Scavenger species-typical alteration to bone: using bite mark dimensions to identify scavengers

Alexandria Young,[1] Ph.D.; Richard Stillman,[1] Ph.D.; Martin J. Smith,[1] Ph.D.; Amanda H. Korstjens,[1] Ph.D.

[1]Faculty of Science and Technology, Bournemouth University, BH12 5BB

ABSTRACT

Scavenger-induced alteration to bone occurs whilst scavengers access soft tissue and during the scattering and re-scavenging of skeletal remains. Using bite mark dimensional data to assist in the more accurate identification of a scavenger can improve interpretations of trauma and enhance search and recovery methods. This study analyzed bite marks produced on both dry and fresh surface deposited remains by wild and captive red fox (*Vulpes vulpes*) and Eurasian badger (*Meles meles*), as well as domestic dog (*Canis familiaris*). The bite marks produced by foxes were distinguishable from those made by badgers and dogs based on ranges of mean length and breadth of pits. The dimensional data of bite marks produced by badgers and dogs were less discernible. Bone modifications vary due to a variety of factors which must be considered, such as scavenger species-typical scavenging behavior, scavenger species' dentition, condition and deposition of remains, and environmental factors.

Keywords: Forensic Science; Forensic Archaeology; Forensic Anthropology; Taphonomy; Scavenging; Bite marks; Canid; Mustelid

Mammalian scavenger-induced alteration to bone can produce both fractures and bite marks on bone surfaces which can obscure and hinder trauma interpretations associated with a set of remains (1-3). The type, dimension, location, and how modifications to bone surfaces are produced by scavengers can vary due to the following factors: species-typical scavenging behavior and scattering patterns; species' dentition, body size, jaw size, and bite force; the condition and deposition of remains, carcass size and bone morphology; and environmental factors (4-9). The analyses of bite marks can aid forensic scientists, investigators, police specialist search officers, and other fields of study, such as archaeology, anthropology, zooarchaeology, taphonomy, palaeoecology, and palaeopathology, in the identification and interpretation of scavengers, the condition and deposition of a set of remains, and the assessment of trauma. Similarly, the analyses of bite marks can assist in enhancing search and recovery methods of scavenged remains by identifying a scavenger and its associated scavenging behavior and scattering patterns. Scavenging behavior and patterns influence the likelihood of a scavenger to scavenge a set of remains; when, how, and to what intensity scavenging occurs; and what areas of the remains are modified through scavenging, disarticulation, or transportation. An accurate interpretation of a scavenger species' scavenging behavior and patterns can indicate key reference points within and around a crime scene area to be searched.

The red fox and Eurasian badger are the largest and most common wild scavengers of surface deposited remains within a mixed temperate woodland environment within the U.K. and to a wider extent Northwestern Europe (10-11). Scavengers of six deer carcasses surface deposited within a typical Northwest European woodland environment were observed in a forensic archaeology study (10-11) using infrared motion detection cameras which recorded the scavenging activities of wood mouse (*Apodemus sylvaticus*), gray squirrel (*Sciurus carolinensis*), buzzard (*Buteo buteo*), carrion crow (*Corvus corone*), red fox, Eurasian badger, and domestic dog. A survey of U.K. police specialist searchers further indicated that these scavenger species can scavenge human remains and affect the search and recovery of buried and surface deposited human remains (12).

There are four main types of bite marks: pits, scores, punctures and furrows (6,13-16). Rodent scavengers do produce gnaw marks on bone surfaces, commonly seen as parallel striations, oblong hexagonal marks termed windows, and uneven margins (5,17). Avian scavengers, dependent on beak morphology, are also capable of producing conical punctures on bone surfaces whilst pecking at soft tissue (18). However, the production of pits, scores, punctures, and furrows on bone surfaces within this study is limited to the dentitions and scavenging activities of red fox, Eurasian badger, and two size groups of domestic dog (23 cm – 35 cm height, 4 kg- 8 kg weight; 36 cm – 42 cm height, 10 kg – 17 kg) (19-20), thus these three species are the focus of this paper.

Pits are indentations in the bone surface made by individual tooth cusps which do not penetrate the bone cortex (6,15-16,21). Punctures are often irregular shaped marks caused by a tooth penetrating cortical bone (6,15). The canine and carnassial teeth, which are used in the shearing of soft tissue, can puncture bone (6,14,19). Furrows, created by premolars and molars, are longitudinal marks commonly located at the ends of bones where scavengers have tried to gain access to marrow (6). A score is any type of mark for which the length is three times greater than the breadth and is often the result of a tooth sliding after creating a pit (16,22).

Previous studies have used the dimensional data of bite marks to identify the general size of scavengers and occasionally taxa (8,14,16,21,23-25). Quantitative methods of analyses have primarily included comparisons of measurements of the mean and maximum length and breadth of pits, scores, and, to a lesser extent, punctures (8,14,16,21,23-25). The majority of archaeological, zooarchaeological, and forensic studies that have analyzed bite marks focused their analyses on marks produced by wolves (*Canis lupus*), domestic dogs, coyotes (*Canis latrans*), hyenas (*Crocuta crocuta*), lions (*Panthera leo*), leopards (*Panthera pardus*), lynx (*Lynx lynx*), and bears (*Ursidae*) which are known to either produce faunal assemblages found in the archaeological record or to be the largest and most prevalent carnivore within their environment (3,4,6,8,14-16,21,23-28). In contrast, research into the dimensional data of bite marks produced by red foxes is limited and, even more so, that of Eurasian badgers (8,16,25).

The majority of forensic studies on scavenger modification of skeletal remains tend to use qualitative methods to describe modifications (6,15). The focus of such forensic studies has not been towards identifying a scavenger species or its scavenging behavior and patterns but has instead focused on the general characterization of bone modification produced by a biological family of scavengers (6,15). This generalization of bone modification and carcass utilization of a single biological family assumes that all scavenger species within that family share the same scavenging behavior and patterns regardless of different factors, such as environment, region, weather, topography, trophic resources, and intra- and inter-species interactions. Moreover, regardless of such factors scavenger species within the same family are theorized to produce the same bite marks on bone surfaces. Different scavenger species within the same family can have different tooth dimensions, bite forces, jaw muscle strength, and scavenging behaviors and patterns, as well as be differently affected by various factors, which can affect the type of bite marks produced on bone surfaces (9-11,20).

This paper addresses three hypotheses relating to scavenger-produced bite marks on surface deposited skeletal remains:

- Hypothesis 1) Wild red foxes were observed in Young *et al*. (10-11) as the most frequent wild mammalian scavengers of surface deposited deer (*Cervus nippon; Capreolus capreolus*) in the U.K. The scavenging behaviors of captive red foxes toward pig (*Sus scrofa*) bones were also observed for comparison in the same study (11). The dentition of captive and wild scavengers of the same species will not be different. However, individual scavengers of the same species can show different scavenging behavior and patterns dependent on a variety of factors, such as trophic resources, environment, and region (9,29-30). Additionally, differences in scavenging behavior can potentially exist between captive and wild scavengers of the same species (9,31-32). Therefore, Hypothesis 1 predicts that the bite mark dimensions of captive and wild red fox will not be significantly different but may show differences in appearance and locations of bone modifications.;

- Hypothesis 2) The dentition of domestic dogs is also considered within this paper because other than red foxes, domestic dogs are the largest canid in the U.K. with potential access to outdoor remains and can produce similar types of bite marks (6-7,24-25,33-37). The red fox and domestic dog are from the same family of canids with similar dentitions but different body sizes, tooth cusp sizes, jaw muscle strengths, bite forces, and scavenging behavior and patterns (11,19-20,33,35-36,38). Thus, Hypothesis 2 predicts that the bite mark dimensions of the red fox will be smaller than those of dogs of equal or greater body size and larger than dogs of a smaller body size.;
- Hypothesis 3) The red fox, domestic dog, and Eurasian badger have dentitions (19) that are capable of producing the same types of bite marks. However, the tooth morphology of the Eurasian badger and these canids differ, such that the dentition of the badger includes generally broader tooth cusps and molars with a more scallop-shaped surface than those of canids (19,39). Moreover, the scavenging behavior and patterns, jaw muscle strength, body size, and bite force of the Eurasian badger, red fox, and domestic dog are different (11,19,33,35-36,38). Therefore, Hypothesis 3 predicts that the bite mark dimensions of the Eurasian badger will be greater than those of the red fox and domestic dogs.

The aims of this paper are: to test these hypotheses; identify the ranges of bite marks' mean lengths and breadths for the red fox, Eurasian badger, and domestic dogs; and assess the use of bite mark analysis in the identification of a scavenger species.

Materials and Methods

A sample of scavenged deer bones was obtained from six deer carcasses (*Cervus nippon*; *Capreolus capreolus*) surface deposited in a mixed temperate woodland in the U.K. Within the U.K., it is not possible to conduct forensic archaeology studies in which human cadavers are exposed to outdoor taphonomic agents and factors because of various ethical and legislative constraints (40-41). However, it is possible to utilize deer as animal analogues in forensic studies seeking to recreate outdoor crime scene scenarios in the U.K. because deer are wildlife and do not present a risk in the spread of disease to domestic livestock (42). Previous studies using deer as human proxies did show some similarities in the scavenging behavior and patterns of different scavenger species towards deer and human remains (10-11, 43).

All deer were about two years old and included both males and females. One deer was provided as gralloched (no head, no hooves, and no internal organs) but the other five deer were fresh whole carcasses (10-11). All six deer, received from an unconnected culling project, were surface deposited and had a gunshot wound (.308-calibre; c. 30 mm to 50 mm) on the right side of the thorax (10-11). All six deer were observed being repeatedly scavenged by at least six wild red foxes at different times over an average length of exposure of 81.17 days and maximum of 210 days (10-11). Wild Eurasian badgers were observed near the deer but did not scavenge any remains, whereas captive badgers were observed scavenging fresh and dry bones (11). Only one of the deer was scavenged by a domestic dog, a Staffordshire Bull terrier, which only lasted for a total time of one hour and 30 minutes (11). The sample size of marks obtained from all scavenged deer included 376 pits, 57 punctures, and 59 scores found on the following skeletal elements: cranium, mandible, hyoid, rib, scapula, humerus, cervical vertebra, thoracic vertebra, lumbar vertebra, pelvis (innominates), femur, tibia, metatarsal, tarsal, and phalanx.

Bite marks on bones were also obtained from feeding experiments conducted with seven captive red foxes and three captive Eurasian badgers from the Wildwood Trust, Kent, U.K., and at the New Forest Wildlife Park, Ashurst, U.K. (11), as well as 10 domestic dogs. Domestic dogs were divided between five small-sized dogs and five Staffordshire Bull terriers. The five small breeds used within this study and their average sizes were as follows: Cairn Terrier (23 cm – 33 cm height, 3.6 kg - 4.5 kg weight); Norfolk Terrier (23 cm – 25 cm, 5 kg – 5.5 kg); Havanese (22 cm – 29 cm; 4.5 kg – 7 kg); Miniature Schnauzer (30.5 cm - 35 cm; 4.5 kg – 8 kg) (37). The average size of the Staffordshire Bull terrier breed is a height of 36 cm – 42 cm height and weight of 10 kg – 17 kg (37). Smaller-sized dogs (23 cm – 35 cm height, 3.6 kg – 8 kg weight) were added to the study for further comparison to red foxes because red foxes have a smaller body size (35 cm – 50 cm height; 5 kg – 10 kg weight) and bite force relative to Staffordshire bull terriers (7,33,36). Staffordshire bull terriers are henceforth referred to as Staffordshires within this study.

All captive and domestic scavengers were given the same types of bones so that marks could be compared. Foxes, badgers, and dogs each received eight dry bones in total. Dry roast ham bones were chosen for health and safety purposes, in particular not to harm the digestion and dentition of dogs, and were obtained from a pet store. Each scavenger was provided with two bones at a time and was allowed to keep bones for two weeks. Observations of scavengers during feeding sessions with a variety of different foods found that two weeks was ample time for scavengers to produce multiple marks and bone fragments. Bite marks observed on bone samples scavenged seven captive red foxes included seven pits, 31 scores, and two punctures. A total of three captive Eurasian badgers produced nine pits and two scores but no punctures. The sample of bones scavenged by small dogs consisted of eight pits, 18 scores, and no punctures. The Staffordshires produced a sample of seven pits, seven scores, and no punctures.

The bite marks on deer bones were not divided between epiphyseal and diaphyseal ends because bite marks were analyzed on bones from across the skeleton, not just long bones. The dry pig bones given to captives and dogs were limited to long bones but were not separated between marks found on epiphyses and diaphyses so that the dimensional data of marks found on deer and pig bones could be compared. All bite marks within this study were identified by the naked eye and a hand lens (2-6x) and measured with handheld digital calipers. For each sample of marks, the mean maximum length and breadth, standard deviation, maximum and minimum length and breadth, and 95% confidence interval are presented. Pearson's and Spearman's coefficient correlations were used to test the relationship between length and breadth dimensions for each sample of pits, punctures and scores.

Separate Kruskal-Wallis tests were performed for pit lengths, pit breadths, score lengths, and score breadths. Kruskal-Wallis tests were not performed for puncture lengths and breadths because punctures were only present on the deer bones (*n*= 57) and the bones scavenged by captive red foxes (*n*= 2). This paper also presents the analyses of pits, scores, and punctures for comparison with previous bite mark studies which focused on these mark types (8,16,25). Within each Kruskal-Wallis test the bite mark dimensional data across all samples of scavenged bones were included in order to test whether it was possible to differentiate between fox, badger and domestic dog scavenging as based only on the dimensional data of bite marks. Following the Kruskal-Wallis test, post hoc Mann-Whitney tests were used to further compare the bite mark dimensional data of each scavenger species. For the Mann-Whitney tests, the bite marks from the deer bones were compared to the marks from all other samples. Bonferroni corrections (0.05/4= 0.0125 level of significance regarding pits and scores) were applied to the Mann-Whitney tests to avoid inflating the Type I error. All statistics were conducted with PASW Statistics version 18.

Results

Bones scavenged by wild red fox

Six deer skeletons scavenged primarily by wild foxes were examined. Bite marks were found most frequently on innominates, vertebrae, ribs, scapulae, and long bones (Table 1). Innominates had a wide variety of marks and damage with punctures commonly at the ilium or acetabulum and pits along the iliac crest and ischial tuberosity (Figure 1). Innominates had the highest occurrence of marks (*n*= 148, 30.08%) (Table 1). Furrowing was also present on the epiphyseal ends of long bones (Figure 2). Marks and fragmentation on vertebrae were common at the spinous process, laminae, and transverse processes. Ribs were often fragmented and had more marks located at sternal ends (Figure 3). The majority of marks and fragmentation on scapulae were observed at the medial border

(Figure 4). Marks were found on all areas of long bones but with a higher quantity on hind limbs than front limbs (Table 1) (Figure 2).Damage to long bones included not only marks but also fracturing and fragmentation at epiphyseal and diaphyseal ends (Figure 5). Mandibles were scavenged mainly at the coronoid process and condyle with no damage observed to the mandibular teeth. All other scavenged bones were found to have marks at a wide variety of locations.

Pits (*n*= 376, 76.42%) were the most commonly found type of bite mark on all deer bone surfaces. The relationships between the length and breadth of pits (r_s= .72, *p*<.001), punctures (r_s= .87, *p*<.001), and scores (r_s= .42, *p*<.001) were all positive and significant (Table 2-3). The mean length of pits was 1.46 mm and the mean breadth was 0.92 mm (Table 2-3). The mean length of punctures was 2.83 mm and the mean breadth was 1.94 mm (Table 2-3). The mean length of scores was 6.03 mm and the mean breadth was 0.96 mm (Table 2-3).

Bones scavenged by captive red fox

The bones scavenged by captive foxes were not fragmented but did have heavily chewed ends with numerous furrows found along the end margins (Figure 6). Scores (77.50%) were the most frequent type of bite mark found on the bones scavenged by captive foxes. Pits and scores were visible on both the shaft and ends of bones but punctures were limited to ends.

The relationship between the length and breadth of pits was positive and significant (r= .047, *p*= .68). The relationship between the length and breadth of scores was also positive but was not significant (r= .10, *p*= .30). The relationship between the length and breadth of punctures could not be tested because of the small sample size but the mean length was 5.25 mm and the mean breadth was 3.41 mm (Table 2-3). The mean length of pits was 2.05 mm and the mean breadth was 1.48 mm (Table 2-3). The mean length of scores was 8.53 mm and the mean breadth was 1.07 mm (Table 2-3).

Bones scavenged by captive Eurasian badger

Badgers did not fragment bones but did heavily chew epiphyseal ends such that ends were often removed and showed signs of scooping (Figure 7). Most notably, heavily scavenged bones were coupled with extensive rodent gnaw marks on shafts (Figure 7). The majority of marks on the bones were pits (81.82%). For pits, the relationship between the length and breadth was positive but not significant ($r = .46$, $p = .11$) (Table 2-3). The mean length of pits was 2.72 mm and the mean breadth was 2.00 mm (Table 2-3). The relationship between the length and breadth of scores could not be tested because, like punctures by the captive foxes, there was a small sample size. The mean length of scores was 3.57 mm and the mean breadth was 0.91 mm (Table 2-3). No punctures were found on the bones.

Bones scavenged by small-sized domestic dogs

The bones scavenged by small-sized dogs varied between heavy fragmentation to just marks on bone surfaces. Bones were fractured along the shaft in the form of transverse and oblique fractures. Furrowing was present at the ends of bones but was not extensive. Scores were the most frequently occurring type of mark found on the bones (69.23%).The mean length of pits was 3.25 mm and the mean breadth was 1.88 mm (Table 2-3). The relationships between the length and breadth of pits and scores were positive and significant ($r = .66$, $p = .04$; $r = .69$, $p = .001$). For scores, the mean length was 9.75 mm and the mean breadth was 1.91 mm (Table 2-3). No punctures were observed for any of the bone scavenged by small-sized dogs.

Bones scavenged by Staffordshire Bull Terriers

Similar to the bones chewed by smaller-sized dogs, the bones scavenged by Staffordshires were found whole and heavily fragmented with marks (Figure 8). In addition to transverse and oblique fractures, longitudinal fractures were present along shafts (Figure 8). Pits and scores were found in the same quantity on bones ($n = 7$). No punctures were found. Pits had a mean length of 2.95 mm and a mean breadth of 2.20 mm (Table 2-3). Scores had a mean length of 8.1 mm and a mean breadth of 1.50 mm (Table 2-3). The relationship between the length and breadth of pits and scores was positive and not significant (r_s= .43, *p*= .17; r_s= .21, *p*= .32).

Comparison of Samples of Scavenged Bones

Pit Dimensions

The range of the mean pit length of the bones scavenged by captive foxes, and the deer bones was < 2.5 mm and mean pit breadth was < 1.5 mm (Table 2-3). In contrast, the range of the mean pit length of bones scavenged by captive badgers, small-sized dogs, and Staffordshires was > 2.5 mm and mean pit breadth was > 1.5 mm (Table 2-3). More specifically, the range of the mean pit length of small-sized dogs was > 3 mm and mean pit breadth was < 2 mm.

Pit lengths from all samples were found to be significantly different, *H* (4) = 49.86, *p*<.001. The pit lengths found on the deer bones were significantly different to those on the bones scavenged by captive foxes (*U*= 628.50, *r*= -.12), captive badgers (*U*= 429.50, *r*= -.20), small-sized dogs (*U*= 219.50, *r*= -.21), and Staffordshires (*U*= 186.00, *r*= -.20). Pit breadths were also significantly different for all samples (*H* (4) = 62.19, *p*<.001). The pit breadths on deer bones were also significantly different to the bones scavenged by captive foxes (*U*= 430.00, *r*= -.16), captive badgers (*U*= 283.00, *r*= -.22), small-sized dogs (*U*= 133.50, *r*= -.23), and Staffordshires (*U* = 61.00, *r*= -.22).

Score Dimensions

The range of all mean score lengths was > 3.5 mm, the majority of which were > 6 mm (Table 2). The range of mean score breadth of bones scavenged by captive foxes, captive badgers, and the deer bones was < 1.5 mm. The range of mean score breadth of bones scavenged by dogs was < 2 mm (Table 3). Score lengths and breadths from all samples proved to be significantly different (*H* (4) = 22.07, *p*<.001; *H* (4) = 25.81, *p*<.001). The score lengths on deer bones were significantly different to those on bones scavenged by captive foxes (*U*= 487.00, *r*= -.38) and small-sized dogs (*U*= 262.00, *r*= -.37). Lengths were not significantly different between those on deer bones and bones scavenged by captive badgers (*U*= 20.50, *r*= -.99) and Staffordshires (*U*= 250.00, *r*= -.03). It is important to note that the bones scavenged by captive badgers only had two score marks and thus may not represent a true comparison of score dimensions between samples. Similar to the score lengths, score breadths found on deer bones were significantly different to those on bones scavenged by small-sized dogs (*U*= 156.50, *r*= -.51). However, score breadths on deer bones were not significantly different to those on bones scavenged by captive foxes (*U*= 702.50, *r*= -.19), captive badgers (*U*= 49.50, *r*= -.05) and Staffordshires (*U*= 210.00, *r*= -.12).

Puncture Dimensions

There were no punctures found on the bones scavenged by captive badgers and domestic dogs. The range of mean puncture length of bones scavenged by captive foxes was > 5 mm, whereas the deer bones had a mean puncture length < 3 mm (Table 2). Similarly, the range of mean puncture breadth of bones scavenged by captive foxes was > 3 mm. The range of mean puncture breadth for the deer bones was < 2 mm (Table 3).

Discussion

The condition of the scavenged bones, the areas on bones affected, and the type of bite marks produced on bone surfaces within this study were consistent with previous studies which identified carnivore-induced bone modification (4-6,14-15,21,25-26,44-48). Typical carnivore damage to scavenged bones is concentrated at the epiphyseal ends of long bones, spinous and transverse processes on vertebrae, distal ends of ribs, scapulae, and innominates (4-6,14-15,26,49-50). However, scavenging behavior and patterns causing bone modifications differ between scavenger species, which, in turn, can be affected by a variety of different factors that must be assessed at each crime scene (e.g. condition of a body, seasonal behaviors).

Hypothesis 1

Hypothesis 1 predicted that the bite mark dimensions of captive and wild red fox would not be significantly different; however, this was not found to be true within this study for a variety of reasons. Moreover, Hypothesis 1 correctly predicted that bone modifications produced by captive and wild red fox would show differences in appearance and locations of bone modifications, such that the frequency in which different marks were produced on bone surfaces and which bones were fragmented did vary. The differences in bone modifications produced by wild and captive scavengers of the same species are due to different factors such as the condition and deposition of remains and scavengers' behaviors.

The differences in using dry roast pig bones versus fresh deer remains may have affected the production of bite marks by scavengers. Fresh bone is stronger and more pliable than dry bone because of the presence of collagen and other fluid retaining properties (51-53). In contrast, bone that has dried will lose its tensile strength and pliability through the depletion of collagen and fluids (51-53). Thus, it is necessary to take into consideration the possible impact that a dry or fresh condition of bone can have on the production of bite marks. Nevertheless, Young *et al*. (10-11) indicated that remains initially deposited as fresh can be further scavenged and modified when skeletonized, so it is important to also analyze bite marks produced on dry bones.

The pit lengths and breadths produced by wild foxes on deer bones and those produced by captive foxes on dry pig bones were significantly different. Out of all of the types of bite marks produced by foxes, pit dimensions should show the most similarity because wild and captive foxes have the same dentition and pits are produced by the cusps of teeth. The significant difference in the pit dimensions produced by the captive and wild foxes may be related to the issue of dry versus fresh bone. Dry bone is less pliable than fresh bone thus causing less resistance to the bite of the scavenger and molding of the tooth cusp on the bone surface. Moreover, pits are commonly produced when foxes are disarticulating, crushing, or consuming remains. The lack of articulated elements and soft tissue in the sample of dry bones given to captive foxes will have affected their scavenging behavior and use of dentition whilst scavenging. Variability in tooth wear may have also affected the dimensions of bite marks. Captive foxes will still have tooth wear but will have better maintenance of their teeth.

The score lengths produced by these wild and captive foxes were significantly different but score breadths were not. Scores have the potential for the most variability in their dimensions because they are the result of a tooth sliding across the bone surface (16,22). Scores can be produced after the production of a pit, whilst the scavenger tries to shear meat off of the bone surface, or access the marrow cavity by continuously biting at the epiphyseal ends. Although score breadths were not significantly different, the mean length and breadth of those produced by captive foxes were greater than wild foxes. The greater dimensions produced by captives may be a consequence of their environments, such that there is less competition for food within an enclosure than in an outdoor environment. Captive foxes would have more available time within their enclosure to scavenge the bones, whereas wild foxes would have pressure from other foxes and scavenger species to scavenge, consume, or cache remains as quickly as possible.

The number of punctures present on the dry bones was much less than those on the deer. The loss of collagen and tensile strength of the dry bones would have been expected to be more conducive to the creation of punctures than the fresh bones. The lack of punctures may be a result of differences in scavenging behaviors between the captive and wild scavengers. In Young *et al*. (11), the captive foxes were observed scavenging less frequently than the wild foxes because their diet consisted of regular feeds of other food items. Captive foxes were also observed caching bones and other food items. Caching allows foxes to bury and hide items in shallow holes (c.12 cm) for scavenging and consumption at a later time (54-55). Thus, bones retrieved from captive fox enclosures may have had less scavenging due to foxes caching bones prior to scavenging or after limited scavenging, as well as the effect of the foxes being fed a regular diet by keepers.

Hypothesis 2

Hypothesis 2 predicted that the bite mark dimensions of the red fox would be smaller than those of dogs of equal or greater body size and larger than dogs of a smaller body size. Hypothesis 2 was found to be correct for the former and incorrect for the latter dependent on the types of bite marks being analyzed, as well as additional factors. The mean length and breadth of pits and the mean score breadth produced by wild foxes on deer bones and captive foxes on dry pig bones were smaller than those of the Staffordshires and smaller-sized dogs. The mean score length of captive foxes was larger than that of Staffordshires, whereas the length on deer bones was smaller. Measurements of score lengths were the most variable in comparison to those of other mark types, thus it is not the most reliable type of bite mark when comparing scavenger species. There were no punctures present on the dry bones scavenged by the dogs so it was not possible to compare the dimensions of punctures. The smaller bite mark dimensions of wild and captive foxes in comparison to small-sized dogs were not expected because the body size and tooth morphology of the latter would be smaller. The smaller bite mark dimensions of the red fox in comparison to domestic dogs are a result of their tooth cusp morphology, jaw size, and bite force (7,19,36). The bite force of domestic dogs is generally greater than the red fox (7,36) but foxes are capable of completely scavenging, disarticulating, and fragmenting a whole deer carcass (11) Additionally, the jaw size dimensions of the red fox is smaller than the domestic dog, which, depending on the morphology of the bone being scavenged, will influence how a scavenger uses and positions its teeth on the bone (20).

Interestingly, the mean length and breadth of scores and the mean pit length of marks from the small-sized dogs were larger than the marks of the Staffordshires. The sample of bones scavenged by the Staffordshires mostly contained fragmented bones with the ends missing or fractures in the shafts. Thus, additional bite marks may have been present on areas that had been removed through scavenging by Staffordshires, whereas the sample from the small-sized dogs consisted of more complete bones with more marks. In comparison to the Staffordshires, the smaller dogs would have less bite force and smaller tooth morphology which would have affected their scavenging behavior and use of dentition.

Small-sized dogs would have to spend more time scavenging the bones until they fragmented and the marrow cavity was accessed.

Hypothesis 3

Hypothesis 3's prediction that the bite mark dimensions of the Eurasian badger would be greater than those of the red fox and domestic dogs was only found to be correct within the analyses of pits. The bite mark dimensions of badgers were found to be greater than the mean length and breadth of pits produced by foxes, and the mean pit breadth of small-sized dogs. In regards to the red fox, the Eurasian badger has a stronger bite force which will influence the bite mark dimensions (36,56). The smaller mean pit breadth of the small-sized dogs may be a result of the difference in dentition and tooth cusp morphology. Moreover, the larger mean pit length and breadth of the Staffordshires and the larger mean pit length of the small-size dogs is due to the differences in the dentition of canids and mustelids, as well as the smaller jaw size and bite force of badgers (19,36,56).

The dimensions of scores produced by the badgers were also smaller than those of the captive and wild red foxes, and dogs. The sample size of scores produced by badgers was low, so it is not possible to fully compare these dimensions to the other samples. Likewise, there were no samples of punctures from the bones scavenged by domestic dogs or badgers.

Bite Mark Analysis: Identifying a Scavenger Species

Overall there was no consistent pattern in the comparisons of bite mark dimensions of each scavenger species. Nevertheless, it was possible to characterize scavenger species based on the ranges of the mean length and breadth of bite marks. These results further emphasize the necessity to use bite mark analysis in conjunction with qualitative methods of analyses and knowledge of species-typical scavenging behavior and patterns in different environments with different factors in order to fully understand scavengers' effects on a set of remains.

The dimensional data of all of the samples of pits in this study suggest that the range of the mean pit length of the red fox is < 2.5 mm and mean pit breadth is < 1.5 mm. The range of mean pit length of bones scavenged by captive badgers, small dogs, and Staffordshires was >2.5 mm and the range of the mean pit breadth was >1.5 mm. There was greater difficulty in distinguishing between the dimensional data of pit marks by dogs and badgers. The range of mean length and breadth of pits found on the deer bones scavenged by wild foxes and the dry bones scavenged by captive foxes is consistent with the range of mean length (< 2.5 mm) and breadth (< 1.5 mm) of pits found on fox scavenged remains presented in Coard (16), Delaney-Rivera *et al*. (8), and Andrés *et al*. (25).

The dimensions of the different samples of scores were more varied, especially mean score lengths. Score lengths would be expected to have the greatest variability amongst these types of marks because a score is the result of a tooth slipping or dragging across the bone surface which can be the result of a variety of factors such as presence of soft tissue, bone morphology, bite force, condition of remains, and scavenger interactions during scavenging (7-9,16,25,36). All mean score lengths, except for the scores from the captive badger sample (3.57 mm), were > 6 mm and did not show any groupings between mean score lengths from the different samples. The mean score length of the captive fox sample was greater than the mean score length of the samples of deer bones, Staffordshires, and captive badgers, as well as the lengths produced by foxes presented in Coard (16), Delaney-Rivera *et al*. (8), and Andrés *et al*. (25). Mean score breadths of the samples were much less varied than lengths. All mean score breadths were < 1.5 mm except for the mean breadths of the small-sized dog (1.91 mm) and Staffordshires samples (1.50 mm). No distinctions could be made between scavengers based on the mean score length and breadth. The range of mean score lengths (< 6 mm) and mean score breadths (< 1 mm) produced by foxes in Coard (16), Delaney-Rivera *et al*. (8), and Andrés *et al*. (25) were smaller than the range of score dimensions in this study.

The range of the mean length of punctures from the deer bones was < 3 mm and the range of mean breadths was both < 2 mm. However, punctures were either present in small quantities or not found in the other samples and could not be used for comparison. The lack of punctures on the dry bones suggests that there is the potential for the underrepresentation and misinterpretation of bite marks produced on partially to completely skeletonized and/or dry bones. Andrés *et al*. (25) claims that the majority of bite marks on bones are made by scavengers whilst bones are still fresh. This is partly true but it fails to take into account that some scavenger species, like the red fox, can produce further marks when re-scavenging and re-scattering bones (11). Examination into the effects of scavenger-induced alteration to dry bones is equally important as that of fresh bones because damage to dry bones by scavengers can still obscure sites of trauma and may produce ranges of mean length and breadth that differ to marks on fresh bones.

Conclusion

This study has found that bite mark analysis cannot be used alone in the identification of a scavenger species because a variety of factors affect how a scavenger modifies skeletal remains and these must be considered. These factors include species-typical scavenging behaviors and patterns, environment, region, topography, seasonality, scavenger size and dentition, carcass size, trophic resources, and the condition and deposition of remains (8-9,11). Using bite mark data juxtaposed with knowledge of species-typical scavenging behaviors and patterns, as well as the aforementioned factors, assists in the more accurate identification of a scavenger size, taxa and, if possible, species. The identification of scavengers can aid in the assessment of trauma, the condition of the remains, and the interpretation of the deposition site, as well as identify key locations for the search and recovery of additional scavenged remains.

Within this study, it was possible to characterize the range of pit dimensions produced by red foxes. Pit marks produced by red foxes, on both fresh and dry bones, have a range of mean length < 2.5 mm and a mean breadth < 1.5 mm. However, the dimensional data of marks produced by domestic dogs (22 cm – 42 cm height) and Eurasian badgers could not be differentiated from each other within this study. The pit marks of dogs and badgers, on dry bone, have a range of mean length >2.5 mm and a mean breadth >1.5 mm. Foxes, dogs, and badgers could not be distinguished based on score mark dimensions.

Bones scavenged by foxes and badgers show typical characteristics of carnivore-modified bone. Interestingly, bones scavenged by badgers appeared to have more extensive rodent gnaw marks on epiphyseal and diaphyseal ends in the form of parallel striations and windows created by continuous gnawing by rodents trying to access bone marrow. The reason for this can be that badgers take scavenged remains down into sett tunnels where rats can have extended periods of access to remains (11).

Acknowledgements

The authors would like to thank Wildwood Trust and New Forest Wildlife Park for allowing research on their foxes and badgers. Thanks also to the staff, owners, and dogs at ABC for Dogs training center.

References

1. Rothschild MA, Schneider V. On the temporal onset of post-mortem animal scavenging "motivation" of the animal. Forensic Sci Int 1997;89:57-64.
2. Byard R, James R, Gilbert J. Diagnostic problems associated with cadaveric trauma from animal activity. Am J Foren Med Path 2002;23(3):238-244.
3. Schulz I, Schneider PM, Olek K, Rothschild MA, Tsokos M. Examination of post-mortem animal interference to human remains using cross-species multiplex PCR. Forensic Sci Med Pathol 2006;2(2);95-101.
4. Haynes G. Evidence of carnivore gnawing on Pleistocene and recent mammalian bones. Paleobiology 1980;6(3):341-351.
5. Johnson E. Current developments in bone technology. Adv Archaeol Method Theory 1985;8:157-230.
6. Haglund WD, Reay DT, Swindler DR. Tooth mark artifacts and survival of bones in animal scavenged human skeletons. J Forensic Sci 1988;33(4);985-997.

7. Christiansen P, Wroe S. Bite forces and evolutionary adaptations to feeding ecology in carnivores. Ecology 2007;88(2):347-358.
8. Delaney-Rivera C, Plummer TW, Hodgson JA, Forrest F, Hertel F, Oliver JS. Pits and pitfalls: taxonomic variability and patterning in tooth mark dimensions. J Archaeol Sci 2009;36:2597-2608.
9. Gidna A, Yravedra J, Domínguez-Rodrigo M. A cautionary note on the use of captive carnivores to model wild predator behavior: a comparison of bone modification patterns on long bones by captive and wild lions. J Archaeol Sci 2013;40:1903-1910.
10. Young A, Stillman R, Smith MJ, Korstjens AH. An experimental study of vertebrate scavenging behavior in a Northwest European woodland context. J Forensic Sci 2014; (available at doi: 10.1111/1556-4029.12468).
11. Young A, Márquez-Grant N, Stillman R, Smith MJ, Korstjens AH. An investigation of red fox (*Vulpes vulpes*) and Eurasian badger (*Meles meles*) scavenging, scattering and removal of deer remains: forensic implications and applications. J Forensic Sci 2014; (available at doi: 10.1111/1556-4029.12554).
12. Young A, Stillman R, Smith MJ, Korstjens AH. Scavenging in Northwestern Europe: a survey of UK police specialist search officers. Policing 2014;8(2):156-164.
13. Binford LR. Bones: ancient men and modern myths. New York: Academic Press, 1981.
14. Haynes G. A guide for differentiating mammalian carnivore taxa responsible for gnaw damage to herbivore limb bones. Paleobiology 1983;9(2):164-172.
15. Milner GR, Smith VG. Carnivore alteration of human bone from a late prehistoric site in Illinois. Am J Phys Anthropol 1989;79:43-49.
16. Coard R. Ascertaining an agent: using tooth pit data to determine the carnivore/s responsible for predation in cases of suspected big cat kills in an upland area of Britain. J Archaeol Sci 2007;34:1677-1684.
17. Haglund WD. Contribution of rodents to post-mortem artifacts of bone and soft tissue. J Forensic Sci 1992;37(6):1459-1465.

18. Komar D, Beattie O. Identifying bird scavenging in fleshed and dry remains. Can Soc Forensic Sci J 1998;31(3):177-188.
19. Hillson S. Teeth. 2nd ed. Cambridge: Cambridge University Press, 2005.
20. Murmann DC, Brumit PC, Schrader BA, Senn DR. A comparison of animal jaws and bite mark patterns. J Forensic Sci 2006;51(4):846-860.
21. Pickering TR, Domínguez-Rodrigo M, Egeland CP, Brain CK. Beyond leopards: tooth marks and the contribution of multiple carnivore taxa to the accumulation of the Swartkrans Member 3 fossil assemblage. J Hum Evol 2004;46:595-604.
22. Selvaggio MM. Carnivore tooth marks and stone tool butchery marks on scavenged bones: archaeological implications. J Hum Evol 1994;27(1-3):215-228.
23. Andrews P, Fernandez-Jalvo Y. Surface modifications of the Sima de los Huesos fossil humans. J Hum Evol 1997;33:191-217.
24. Domínguez-Rodrigo M, Piqueras A. The use of tooth pits to identify carnivore taxa in tooth-marked archaeofaunas and their relevance to reconstruct hominid carcass processing behaviors. J Archaeol Sci 2003;30:1385–1391.
25. Andrés M, Gidna AO, Yravedra J, Domínguez-Rodrigo M. A study of dimensional differences of tooth marks (pits and scores) on bones modified by small and large carnivores. Archaeol Anthropol Sci 2012;4:209-219.
26. D’Andrea AC, Gotthardt RM. Predator and scavenger modification of recent equid skeletal assemblages. Arctic 1984;37(3):276-283.
27. Pickering TR. Carnivore voiding: a taphonomic process with the potential for the deposition of forensic evidence. J Forensic Sci 2001;46(2):406-411.
28. Selvaggio MM, Wilder J. Identifying the involvement of multiple carnivore taxa with archaeological bone assemblages. J Archaeol Sci 2001;28:465-470.
29. Doncaster C P, Macdonald DW. Drifting territoriality in the red fox Vulpes vulpes. J Anim Ecol 1991;60(2):423-439.
30. Roper TJ, Ostler JR, Conradt L. The process of dispersal in badgers *Meles meles*. Mammal Rev 2003;33(3):314-318.

31. McPhee ME. Generations in captivity increases behavioral variance: considerations for captive breeding and reintroduction programs. Biol Conserv 2003;115:71-77.

32. Vickery S, Mason G. Behavioral persistence in captive bears: implications for reintroduction. Ursus 2003;14(1):35-43.

33. Corbet GB, Harris S. The Handbook of British Mammals. 3rd ed. London: Blackwell Scientific Publications, 1991.

34. Alderton D. Foxes, wolves and wild dogs of the world. London: Blandford, 1994.

35. Sterry P. Complete British animals. London: Collins, 2005.

36. Wroe S, McHenry C, Thomason J. Bite club: comparative bite force in big biting mammals and the prediction of predatory behavior in fossil taxa. Proc R Soc B 2005;272:619-625.

37. American Kennel Club (AKC), 2013. Available from: http://www.akc.org/breeds/index.cfm (Accessed 18 February 2013).

38. Schmitz OJ, Lavigne DM. Factors affecting body size in sympatric Ontario Canis J Mammal 1987;68(1):92-99.

39. Baryshnikov GF, Puzachenko AY, Abramov AV. New analysis of variability of cheek teeth in Eurasian badgers (Carnivora, Mustelidae, Meles). Russian J Theriol 2003;1(2):133-149.

40. Cross P, Simmons T, Cunliffe R, Chatfield L. Establishing a taphonomic research facility in the United Kingdom. Forensic Science Policy and Management 2009;1:187-191.

41. McHanwell S, Brenner E, Chirculescu ARM, Drukker J, Van Mameren H, Mazzotti G, et al. The legal and ethical framework governing Body Donation in Europe: a review of current practice and recommendations for good practice. Eur J Anat 2008;12(1):1-24.

42. Department for Environment Food and Rural Affairs (Defra), 2012. Available from: http://www.defra.gov.uk (Accessed 17 January 2012).

43. Willey P, Snyder LM. Canid modification of human remains: implications for time-since-death estimations. J Forensic Sci 1989;34(4):894-901.

44. Haynes G. Frequencies of spiral and green-bone fractures on ungulate limb bones in modern surface assemblages. Am Antiquity 1983;48(1):102-114.

45. Haglund WD, Reay DT, Swindler DR. Canid scavenging/disarticulation sequence of human remains in the Pacific Northwest. J Forensic Sci 1989:34(3):587-606.

46. Horwitz LK, Smith P. The effects of striped hyena activity on human remains. J Archaeol Sci 1988;15:471-481.

47. Patel F. Artefact in forensic medicine: post-mortem rodent activity. J Forensic Sci 1994;39(1):257-260.

48. Janjua MA, Rogers TL. Bone weathering patterns of metatarsal v. femur and the post-mortem interval in Southern Ontario. Forensic Sci Int 2008;178:16-23.

49. Haynes G. Utilisation and skeletal disturbances of North American prey carcasses. Arctic 1982;35(2):266-281.

50. Shipman P. Life history of a fossil: an introduction to taphonomy and paleoecology. Cambridge: Harvard University Press, 1981.

51. Nicholson R. Bone survival: the effects of sedimentary abrasion and trampling on fresh and cooked bone. Int J Osteoarchaeol 1992;2:79-90.

52. Sauer N. The timing of injuries and manner of death: distinguishing among antemortem, perimortem and postmortem trauma. In: Reichs K, editor. Forensic Osteology: advances in the identification of human remains. Springfield: Charles C. Thomas Publisher, 1998;321-332.

53. Wieberg D, Wescott D. Estimating the timing of long bone fractures: correlation between the postmortem interval, bone moisture content, and blunt force trauma fracture characteristics. J Forensic Sci 2008;53(5):1028-1034.

54. Henry JD. The use of urine marking in the scavenging behavior of the red fox (*Vulpes vulpes*). Behavior 1977;61(1/2):82-106.

55. Caraeu V, Giroux JF, Berteaux D. Cache and carry: hoarding behavior of arctic fox. Behav Ecol Sociobiol 2007;62:87-96.

56. Lee S, Mill PJ. Cranial variation in British mustelids. J Morphol 2004;260:57-64.

57. Gittleman JL, Harvey PH. Carnivore home-range size, metabolic needs and Ecology. Behav Ecol Sociobiol 1982;10(1):57-63.

58. Lindström E. Population ecology of the red fox (*Vulpes vulpes* L.) in relation to food supply [Thesis (PhD)]. Stockholm (Sweden): Stockholm University, 1982.

59. Hiraldo F, Blanco JC, Bustamante J. Unspecialized exploitation of small carcasses by birds. Bird Study 1991;38:200-207.

60. Cavallini P. Variation in the social system of the red fox. Ethol Ecol Evol 1996;8:323-342.

61. Kauhala K, Laukkanen P, von Rége I. Summer food composition and food niche overlap of the raccoon dog, red fox and badger in Finland. Ecography 1998;21(5):457-463.

62. Leckie FM, Thirgood SJ, May R, Redpath SM. Variation in the diet of red foxes on Scottish moorland in relation to prey abundance. Ecography 1998;21:599-604.

63. Revilla E, Palomares F. Differences in key habitat use between dominant and subordinate animals: intraterritorial dominance payoffs in Eurasian badgers? Can J Zool 2001;79:165-170.

64. Kjellander P, Nordstrom J. Cyclic voles, prey switching in red fox, and roe deer dynamics- a test of the alternative prey hypothesis. Oikos 2003;101:338-344.

65. Jarnemo A. Predation processes: behavioral interactions between red fox and roe deer during the fawning season. J Ethol 2004;22:167-173.

66. Selva N, Fortuna MA. The nested structure of a scavenger community. Proc R Soc B 2007;274:1101-1108.

Additional Information – Reprints Not Available from Author

Corresponding Author:

Alexandria Young, Ph.D.

Faculty of Science and Technology, Bournemouth University, BH12 5BB

List of Figures and Tables

distributions of each mark type per sample.

Table 1. The number of bite marks found on each skeletal element of the sample of deer bones scavenged by wild red foxes.

	Bite Marks	
Bone	N	%
Cranium	7	1.42
Mandible	9	1.83
Hyoid	7	1.42
Rib	64	13.01
Scapula	23	4.67
Humerus	14	2.85
Cervical Vertebra	13	2.64
Thoracic Vertebra	19	3.86
Lumbar Vertebra	22	4.47
Innominate	148	30.08
Femur	47	9.55
Tibia	38	7.72
Metatarsal	38	7.72
Tarsal	30	6.10
Phalanx	13	2.64
Total	492	

Table 2. The dimensional data for the length of marks on samples of bones chewed by wild foxes, captive foxes, captive badgers, small dogs and Staffordshire Bull Terrier dogs. Sample sizes, mean, minimum and maximum values, 95% confidence intervals, and standard deviations are presented. Pearson's coefficient (r) and Spearman's coefficient (r_s) are provided showing the relationship between the length and breadth distributions of each mark type per sample.

	N	Mean	S.D.	95% *C.I.*	r	r_s	Minimum	Maximum
Wild Fox Pit	376	1.46	0.72	1.39-1.53		0.72	0.58	5.01
Captive Fox Pit	7	2.05	0.71	1.40-2.71	0.68		1.21	3.12
Small Dog Pit	8	3.25	1.21	2.23-4.26	0.66		1.97	4.81
Staffordshire Pit	7	2.95	0.67	2.33-3.58		0.43	2.35	4.01
Captive Badger Pit	9	2.72	0.83	2.08-3.35	0.46		1.19	3.89
Wild Fox Score	59	6.03	2.83	5.29-6.77		0.42	1.94	13.92
Captive Fox Score	31	8.53	3.03	7.41-9.64	0.10		3.24	14.09
Small Dog Score	18	9.75	4.54	7.49-12.01	0.69		2.67	18.19
Staffordshire Dog Score	7	8.10	3.2	5.14-11.06		0.21	3.68	12.31
Captive Badger Score	2	3.57	0.25	1.28-5.86			3.39	3.75
Wild Fox Puncture	57	2.83	1.23	2.50-3.16		0.87	0.15	6.01
Captive Fox Puncture	2	5.25	1.19	-5.48-15.99			4.41	6.10
Small Dog Puncture	0							
Staffordshire Dog Puncture	0							
Captive Badger Puncture	0							

Table 3. The dimensional data for the breadth of marks on samples of bones chewed by wild foxes, captive foxes, captive badgers, small dogs and Staffordshire Bull Terrier dogs. Sample sizes, mean, minimum and maximum values, 95% confidence intervals, and standard deviations are presented. Pearson's coefficient (*r*) and Spearman's coefficient (r_s) are provided showing the relationship between the length and breadth distributions of each mark type per sample.

	N	Mean	S.D.	95% *C.I.*	*r*	r_s	Minimum	Maximum
Wild Fox Pit	376	0.92	0.34	0.89-0.96		0.72	0.29	2.65
Captive Fox Pit	7	1.48	0.55	0.97-1.98	0.68		0.80	2.46
Small Dog Pit	8	1.88	0.52	1.44-2.32	0.66		1.17	2.89
Staffordshire Pit	7	2.20	0.92	1.35-3.05		0.43	1.45	4.18
Captive Badger Pit	9	2.00	0.76	1.41-2.59	0.46		0.8	3.43
Wild Fox Score	59	0.96	0.65	0.79-1.13		0.42	0.35	4.56
Captive Fox Score	31	1.07	0.47	0.90-1.24	0.10		0.37	2.12
Small Dog Score	18	1.91	0.95	1.44-2.39	0.69		0.65	4.28
Staffordshire Dog Score	7	1.50	0.69	0.85-2.14		0.21	0.12	2.23
Captive Badger Score	2	0.91	0.35	-2.21-4.02			0.66	1.15
Wild Fox Puncture	57	1.94	0.84	1.71-2.16		0.87	0.70	4.26
Captive Fox Puncture	2	3.41	1.75	-12.34-19.16			2.17	4.65
Small Dog Puncture	0							
Staffordshire Dog Puncture	0							
Captive Badger Puncture	0							