat, puncture wounds in the skin and muscle, tooth marks on bones, and appearance of the wound edges. The results of this study have already proven invaluable, by providing robust scientific evidence with which to compare postmortem findings in two smaller scale investigations into the cause of unexplained cat deaths and mutilations in the United Kingdom, both of which were shown to be caused by human intervention.[9,29]

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Supplemental Material

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