AN INVESTIGATION OF PATTERNS OF MAMMALIAN SCAVENGING IN RELATION TO VERTEBRATE SKELETAL REMAINS IN A NORTHWEST EUROPEAN CONTEXT: FORENSIC APPLICATIONS

Alexandria Young

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ABSTRACT

Mammalian scavenging, disarticulating, scattering and removal of human remains can alter and obscure both soft tissue and skeletal remains which are essential to making interpretations and identifications during forensic investigations. The effects of scavenging vary between regions, environments, scavenger species, and crime scene scenarios due to a variety of factors. Nonetheless, there is a gap in the knowledge of scavenger species found within Northwestern Europe. The red fox (*Vulpes vulpes*) and Eurasian badger (*Meles meles*) are the largest wild mammalian scavenger species inhabiting peri-urban and rural environments within Northwestern Europe. These mammalian scavengers have dentitions and bite forces capable of heavily modifying and widely transporting human remains yet there are currently no species-typical and region-specific studies of these scavengers and their impacts on forensic investigations and physical searches for human remains. Forensic scientists, investigators and police search officers have been forced to rely on anecdotal evidence and scavenging studies focused on scavengers not found in this region. Scavenging studies have previously concentrated on scavenger species found in North America and Africa, such as coyote (*Canis latrans*), wolf (*Canis lupus*), hyena (*Crocuta crocuta*), lion (*Panthera leo*) and leopard (*Panthera pardus*), which have differing species-typical scavenging behaviour and patterns in comparison to foxes and badgers. Likewise, knowledge of the characteristics of the effects on bone surfaces of fox and badger scavenging is lacking, more so for the latter scavenger. The overall aim of this thesis is to aid forensic investigations by filling the gaps in the knowledge and identification of red fox and Eurasian badger species-typical scavenging behaviour and patterns.

Avian scavenging can also modify soft tissue and skeletal remains. The buzzard (*Buteo buteo*) and carrion crow (*Corvus corone*) are the most common avian scavengers within this region. The scavenging behaviours of these avians modified soft tissue and affected mammalian scavengers' scavenging behavours.

A survey of police search officers within the U. K. indicated that the scavenging of surface deposited human remains within this region is common and that scavenging affects the recovery rates of remains. Despite the impact of scavenging on the recovery of scavenged remains, there is a lack of knowledge and literature available to forensic scientists, investigators, and police search officers to aid in the identification of scavenger species and scavenger species-typical scavenging behaviour and patterns. Thus these forensic professionals have been relying primarily on anecdotal evidence to identify scavengers or have not made efforts to identify scavengers.

Experiments, conducted in southern England, using deposited deer (*Cervus nippon*; *Capreolus capreolus*) and the observation of captive scavengers found that within a woodland environment common scavengers include wood mouse (*Apodemus sylvaticus*), grey squirrel (*Sciurus carolinensis*), carrion crow, buzzard, Eurasian badger, and red fox. Scavenging activities by all scavenger species observed at remains were affected in various ways by seasonality, trophic resources, territoriality, insect activity, carcass size and condition, and decomposition. Of those scavengers, the red fox was the most frequent scavenger of surface deposited remains. The species-typical scavenging behaviour and pattern, as well as bite mark dimensions, of the red fox proved to differ to that of badgers and other canids, such as domestic dogs (*Canis familiaris*), coyotes and wolves.

The benefits of the knowledge of scavenger species-typical scavenging behaviour and pattern to forensic investigations and physical searches were assessed by applying the results gained from the experiments within this research to current forensic investigations and search exercises performed with police search officers. The application of information on species-typical scavenging behaviour and patterns was found to improve police search officers’ search and recovery efforts of scavenged remains.

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AUTHOR'S DECLARATION

I confirm that the thesis is my own work.

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Alexandria Young

Chapter 1

General introduction

Mammalian and avian scavengers can modify and obscure human remains and so hinder identifications and interpretations of the individual and the associated condition and deposition of the remains. All scavenger species do not share the same scavenging behaviour nor are all crime scene scenarios identical. Despite the variability in scavenger species and crime scenes, the majority of research into the scavenging of human remains is focused on large mammalian scavengers within North America (Haglund *et al*. 1989; Willey and Snyder 1989; Bell *et al*. 1996; Komar 1998). There is no standard range of weight used to classify mammalian scavenger size as large, medium, or small, however, for this research the following range of weights, based on Delaney-Rivera *et al*. (2009) and Andrés et al. (2012), was used to label scavenger sizes: large (> 40 kg), medium (11-40 kg), and small (< 10 kg). Within North America, the majority of such mammalian and avian scavengers include the coyote (*Canis latrans*), wolf (*Canis lupus*), bear (*Ursus americanus*; *Ursus arctos*), domestic dog (*Canis familiaris*), mountain lion (*Puma concolor*), and vultures (*Coragyps atratus*; *Cathartes aura*) (Haynes 1980, 1983a, 1983b; Haglund *et al*. 1988, 1989; Milner and Smith 1989; Willey and Snyder 1989; Komar 1998; Vanlaerhoven and Hughes 2008; Kjorlien *et al*. 2009; Reeves 2009; Spradley *et al*. 2011). Additionally, a large number of scavenging studies focus on large mammalian scavenger species found in Africa, such as hyena (Hyaenidae; *Crocuta crocuta*), leopard (*Panthera pardus*), and lion (*Panthera leo*) (Behrensmeyer and Boaz 1980; Blumenschine 1988; Marean and Spencer 1991; Selvaggio 1994; Domínguez-Rodrigo 1999; Domínguez-Rodrigo and Barba 2006).

These larger scavenger species, even though they are the most prevalent scavenger species within their regions, are not the most common wild mammalian and avian scavengers found within Northwestern Europe, in particular within Britain. The most common avian scavengers in Britain are the carrion crow (*Corvus corone*) and buzzard (*Buteo buteo*). The most common wild mammalian scavenger in Northwestern Europe and the largest within Britain is the red fox (*Vulpes vulpes*), which is widespread in urban, peri-urban and rural regions. The second most common and largest mammalian scavenger in this region is the Eurasian badger (*Meles meles*), but this species is most often limited to rural and peri-urban settings. Despite the dense populations of foxes and badgers in this region, there is a lack of literature discussing these animals' scavenging behaviours and effects on human remains. The red fox does inhabit North America but it is not a main focus of the many scavenging studies conducted in that region where larger canids and felids are found. Even rarer are studies exploring the scavenging of human remains by the Eurasian badger and buzzard even though both are found widespread throughout Northwestern Europe. Forensic scientists, investigators, and police search officers within this region are thus at a disadvantage when investigating scenes involving scavenged human remains.

This chapter introduces the subject of scavenging and its applicability within taphonomic and forensic studies, with an emphasis on the scavenging behaviour and patterns of the red fox and Eurasian badger. Scavenging studies are outlined to highlight the lack of studies based on Northwest European scavenger species. Lastly, this chapter outlines the thesis structure and provides the overall aims and objectives of the thesis.

1.1 TAPHONOMY

Taphonomy is the study of the modifying agents and processes which cause the preservation or assemblage of faunal remains, including peri- and post-mortem modifications (Behrensmeyer and Kidwell 1985; Johnson 1985; Lyman 1994, 4; Andrews 1995). The effects of taphonomic agents and processes on faunal remains are identified and measured through taphonomic analysis (Lyman 1994, 4). Taphonomic analysis has been widely used in both palaeoecological, archaeological, and zooarchaeological research in order to interpret preservation and the accumulation of archaeological assemblages of animal bone (Behrensmeyer 1978; Shipman 1981; Andrews 1995; Fernández-Jalvo *et al*. 2002; Bartosiewicz 2008). The application of taphonomy to assemblages of animal bone is of equal relevance to the analysis of human remains both in a forensic scenario and the archaeological record.

1.1.1 Taphonomy in Archaeology

Within archaeological and zooarchaeological research into taphonomy the focus of taphonomic analysis has included hominin behaviour and animal behaviour that have produced archaeological assemblages of faunal bone and/or hominin bone. In regards to hominin behaviour, taphonomic analysis often focusses on hunting and butchering activities (Olsen and Shipman 1988; Shipman 1981; Bartosiewicz 2008; Thompson and Henshilwood 2011). Taphonomic analysis of animal behaviour includes analyses of the relationship between hominins and fauna in the archaeological record, as well as the assemblage and alteration of hominin and faunal bones by animal scavengers (Olsen and Shipman 1988; Shipman 1981; Johnson 1985; Marean and Spencer 1991; Treves and Naughton-Treves 1999). Taphonomic processes, such as weathering, trampling, chemical agents, root staining, fluvial transport, and other agents associated with an assemblage are also important to analyses. Taphonomic analysis of the animal scavenging of hominin and faunal remains is also of great interest to archaeological investigations and zooarchaeological research.

1.1.2 Taphonomy in Forensic Anthropology and Forensic Archaeology

Scavenging is defined within this research as an animal using their dentition to tear, remove, masticate, or break down soft tissue or bone. In regards to avian scavengers, this definition of scavenging applies to the use of the mandibles to remove, consume, or break down soft tissue or bone. Forensic studies into scavenging draw from the taphonomic research seen in archaeology and zooarchaeology, such that taphonomic processes and agents and their effects on human remains within a forensic context are analysed. For instance, like taphonomic research and its use of actualistic studies, scavenging experiments within forensic anthropology and forensic archaeology seek to recreate the crime scene or forensic scenario in which scavenging occurred. Actualistic methods compare taphonomic processes and/or actions (i.e. scavenging) in the present to those in the past in order to better understand the circumstances surrounding past events (i.e. crime scene scenario) (Lyman 1994, 4). Experiments into scavenging within a forensic context have been used to interpret post-mortem interval (PMI), disarticulation and scattering, interpreting ante-, peri- and post-mortem bone modification, improve field recovery methods, interpret taphonomic preservation and for identifying animal scavenger species (Willey and Snyder 1989; Komar and Beattie1998a,1998b; Pickering 2001; Byard *et al*. 2002; Morton and Lord 2006; Schulz *et al*. 2006). However, the majority of research on the scavenging of human remains has concentrated on large canids and felids which do not inhabit Northwestern Europe, apart from domesticated animals (Appendix I, Table A1-1 for a detailed review of scavenging literature). Table A1-1 highlights the focus of research on scavenger species other than the red fox and Eurasian badger despite their abundance in many urban, peri-urban and rural locations. Table A1-1 and Figure 1.1 also show that previous scavenging studies have primarily been based in North America (39.71%, n= 27) and Africa (23.53%, n= 16).

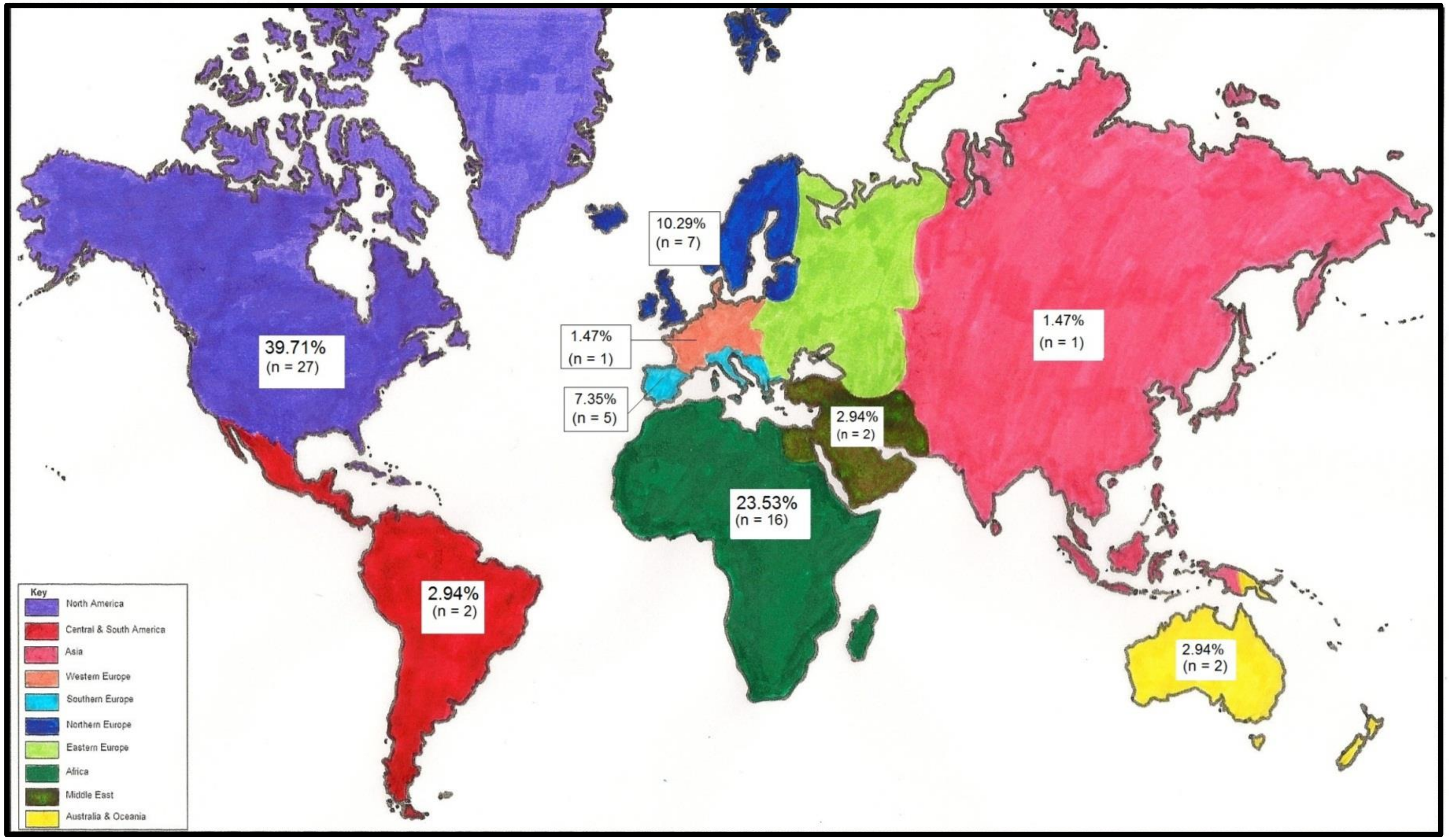

Figure 1.1. The regional concentrations of outdoor scavenging literature from the fields of taphonomy, zooarchaeology, archaeology, forensic anthropology, forensic archaeology, paleoecology, and forensic pathology.

There are a multitude of reasons as to why applying scavenging research to different scavenger species found in different geographical locations should be done with caution. Firstly, differences can be found amongst species, such as skull size, dentition, body size, muscle strength, and bite force. For example the coyote, common to North America has a larger body size than the red fox found in Northwestern Europe; consequently the daily dietary intake of these species will differ and affect their scavenging behaviour (Schmitz and Lavigne 1987; McNab 2000). Furthermore, their ability to disarticulate, scatter and remove remains will differ due to body size and muscle strength (Christiansen and Wroe 2007). Secondly, the behaviour of a scavenger will be impacted by the environment in which it inhabits (Revilla and Palomares 2001, 2002; Gidna *et al*. 2013). Thirdly, each crime scene scenario will vary and those variations must be taken into consideration when conducting an experiment or study because a scavenger's scavenging behaviour can be affected. For instance, some scavenger species may prefer to scavenge when remains are at a certain stage of decomposition.

The gap in the knowledge of red fox and Eurasian badger scavenging of human remains has caused forensic scientists, investigators, and police search officers within Northwestern Europe to make interpretations based on anecdotal evidence and studies specific to species which are not scavengers within this region (e.g. coyotes, wolves). Table 1.1 is a review of published forensic case studies of scavenged surface deposited human remains. Table 1.1 and Figure 1.2 illustrate the concentration of published forensic case studies involving scavenging from non-European regions. There is a lack of published forensic case studies involving scavenging in Northwestern Europe most likely due to the following reasons: the confidentiality of various cases thus limiting access to information; and the possible misinterpretations by forensic scientists, investigators, and police search officers of scavengers and scavenging behaviour, which has the potential to cause these forensic professionals to underestimate and not record the impacts of scavenging on human remains or the outcome of cases.

Table 1.1. Forensic case studies of scavenged surface deposited human remains in outdoor settings. Cases highlight the effects of scavenging and the lack of published forensic cases of scavenged human remains in Northwestern Europe.

Author(s); Year	**Region**	**Case #: M/F, Age**	**Cause of Death**	**Time of Exposure; State of Remains**	**Recovery Location; Recovered elements**	**Scavenged Elements**	**Scavenger species**	**Results**
Moraitis & Spiliopoulou; 2010	Greece	1/4: F, 30-34 yrs.	Fall from a height; based on peri-mortem fractures on the skull and 3rd, 4th and 6th ribs.	1 yr; Skeletonised with some dried soft tissue.	A steep ravine; Police unable to recover all skeletal elements. Clothing and personal effects recovered. Bones scattered over a 15m radius.	L. Ulna; 1st-4th R. Metacarpals; Femora; L. Tibia; Humerii; T12 Vertebra	Not identified	Victim identified based on ante-mortem dental records.
	Greece	2/4: M, 23-28 yrs.	N/A	6 months; Partially skeletonised, mummified and scattered.	A slope (body in a supine position); Hair mass, wristwatch, articulated R. arm, skull & mandible, articulated lower R. leg & foot recovered in from upslope and down slope locations. No phalanges recovered. Scattered with personal effects in a 3m radius.	Sternum; Sacrum; Ribs at sternal ends; R. Clavicle; Scapulae; 4th-5th R. & L. Metacarpals; R. Innominate bone; L. Metatarsals; R. & L. Phalanges	Not identified	No victim identification (lack of dental records or radiographs).

Table 1.1 (continued). Forensic case studies of scavenged surface deposited human remains in outdoor settings. Cases highlight the effects of scavenging and the lack of published forensic cases of scavenged human remains in Northwestern Europe.

Author(s); Year	**Region**	**Case #: M/F, Age**	**Cause of Death**	**Time of Exposure; State of Remains**	**Recovery Location; Recovered elements**	**Scavenged Elements**	**Scavenger species**	**Results**
Moraitis & Spiliopoulou; 2010	Greece	3/4: M, 28-33 yrs.; F, 34-39 yrs.	Peri-mortem trauma was attributed to both a fall from the top of a ravine and from scavengers.	1.5 years; Skeletonised and scattered with clothing and personal effects.	A forested ravine; Bones scattered over about a 200m radius. Commingling of incomplete skeletal elements and presence of clothing belonging to more than one individual prevented MNI from being conducted on site.	Both individuals presented the following: L4 Vertebra; Sacrum; Coccyx; 3rd R. rib splintered; Innominate bones; Femora; L. Fibula; Tibiae. For the male: Ulna; Radius. For the female: Humerus.	Not identified	The scavenged R. innominate bone of the female modified the morphology of the peri-mortem fracture located on the inferior ramus of the pubis. Victims not identified.
	Greece	4/4: M, 65-75 yrs.	N/A	Skeletonised and disarticulated; some bones bleached by the sun and others covered by debris from the river. Possibly exposed for 5 yrs.	Riverside; All skeletal elements recovered in close proximity to the main collection of bones. A deteriorating pair of shorts found with the remains.	Mandible; Ribs splintered; R. Scapula; R. 3rd & L. 5th Metacarpals (R. 3rd fractured).	Not identified	Victim identified based on ante-mortem medical records.

Table 1.1 (continued). Forensic case studies of scavenged surface deposited human remains in outdoor settings. Cases highlight the effects of scavenging and the lack of published forensic cases of scavenged human remains in Northwestern Europe.

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Haglund *et al*. ; 1989	North America (Pacific NW)	1/5: F, 29 yrs.	Gunshot wound to head.	4 hours; Soft tissue, bone and clothing scavenged. Soft tissue mixed with torn sweater fibres. Exposed for 4 hrs.	An industrial urban area.	Puncture marks present on the bones surrounding the left orbit and on the nasal bones. The transverse processes of four cervical vertebrae were removed. Skin, hair, major muscles, and eyes all removed through scavenging.	Domestic dog seen at near remains; shape of injuries to bone and soft tissue suggested dog.	Dog scavenged soft tissue, thus leaving bite marks on bone and damaging clothing worn by victim. Victim identification not given.
	North America (Pacific NW)	2/5: M, 25 yrs.	Stabs wound in the back of the victim and blunt force trauma to the head.	22 days; Soft tissue damage, scavenging and removal of bone. Partially clothed.	A rural evergreen area; Found partially clothed in lowered trousers. Shirt found 11m away. Sternum, R. Scapula, and Clavicles missing.	Ribs heavily scavenged; V-shaped bite marks and irregular margins present in the soft tissue: damage to nose, masseter muscles, removal of all viscera except prostate gland and of skin from lower face; defleshed left upper extremity.	Shape of marks in soft tissue and presence of gnawing on bone interpreted only as carnivore scavengers.	Underside of remains and lower extremities not scavenged. Victim identification not given.

Table 1.1 (continued). Forensic case studies of scavenged surface deposited human remains in outdoor settings. Cases highlight the effects of scavenging and the lack of published forensic cases of scavenged human remains in Northwestern Europe.

Author(s); Year	**Region**	**Case #: M/F, Age**	**Cause of Death**	**Time of Exposure; State of Remains**	**Recovery Location; Recovered elements**	**Scavenged Elements**	**Scavenger species**	**Results**
Haglund *et al*. ; 1989	North America (Pacific NW)	3/5: F, 19 yrs.	N/A	2 months; Disarticulation and scattering of remains. All soft tissue removed.	A wooded area; Disarticulation of the lower and upper extremities. Mandible recovered 6m from remains. Upper extremities, coccyx, clavicles and scapulae missing.	Ribs, Femora, Mandible, and Innominate bones scavenged.	Scavenger species only identified as carnivore.	Heavily scavenged remains; Vertebrae, skull, innominate bones, and femora were found articulated. Victim identification not given.
	North America (Pacific NW)	4/5: M, 49 yrs.	Gunshot wound to head.	6 months; Disarticulation and scattering of remains.	A rural woodland area; Scattered bones recovered over an area of 61m.	Ribs, Innominate bones, L. Femur heavily scavenged; Minimal scavenging on skull and mandible.	Scavenger species only identified as carnivore.	Heavily scattered remains; only articulated areas were the sacrum with 10 thoracic and lumbar vertebrae, 1-7 cervical vertebrae, and one rib fragment. Victim identification not given.

Table 1.1 (continued). Forensic case studies of scavenged surface deposited human remains in outdoor settings. Cases highlight the effects of scavenging and the lack of published forensic cases of scavenged human remains in Northwestern Europe.

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Haglund *et al*. ; 1989	North America (Pacific NW)	5/5: F, 19 yrs.	N/A	2.5 yrs; Disarticulated and scattered remains.	Recovery of scattered bones in three locations (A-C) within 101m; skull, mandible and femora shafts recovered in location A; R. scapula, and R. shafts of the humerus, radius and ulna in location B; L. scapula, and L. shafts of humerus, radius and ulna in location C.	Scavenging of bone resulted in scattering of bones.	Scavenger species only identified as carnivore.	Heavily scattered remains; no articulated remains recovered. Victim identification not given.
Haglund; 1992	North America (Pacific NW)	1/1: M, 27 yrs.	Suffocation from inhalation of propane tank.	3 days; Fully clothed with head, thorax and left arm (holding propane tank) covered by a plastic bag secured in his waist belt; plastic bag chewed open by rats; mix of soft tissue removal, scavenging, and missing bones. Both forearms skeletonised.	Recovered from inside a wooden shack. Bones from the L. hand and R. metacarpals not recovered.	Heavy soft tissue damage to face, neck, eyes and skull.	Rodents identified as scavengers based on rat droppings and fur, and scalloped shaped wound margins on soft tissue.	Rodents able to remove small bones of the hand. Victim committed suicide.

Table 1.1 (continued). Forensic case studies of scavenged surface deposited human remains in outdoor settings. Cases highlight the effects of scavenging and the lack of published forensic cases of scavenged human remains in Northwestern Europe.

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Möttönen & Nuutila; 1977	Finland	1/1: M, N/A	Pig bite wounds.	Soft tissue damage.	Found in a pig sty with 12 pigs. Only soft tissue damage.	Soft tissue damage to face, neck, eyes, side of abdomen, and genitals.	Domestic pig; visual observation and presence of only pigs near remains.	Biochemical determination indicated the majority of wounds were ante-mortem injuries.
Asamura *et al*.; 2004	Japan	1/2: M, N/A.	Presence of soot in main bronchi indicated fire as cause of death; suicide note left by victim gave more information on events;	N/A; Charred body accompanied with gas tank and lighter; some mummified skin; Only soft tissue damage; No soft tissue in face, neck, chest and limbs.	A flood plain; body in a supine position.	Only soft tissue damage; ‘‘string-like fluffy remains" present as nerve and muscle fibres in limb joints, and periosteum of skull, ribs and limb bones recorded as "fluffy" in appearance; cervical vertebrae exposed; no digestive organs identified.	Crows; Identified by presence of crow droppings and serrated margin of soft tissue damage and "string-like fluffy" remains.	Victim identification difficult but made based on dental records.

Table 1.1(continued). Forensic case studies of scavenged surface deposited human remains in outdoor settings. Cases highlight the effects of scavenging and the lack of published forensic cases of scavenged human remains in Northwestern Europe.

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Asamura *et al*.; 2004	Japan	2/2: F, 77 yrs.	Blood analysis of Hb-CO value and presence of erythema in the back indicated fire as cause of death	Several days; Charred remains, partially skeletonised. Skin intact and not carbonized located on the back. Only soft tissue damage.	A garden; Remains found in a supine position.	No internal organs in thoracic or intraperitoneal cavity; No trachea. 'String-like fluffy" nerve and muscle fibres in head and limbs; "fluffy" appearance of periosteums and ligaments in pelvis.	Crows; Identified by presence of crow droppings, tracks, visual observation of wound shapes, and witness accounts.	Victim identification difficult but made based on DNA analysis.
Bell *et al*.; 1996	North America (Canada)	1/2: F, 86 yrs.	N/A	3 months; Completely defleshed tibial shaft.	A wet coastal area; Only a tibial shaft recovered from a carnivore scat.	A digested tibial shaft from a carnivore scat.	Identified only as carnivore based on bone in scat.	Only one skeletal element recovered. Further information not provided.
	North America (Canada)	2/2: M, 24 yrs.	N/A	At least 1 yr; Skeletonised remains with dried cartilage and periosteum; lower half of body not present.	Remains found in a dry, cold environment. Lower half of body not recovered. Further information about recovery of bones not provided.	Lower half of body possibly removed by scavengers.	Identified only as "animals".	Further information not provided.

Table 1.1 (continued). Forensic case studies of scavenged surface deposited human remains in outdoor settings. Cases highlight the effects of scavenging and the lack of published forensic cases of scavenged human remains in Northwestern Europe.

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Byard *et al*.; 2002	S. Australia	1/2 : M, adult.	Victim had been strangled and stabbed.	N/A; Soft tissue damage mainly to anterior chest.	Outdoors; Remains recovered whole.	Scavenging and insect damage to the anterior chest wall only.	Identified as fox (method of identification not given).	Damage by scavengers concealed trauma caused by a stab wound to the anterior chest; stab wound not apparent until autopsy; scavenging damage prevented identification of the type of blade used for injury.
	S. Australia	2/2 : M, 22 yrs.	Heroin overdose.	N/A; Soft tissue damage as lesions to the hands.	Bushland area; recovered whole.	Scavenging by rodents produced small lesions to the hands.	Rodent damage identified by shape of lesions.	Rodent activity first interpreted as defence wounds from being attacked. Identification of rodent activity disproved defence like wounds.
Komar; 1998	North America (Canada)	1/7: M, 48 yrs.	Undetermined.	4 months; Skeletonised with little soft tissue.	A wooded area; Pair of jeans recovered. Skull, cervical vertebrae, ribs, sternum, clavicles, scapulae, upper extremities and L. hand not recovered. R. hand disarticulated but recovered fleshed.	Disarticulation and scattering; R. hand disarticulated but fleshed. Scalp, hair and nose missing due to scavenging.	Rodent activity (identification method not given).	Rodent activity caused removal of soft tissue. Victim identified based on ante-mortem radiographs and fingerprints.

Table 1.1 (continued). Forensic case studies of scavenged surface deposited human remains in outdoor settings. Cases highlight the effects of scavenging and the lack of published forensic cases of scavenged human remains in Northwestern Europe.

Author(s); Year	**Region**	**Case #: M/F, Age**	**Cause of Death**	**Time of Exposure; State of Remains**	**Recovery Location; Recovered elements**	**Scavenged Elements**	**Scavenger species**	**Results**
Komar; 1998	North America (Canada)	2/7: M, 21 yrs.	Drug overdose and hypothermia.	Less than 2 months; Frozen remains due to winter conditions; soft tissue damage; fully clothed with winter coat.	A park; Recovered whole and clothed.	Heavy carnivore scavenging. Soft tissue removed from face and nose.	Only identified as carnivore scavenging.	Victim identification by fingerprints.
	North America (Canada)	3/7: M, 32 yrs.	Undetermined.	18 months; Skeletonised with little soft tissue.	A wooded area. Ski pants, socks and boots recovered. Cervical vertebrae, ribs, some thoracic and lumbar vertebrae, radii, ulnas, and hands not recovered.	Heavy carnivore scavenging causing disarticulation and scattering of bones.	Only identified as carnivore scavenging.	Victim identified by ante-mortem radiographs.
	North America (Canada)	4/7: M, 71 yrs.	Undetermined.	18 months; Fully skeletonised and clothed with a jacket.	A farmer's field. R. & L. phalanges and L. foot not recovered.	Scavenging and removal of bones.	Rodent scavenging (identification method not given).	Victim identified based on radiographs and superimposition.
	North America (Canada)	5/7: M, 23 yrs.	Undetermined.	16 months; Fully skeletonised and clothed with boots.	Woodland area; L. hand and hyoid not recovered.	Scavenging and removal of bones.	Only identified as carnivore scavenging.	Victim identified based on dental records.
	North America (Canada)	6/7: M, 53 yrs.	Gunshot wound to head.	8 yrs.; Fully skeletonised.	Recovered from woods. Only the skull recovered (maxilla and mandible absent).	Heavy scavenging resulting in only skull present.	Only identified as carnivore scavenging.	Victim identified by superimposition.

Table 1.1 (continued). Forensic case studies of scavenged surface deposited human remains in outdoor settings. Cases highlight the effects of scavenging and the lack of published forensic cases of scavenged human remains in Northwestern Europe.

Author(s); Year	**Region**	**Case #: M/F, Age**	**Cause of Death**	**Time of Exposure; State of Remains**	**Recovery Location; Recovered elements**	**Scavenged Elements**	**Scavenger species**	**Results**
Komar; 1998	North America (Canada)	7/7: Male, 26 yrs.	Gunshot wound to head.	15 months; Fully skeletonised.	A wooded ravine. Shirt, jacket, and trousers recovered. Mandible, Vertebrae, L. innominate bone, L. humerus, L. radius, L. ulna, R. hand, clavicles, L. scapula, ribs, sacrum, coccyx, L. tibia and both feet were not recovered.	Heavy scavenging.	Only identified as carnivore scavenging.	Victim identified by ante-mortem radiographs and superimposition.
Willey & Snyder; 1989	North America (Tennessee)	1/1: M, N/A.	Homicide.	2 days; Only soft tissue damage. Fully clothed.	Outdoors; N/A.	Soft tissue damage by dogs involved the opening of the thoracic and abdominal cavities. Damage also at the face and nose.	Dogs identified as scavengers (identification method not given).	The opening of the thoracic and abdominal cavities similar to captive wolves scavenging a deer carcass.

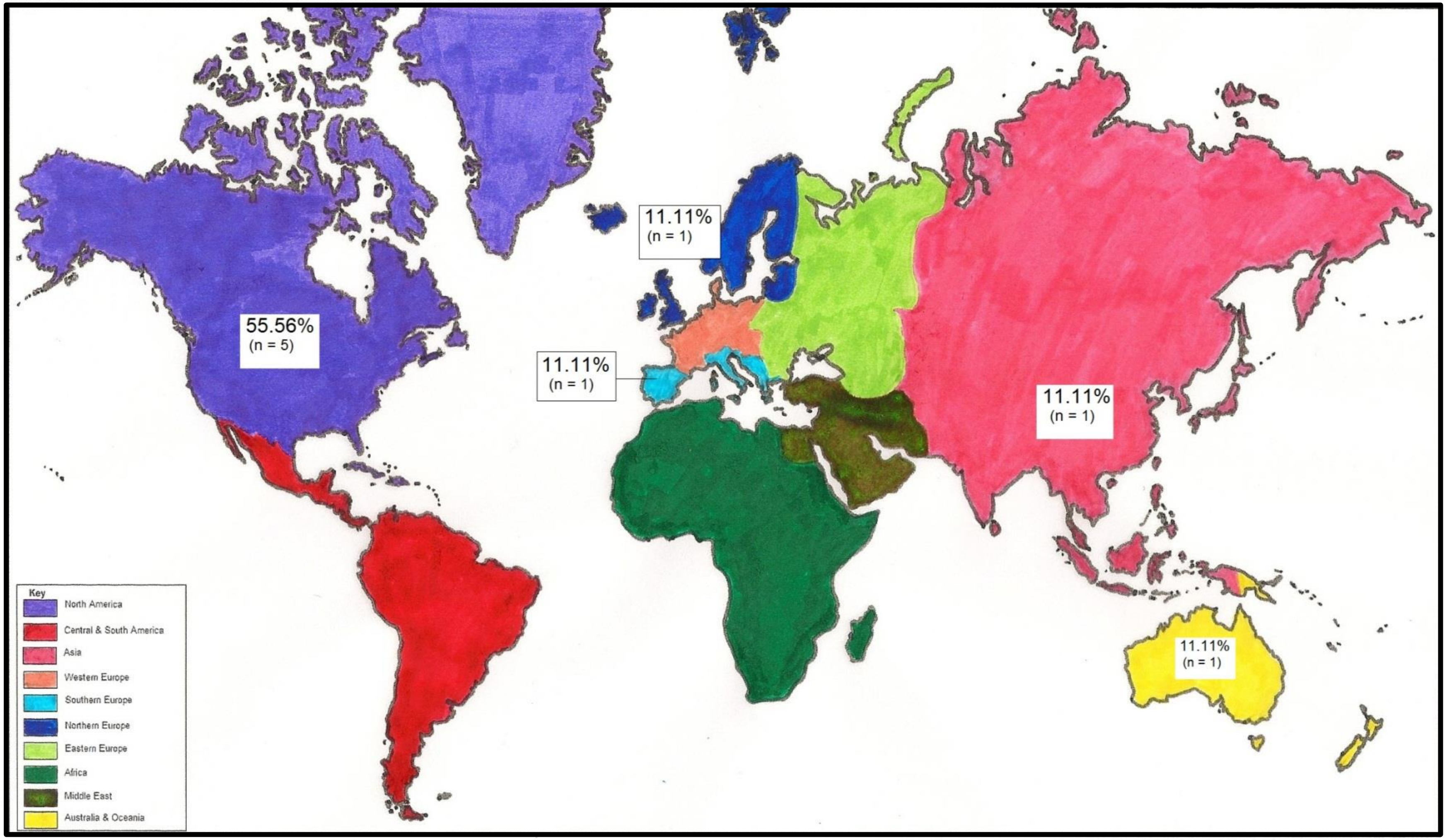

Figure 1.2. The regional concentrations of forensic case studies of scavenged surface deposited human remains in outdoor settings.

1.2 SCAVENGERS: EFFECTS ON HUMAN REMAINS

1.2.1 Soft Tissue Damage

Scavenging can result in the modification of soft tissue and skeletal remains, as well as the scattering and removal of remains from deposit sites. The removal of soft tissue by scavengers can obscure the site of ante- or peri-mortem trauma such as an entry or exit wound that contributed to death, for example at the site of a knife wound that has penetrated both the skin and bone underneath (Rothschild and Schneider 1997; Byard *et al*. 2002). Trauma associated with the cause of death of the victim can be modified and obscured by scavenging, through either fracturing bone at the site of trauma or producing a bite mark on bone that obscures the site of trauma.

The process of scavenging and disarticulating remains also exposes areas of soft tissue and bone to the surrounding weather conditions and insect activity, which in turn can increase the rate at which remains decompose. Increased decomposition rates can affect the interpretation of the post-mortem interval (PMI) (Haglund *et al*. 1989; Willey and Snyder 1989; Mann *et al*. 1990). Increased decomposition rates can also limit the time in which police search officers have to search and recover remains before soft tissue fully decomposes, thus allowing scavengers easier access to skeletal elements that can be removed from the crime scene area (Clark *et al*. 1997; Komar 1998; Morton and Lord 2006).

Whilst trying to access soft tissue and bone, scavengers can also damage and scatter clothing, personal effects, or the material in which remains were deposited and concealed. The removal of these items during scavenging can hinder the identification of the victim and destroy key evidence that links the perpetrator to the victim, such as an item of jewellery or torn piece of clothing (Haglund *et al*. 1989). Likewise, damage to clothing caused by ante-mortem or peri-mortem trauma can be obscured by scavengers trying to access areas underneath clothing, such as clothing with a tear from a knife wound to the chest being further torn by scavenging. The recovery of textiles can hold key evidence such as sites of trauma, bodily fluids associated with ante- or peri-mortem trauma, and decomposition fluids, as well as indicate the environmental conditions in which remains were deposited (Janaway 2002; Szostak-Kotowa 2004). The presence of textiles can affect the scavenging behaviour of different scavenger species and their access to remains. For instance, remains located outdoors exhibiting minimal or no signs of scavenging may indicate that a large textile, such as a large carpet, deterred smaller scavenger species and concealed remains (Haglund 1992, 1997; Komar 1998). In contrast, a set of remains left exposed outdoors with no form of concealment would be expected to have a higher level of scavenging by outdoor scavengers such as foxes.

1.2.2 Modification of Skeletal Remains

Scavenger-induced alteration to human and animal bone has three main characteristics: the fracturing of bone, modification to bone surface (e.g. bite marks), and disarticulation leading to bone dispersal. As an animal scavenges human remains, first accessing soft tissue with the aim of de-fleshing and consuming meat, the teeth of the scavenger can cause damage to the soft tissue and bone surface (Haynes 1980; Johnson 1985; Haglund *et al*. 1988; Hillson 2005). If scavenging progresses, the animal may continue removing flesh and begin to attempt to access the marrow cavity. The easiest option for the scavenger is to remove various articulated elements of the remains so that they can further scavenge and/or consume without fear of predators or threat of competition from other scavengers, and to allow more time for accessing bone. The disarticulation and removal of remains, either with or without flesh, will allow the scavenger more time to consume remains and access marrow. Prolonged time with remains can be expected to result in greater and more varied dispersal distances, bite marks, and also decrease the percentage of skeletal elements recovered (Komar 1998).

There are four main types of bite marks found on bone: punctures, pits, scoring and furrows (Binford 1981; Haynes 1983a; Haglund *et al*. 1988; Milner and Smith 1989; Andrews and Fernandez-Jalvo 1997; Pickering *et al*. 2004; Coard 2007; Delaney-Rivera *et al*. 2009; Andrés et al. 2012). Punctures are perforations seen in the bone surface when the thin bone surface collapses; they can vary greatly in depth (Binford 1981; Haynes 1983a; Haglund *et al*. 1988; Milner and Smith 1989; Coard 2007; Pickering *et al*. 2004; Delaney-Rivera *et al*. 2009). Pits are indentations in the bone surface caused by the tip of a tooth cusp and do not involve the bone surface collapsing (Binford 1981; Haynes 1983a; Haglund *et al*. 1988; Milner and Smith 1989; Pickering *et al*. 2004; Coard 2007; Delaney-Rivera *et al*. 2009). Scoring is caused by a tooth that has dragged over the bone surface, identifiable from a pit or puncture because its length is generally three times greater than its breadth (Coard 2007; Delaney-Rivera *et al*. 2009). Furrows are caused by molars that have been used to access the marrow cavity of the bone often appearing as longitudinal features at the end of open shafts (Binford 1981; Haynes 1983a; Haglund *et al*. 1988; Milner and Smith 1989; Pickering *et al*. 2004; Coard 2007; Delaney-Rivera *et al*. 2009). Haglund *et al*. (1988) also identifies "scooping" as a type of mark seen on the ends of long bone shafts where the scavenger continuously licked marrow out from the open end of the shaft. In Binford's (1981) work with wolf dens he also identified a type of 'boredom' chewing which was the result of bones being chewed over a long period of time within the den site, this type of chewing was identified by extensive pitting and scoring of the bone. The presence of such bite marks on scavenged remains, both human and animal, has been widely documented and used in both archaeological and forensic investigations (Haglund *et al*. 1988, 1989; Domínguez-Rodrigo 1999; Küchelmann *et al*. 2004; Bartosiewicz 2008). The identification of scavenger species within the fields of forensics, archaeology, zooarchaeology, taphonomy and paleobiology have no set standard method of bite mark analysis but tend to utilise both qualitative and quantitative methods (Brain 1981; Haynes 1983a; Haglund *et* al. 1988; Milner and Smith 1989; Cruz-Uribe 1991). Qualitative methods have included descriptions of the appearance of scavenged remains and the location of bite marks on skeletal elements (Haynes 1980, 1983a; D'Andrea and Gotthardt 1984; Haglund *et* al. 1988). Quantitative methods of bite mark analysis vary from measurements of dental arch length, jaw length and width, individual bite mark length and breadth, distances between bite marks, and distances between tooth cusps of the carnassial tooth (Selvaggio 1994; Andrews and Fernandez-Jalvo 1997; Domínguez-Rodrigo and Piqueras 2003; Pickering *et al*. 2004; Murmann *et al*. 2006; Coard 2007; Delaney-Rivera et al. 2009; Andrés et al. 2012) (Table 1.2).

Table 1.2. Literature from the fields of taphonomy, zooarchaeology, archaeology, forensic archaeology, and forensic anthropology, in which scavenger-induced bone modifications are described and/or analysed.

Author(s)	Year	Methods	Region	Aim	Scavenger(s)	Scavenged remains
Haynes, G.	1980	Descriptions of carnivore damage to bone	North America	Characterisation of carnivore damage to bones	Wolf	Ungulates
Brain, C.K.	1981	Descriptions of carnivore damage to bone and some analysis of frequency of tooth marks on bones	Africa	Characterisation of carnivore accumulation and damage of bones; differentiate between hominin and carnivore damage	Hyena; leopard	Faunal remains
Haynes, G.	1983a	Descriptions of carnivore damage to bone (tooth marks) with measurements of typical bone fragments' dimensions	North America; Africa	Differentiate mammalian carnivore taxa	Captive and wild: wolf; hyena; bear; lions; hyenas; jaguar (*Panthera onca*)	Domestic cattle bones (*Bos taurus*); bison (*Bison*); horse (*Equus caballus*); giraffe (*Giraffa camelopardalis*); elephant (*Loxodonta africana*); moose (*Alces alces*); Deer (*Cervus*); African buffalo (*Syncerus caffer*)
D'Andrea, A.C. & Gotthardt, R.M.	1984	Descriptions of carnivore damage to bone	North America	Characterisation of carnivore damage to bones	Wolf	Horse
Haglund, W.D., Reay, D.T., & Swindler, D.R.	1988	Descriptions of carnivore damage to bone and some quantitative analysis of recovery rates of bones	North America	Characterisation of carnivore damage to bones	Coyotes; wolves; domestic dogs	Human remains

Table 1.2 (continued). Literature from the fields of taphonomy, zooarchaeology, archaeology, forensic archaeology, and forensic anthropology, in which scavenger-induced bone modifications are described and/or analysed.

Author(s)	Year	Methods	Region	Aim	Scavenger(s)	Scavenged remains
Milner, G.R., & Smith, V.G.	1989	Descriptions of carnivore damage to bone and some quantitative analysis of survivability rates of bones	North America	Characterisation of carnivore damage to bones	Dogs; coyotes; wolves	Human remains
Cruz-Uribe, K.	1991	Descriptions of carnivore damage to bone	Africa	Differentiate between hyena and hominin accumulation and damage of bone	Hyena	Bovids
Selvaggio, M.M.	1994	Descriptions of carnivore damage to bone and the analysis of frequency of tooth marks on bones	Africa	Characterise hominin-carnivore interactions	Lion; leopard; cheetah (*Acinonyx jubalus*); spotted hyena; jackal (*Canis aureus*)	Faunal remains
Andrews, P., & Fernandez-Jalvo, Y.	1997	Description of bone modifications and quantitative analyses of frequencies of bone breakage and tooth mark dimensions on bones	Southern & Northern Europe	Determine carnivore and hominin damage to bones; identify carnivore taxa or size	Red fox	Hominin fossils; Sheep remains
Domínguez-Rodrigo, M.	1999	Descriptions of lion modifications to soft tissue and bone; analysis of distribution of tooth mark types found on skeletal elements	Africa	Characterisation of lion modification of soft tissue and bone	Lion	Wildebeest (*Connochaetes*); zebra (*Equus quagga*); topi (*Damaliscus korrigum*); buffalo

Table 1.2 (continued). Literature from the fields of taphonomy, zooarchaeology, archaeology, forensic archaeology, and forensic anthropology, in which scavenger-induced bone modifications are described and/or analysed.

Author(s)	Year	Methods	Region	Aim	Scavenger(s)	Scavenged remains
Domínguez-Rodrigo, M. & Piqueras, A.	2003	Quantitative analysis of tooth mark dimensions (Length & breadth; ratio) on bones	Southern Europe; Africa	Identify different carnivore taxa	Lion; jackal; bear; hyena; domestic dog; baboon (*Papio*)	Bovid; equid
Pickering, T., Domínguez-Rodrigo, M., Egeland, C., & Brain, C.	2004	Quantitative analysis of tooth mark dimensions (length & breadth) on bones	Africa	Determine tooth marks produced by leopards; Identify carnivore size	Leopard; spotted hyena; jackal; dog; lion; cheetah	Hominin and faunal remains
Murmann, D., Brumit, P., Schrader, B., & Senn, D.	2006	Quantitative analysis of bite mark patterns (intercanine width) and descriptions of bite mark arch	North America	Determine the bite mark pattern of different carnivores	Lynx (*Lynx lynx*); mountain lion; wolverine (*Gulo gulo*) ; black bear; coyote; gray wolf; grizzly bear; red fox; gray fox; lynx; domestic cat; domestic dog; bobcat (*Lynx rufus*)	N/A (skulls of carnivores measured)
Coard, R.	2007	Quantitative analysis of tooth mark dimensions (length:breadth ratio) on bones and distances between tooth cusps	Northern Europe	Identify carnivore taxa or size	Leopard; puma (*Puma concolor*); wolf; red fox	Sheep (*Ovies aries*) and foal carcasses

Table 1.2 (continued). Literature from the fields of taphonomy, zooarchaeology, archaeology, forensic archaeology, and forensic anthropology, in which scavenger-induced bone modifications are described and/or analysed.

Author(s)	Year	Methods	Region	Aim	Scavenger(s)	Scavenged remains
Delaney-Rivera, C., Plummer, T.W., Hodgson, J.A., Forrest, F., Hertel, F., & Oliver, J.S.	2009	Quantitative analysis of tooth mark dimensions (major & minor axes) on bones and tooth mark shapes	North America	Identify carnivore taxa or signatures	American alligator (*Alligator mississippiensis*); Virginia Opossum (*Didelphis virginiana*); Hominins; Red fox; Coyote; Domestic dog; Striped skunk (*Mephitis mephitis*); S. American coati (*Nasua nasua*); raccoon (*Procyon lotor*); Ocelot (*Leopardus pardalis*); Bobcat; Serval (*Leptailurus serval*); Caracal (*Caracal caracal*); Mountain lion; Tiger (*Panthera tigris*); African lion; Spotted hyena	Small goat (*Capra aegagrus hircus*) bones; defleshed cow bones

Table 1.2 (continued). Literature from the fields of taphonomy, zooarchaeology, archaeology, forensic archaeology, and forensic anthropology, in which scavenger-induced bone modifications are described and/or analysed.

Author(s)	Year	Methods	Region	Aim	Scavenger(s)	Scavenged remains
Lloveras, L., Moreno-Garcia, M., & Nadal, J.	2011	Description of bone modifications and quantitative analyses of frequencies of bone breakage and tooth marks on bone surfaces	Southern Europe	Assess effects of red fox scavenging on rabbits	Captive red fox	Rabbit (*Oryctolagus cuniculus*) carcasses
Andrés, M., Gidna, A.O., Yravedra, J., & Domínguez-Rodrigo, M.	2012	Quantitative analysis of tooth mark dimensions (length & breadth) on bones	Southern Europe; Africa	Differentiate mammalian carnivore size	Spotted hyena; leopard; lion; fox; wolf; bear; puma; baboon; domestic dog; human	Sheep carcasses; other carcasses stated simply as faunal remains

The information that can be gained within a forensic context from using both qualitative and quantitative methods of analysing bite marks on bone surfaces allows for a clearer interpretation and identification of a scavenger species. A more accurate interpretation and identification of bite marks and scavenger species-typical scavenging behaviour and pattern can provide forensic scientists, investigators, and police search officers with a variety of important information such as:

- The identification of animal scavenger species and scavenging behaviour;
- And the identification of a local, foreign, or unexpected scavenger which can be indicative of where remains were initially deposited; for instance the presence of bite marks of an outdoor rural scavenger on remains recovered in an indoor urban setting,;
- The intensity of scavenging (e.g. no scavenging versus fully fragmented bones) can indicate how easily accessible remains were to different sized scavenger species. For example, scavenging and bite marks limited to only one area of a body can indicate all other areas were concealed or that the scavenger was unable to remove the textile. This also applies to interpreting primary and secondary deposit sites where remains may have been moved and certain scavenger species access was allowed or prohibited based on the location. ;
- Interpretations associated with the PMI may be helped by the comparison of the rate of decomposition, level of insect activity, and the level of scavenging; however this is still a highly debated topic within the literature (Haglund *et al*. 1989; Willey and Snyder 1989; Mann *et al*. 1990; Janjua and Rogers 2008).;
- Without clear identification of scavenger-induced trauma it is possible to incorrectly interpret trauma as ante- or peri-mortem trauma; for example sharp trauma penetrating through soft tissue (Byard *et al*. 2002; Schulz *et al*. 2006).;
- Identification of a scavenger species is important in determining the species-specific scavenging, disarticulation, scatter and removal pattern of a scavenger. Knowledge of the species-specific scattering and removal pattern can indicate needed search and recovery methods, key topographical areas to search based on environment

and scavengers, directional cues for searching, and recovery distances (Komar 1999; Listi *et al*. 2007; Vanlaerhoven and Hughes 2008).

Scavengers' scavenging behaviour and pattern of disarticulation, scattering and removal of remains will differ amongst species and individuals due to a variety of factors based on environmental conditions, the size of remains, where and how remains are deposited, the size of the scavenger, the overall diet of the scavenger, interactions between scavengers at the site of remains, and the availability of other food resources (Gittleman and Harvey 1982; Carr and Macdonald 1986; Doncaster and Macdonald 1991; Doncaster *et al*. 1990; Kauhala *et al*. 1998; Leckie *et al*. 1998; Reif *et al*. 2001; Revilla and Palomares 2001; DeVault *et al*. 2004; Caraeu *et al*. 2007; Selva and Fortuna 2007; Sidorovich *et al*. 2011; Gidna *et al*. 2013). Therefore, when making interpretations about scavenging, disarticulation and scattering it is necessary to use a multidisciplinary approach that includes behavioural ecological, taphonomic, and forensic methods. However, previous forensic studies on the scavenging of human remains have yet to fully incorporate a multidisciplinary approach in their interpretations and identifications of the causes and effects of scavenging by different scavenger species. Presently, forensic studies have only briefly discussed the potential influences that hunting behaviour (e.g. hunting in packs) and availability of food resources have on the scavenging, disarticulation and scattering of human remains by outdoor scavengers (Haglund *et al*. 1988, 1989; Willey and Snyder 1989; Haglund 1997b). In contrast, ecological studies have widely discussed and analysed the effects of the availability of food resources for different scavenger species (Watts1968; Doncaster *et al*. 1990; Da Silva *et al*. 1993; Todd *et al*. 2000). Apart from the occasional acknowledgement in forensic studies of whether a scavenger hunts in packs or alone (Haglund *et al*. 1988, 1989; Willey and Snyder 1989), there is a lack of application of information from behavioural ecological studies on scavenger social behaviour and inter- and intra-species interactions (Macdonald 1983; Revilla and Palomares 2002). Studies by Morton and Lord (2006) and O'Brien *et al*. (2007) have sought to show the different types of scavenger species that will visit and scavenge from a carcass but do not give thorough explanations as to what factors may influence what and when scavenger species are present. For instance, territory size, dispersal behaviour, home ranges, food resources dispersion, scavenging behaviour, inter- or intra-specific aggression, seasonality, breeding season, or metabolic needs are factors that can affect scavengers and how human remains are scavenged. Moreover, the effects of seasonality on scavenger behaviour is more widely discussed in regards to rates of decomposition of human remains rather than the effects on scavenger activities and their diets, which, in turn, affect how human remains are modified (Galloway *et al*. 1989; Mann *et al*. 1990; Micozzi 1991; Komar 1998; Magyesi *et al*. 2005).

Table 1.1 and 1.2 show that many forensic studies generalise their identifications of scavenger species (e.g. carnivores, animals) and often base their search for scattered human remains on subjective criteria found near deposit sites such as scat, feathers, and known or assumed wildlife in the area, which do not definitively show that an animal scavenged a set of remains but only shows their presence (Haglund *et al*. 1989; Bell *et al*. 1996; Komar 1998). The analysis of bite marks on skeletal remains has been used by some forensic studies to overcome bias identifications of scavengers (Haglund *et al*. 1988; Asamura *et al*. 2004) but, unlike taphonomic studies (Andrews and Fernandez 1997; Domínguez-Rodrigo and Piqueras 2003; Pickering *et al*. 2004; Andrés *et al*. 2012), tend to use a more qualitative analysis. The generalisation in the identification of scavenger species and the absence of applied ecological information by forensic studies have resulted in the underrepresentation of medium and small-sized scavengers, which, due to the aforementioned factors, may produce similar bone modifications as large scavengers with similar dentitions (Haglund *et al*. 1989; Willey and Snyder 1989; Bell *et al*. 1996; Komar 1998; Byard *et al*. 2002). Moreover, by focusing on large scavengers, such forensic studies tend to exclude other sized scavengers which are capable of transporting, assembling, or caching skeletal elements, thus negatively impacting the search, recovery, and interpretation of scavenged human remains. Forensic studies would gain from incorporating ecological and taphonomic studies for more accurate interpretations and identifications of scavenging and its effects on human remains, thus providing more in depth and accurate explanations of patterns and variations in the utilisation of human remains by different scavenger species.

1.3 RODENT AND AVIAN SCAVENGING

1.3.1 Rodent Scavenging

Rodent scavengers are well known in forensic and taphonomic studies as scavengers of both soft tissue and skeletal remains (Brain 1981; Johnson 1985;

Haglund *et al*. 1988; Milner and Smith 1989; Mann *et al*. 1990; Haglund 1992, 1997b; Patel 1994; Ropohl *et al*. 1995; Tsokos and Schulz 1999; Potmesil 2005; Klippel and Synstelien 2007) (Table A1-1; Table 1.1). Damage to soft tissue and bone surfaces by rodents is often identifiable by the presence of regular wound margins with parallel striations and serrated edges caused by the upper incisors of rodents (Haglund 1992, 1997b; Patel 1994; Tsokos and Schulz 1999; Klippel and Synstelien 2007). In contrast, canid, felid, and mustelid scavengers' dentitions do not commonly produce parallel striations or as regular wound margins on soft tissue or bone surfaces (Patel 1994; Tsokos and Schulz 1999; Klippel and Synstelien 2007). The lower incisors of rodents also produce readily identifiable windows or scallop shaped marks on bone surfaces which are not produced by the dentitions of canids, felids, and mustelids (Johnson 1985; Klippel and Synstelien 2007).

Rodents are also capable of transporting skeletal elements, dependent on the sizes of the rodent and carcass (Brain 1981; Haglund 1992,1997b; Klippel and Synstelien 2007). For example, Klippel and Synstelien (2007) recorded the transportation of clavicles from human remains by Eastern gray squirrels (*Sciurus carolinensisi*) and Brain (1981) observed the collection of vertebrae and long bones of bovids by the African porcupine (*Hystrix africaeaustralis*). Carcass utilisation by rodents also includes the use of human remains as nests (Haglund 1992,1997b). For instance, Haglund (1992) observed common rats (*Rattus norvegicus*) nesting within the thoracic cavity of human remains.

1.3.2 Avian Scavenging

In addition to mammalian scavengers, avian scavengers are capable of modifying surface deposited human remains (Mann *et al*. 1990; Bass 1997; Komar and Beattie 1998c; Asamura *et al*. 2004; Reeves 2009; Spradley *et al*. 2011). Depending on the body size, beak and claw morphology, avian scavengers are capable of modifying soft tissue and bone surfaces (Fowler *et al*. 2009; Reeves 2009; Domínguez-Solera and Domínguez-Rodrigo 2011; Spradley *et al*. 2011). Likewise, these factors juxtaposed with carcass size can limit whether certain avian scavengers are capable of scattering and removing skeletal elements (Simmons *et al*. 2010; Domínguez-Solera and Domínguez-Rodrigo 2011). Damage caused by avian scavengers has the potential to obscure and modify sites of ante- or peri-mortem trauma to soft tissue and, depending on the avian species, bone surfaces (Asamura *et al*. 2004; Domínguez-Solera and Domínguez-Rodrigo 2011). Additionally, avian scavengers have been recorded in previous studies to remove personal effects from human remains (Komar and Beattie 1998c) and hair for nesting (Bass 1997).

Taphonomic and forensic studies on avian scavengers tend to focus on the more common scavengers of human remains and large size carrion, such as vultures (*Cathartidae*, *Accipitridae*), carrion crows, ravens (*Corvus corax*), and magpies (*Pica pica*) (Mann *et al*. 1990; Bass 1997; Komar and Beattie 1998c; Asamura *et al*. 2004; O'Brien *et al*. 2007; Reeves 2009; Domínguez-Solera and Domínguez-Rodrigo 2011; Spradley *et al*. 2011). The scavenging activities of other birds of prey, such as the common buzzard, in relation to surface deposited human remains are less known and are instead found more commonly discussed within ecological and behavioural studies concerned with diet and prey populations (Hiraldo *et al*. 1991; Reif *et al*. 2001; Brown *et al*. 2006; Blásquez *et al*. 2009).

1.4 RED FOX (*VULPES VULPES*) AND EURASIAN BADGER (*MELES MELES*): BEHAVIOURAL ECOLOGY AND SCAVENGING BEHAVIOUR

The behavioural ecology and species-typical scavenging behaviour of mammalian scavengers affect forensic investigations and physical searches of scenes in a variety of ways, for instance how and when a set of human remains is modified, and the distances and locations to which different elements of the remains are moved and scattered. The effects of scavenging influence the execution of search and recovery methods by police search officers, as well as interpretations based on recovered scavenged remains. Investigations involving deposited human remains seek to ideally recover all of the individual, if possible. The recovery of as many skeletal elements as possible pertaining to the set of remains is both for the identification of the individual and interpretations related to the investigation but also for the respect of the relatives of the individual. An understanding of the behavioural ecology and the species-typical scavenging behaviour of scavengers inhabiting the crime scene and surrounding area has the potential to improve search and recovery efforts, as well as interpretations based on recovered scavenged remains.

1.4.1 Red Fox and Eurasian Badger: Introduction

The red fox body size varies between the sexes (males being larger than females) and seasons but generally the body length is anywhere from 56 cm - 90 cm (35 cm – 50 cm height), and weight from 5 kg - 14 kg (Corbet and Harris 1991; Alderton 1994; Sterry 2005). The red fox occurs throughout most of the northern hemisphere and is the only canid present on five continents (Corbet and Harris 1991; Macdonald and Reynolds 2004; Sillero-Zubiri and Macdonald 2004) (Figure 1.3). In Britain, the red fox is widespread throughout but does have higher densities in southern England and Scotland (Corbet and Harris 1991). The red fox can be found in the following habitats: urban, woodland, farmland, upland (Corbet and Harris 1991; Alderton 1994; Sterry 2005). The red fox lives in dens which can be made from a variety of features depending on the environment, such as banks, under buildings, drains, rock crevices, wood piles, heavy vegetation, or disused burrows, such as rabbits (Corbet and Harris 1991; Fuller and Cypher 2004; Macdonald and Reynolds 2004; Sterry 2005). Likewise, the red fox will often use an abandoned Eurasian badger sett or shared sett with badgers as a den before the breeding season typically from November to February (Corbet and Harris 1991; Fox 2007). The use of a den increases during the breeding season and with the birth of cubs between March and April, when not the breeding season the red fox tends to seek refuge in areas of thick vegetation cover (Corbet and Harris 1991; Alderton 1994; Sterry 2005; Fox 2007). The home range size for the red fox has been recorded to vary anywhere from 20 ha - 4000 ha depending on the habitat, availability of trophic resources, and the presence of predators (Corbet and Harris 1991; Doncaster and Macdonald 1991; Alderton 1994).

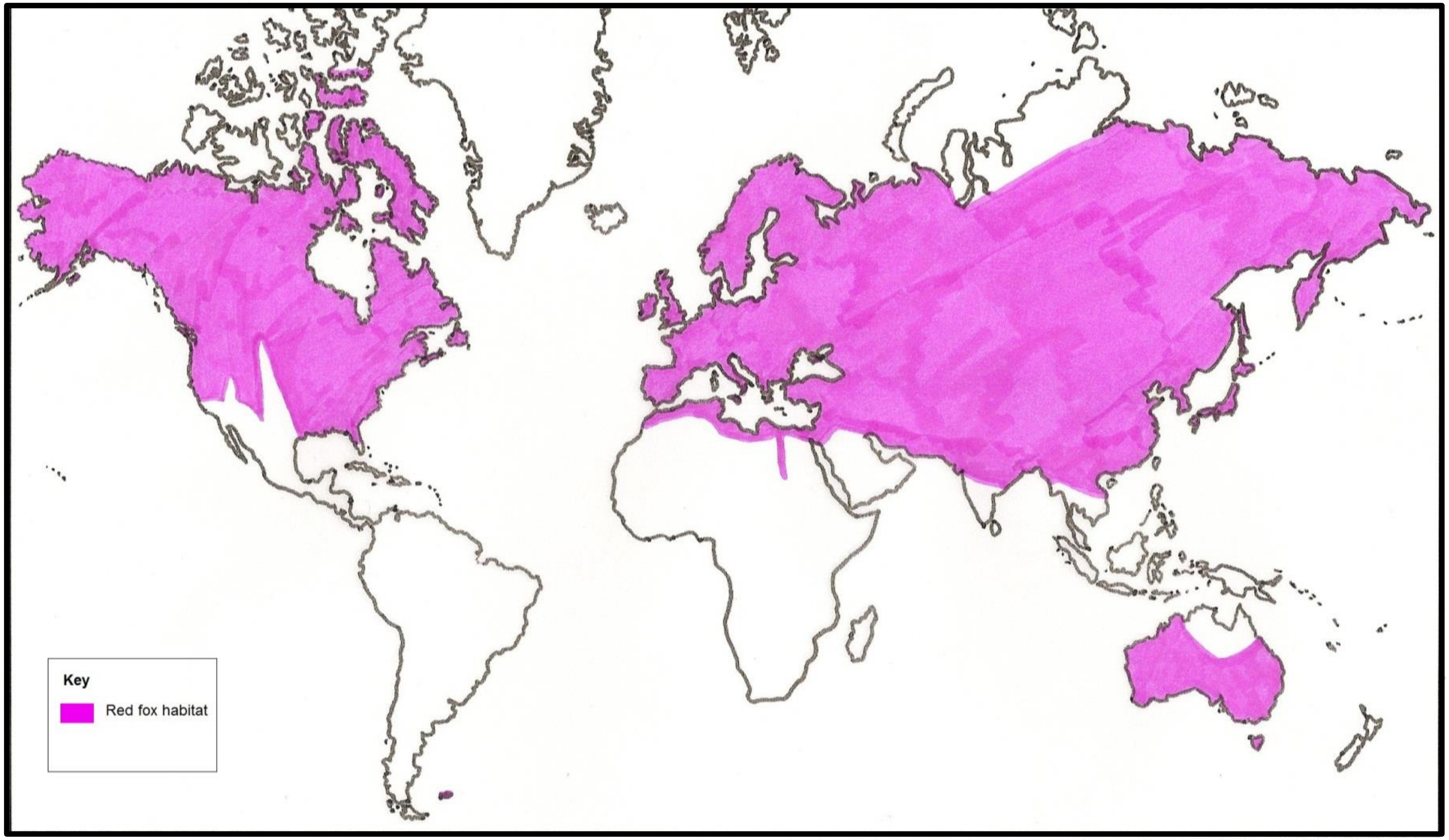

Figure 1.3. The geographical distribution of the red fox (Linström 1982; Larivière and Pasitschniak-Arts 1996; Macdonald and Reynolds 2004; Sterry 2005; Temple and Terry 2007).

The Eurasian badger has a body size of 65 cm - 80 cm in length and has a varied weight depending on the season: September-February the average weight is 12.2 kg and March-May it is 8.8 kg (Corbet and Harris 1991; Sterry 2005). The breeding season of Eurasian badgers is from February to May with births occurring between November and the following February (Corbet and Harris 1991; Sterry 2005; Wang 2011). The Eurasian badger is widespread throughout Europe and within Britain has a higher density in England (Corbet and Harris 1991) (Figure 1.4). The badger can be found in deciduous and mixed woodlands, pastures, scrub, hedgerows, and arable lands but have been observed in peri-urban environments (Corbet and Harris 1991; Sterry 2005). Eurasian badgers live in setts, of which there are two general types: the main sett and outlier setts or outliers (Davies 1936; Macdonald *et al*. 1996). The home range size of the Eurasian badger can be as small as 30 ha or at least as great as 150 ha depending on the habitat and availability of trophic resources (Corbet and Harris 1991).

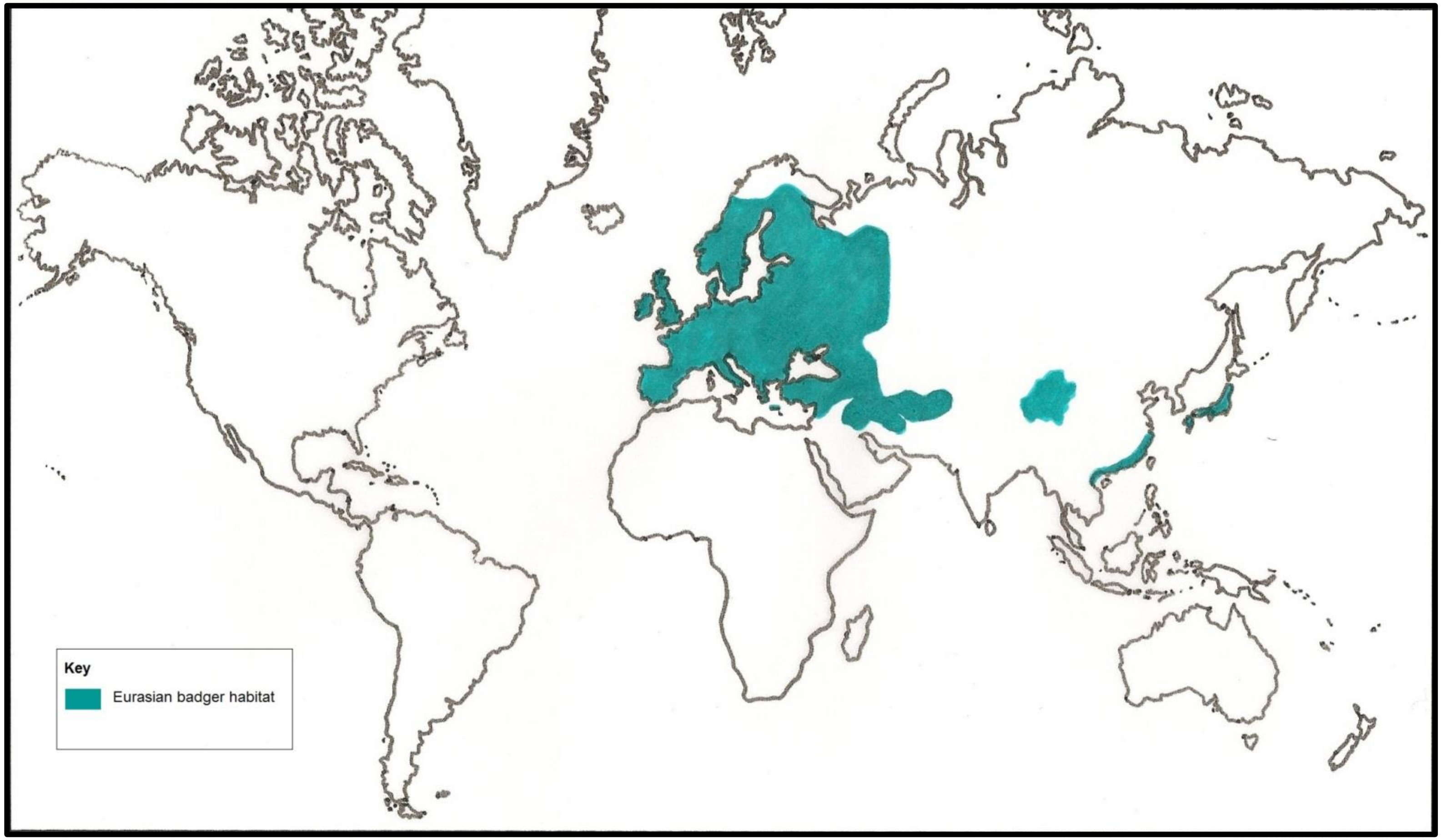

Figure 1.4. The geographical distribution of the Eurasian badger (Da Silva *et* al. 1993; Kurose *et al*. 2001; Revilla and Palomares 2002; Macdonald *et al*. 2004; Sterry 2005; Temple and Terry 2007; Wang 2011).

1.4.2 Red Fox and Eurasian Badger Diet

Scavengers can be labelled as either obligate or facultative scavengers. Obligate scavengers are those whose diets rely primarily on carrion. Facultative scavengers or opportunistic scavengers are those scavengers that rely on scavenging as one of their main methods of gathering food but not the sole source (Selva and Fortuna 2007). Generalist predators are labelled as such because they are able to switch between their main prey and alternative prey, especially in times when their main prey is scarce (Leckie *et al*. 1998). The red fox and Eurasian badger are solitary foragers, facultative scavengers, and generalist predators. The red fox's diet consists of earthworms (*Lumbrius terrestris*), anthropogenic food, fruits, invertebrates, small mammals, sheep, pig (*Sus scrofa*), and other ungulates (mostly fawn) (Doncaster *et al*. 1990; Kauhala *et al*. 1998; Leckie *et al*.1998; Jarnemo and Liberg 2005). The main food source for the Eurasian badger is earthworms but also includes oats, barley, small mammals, rodents, lagomorphs, fruits, and invertebrates (Kruuk and Parish 1981, 1985; Kauhala *et al*. 1998; Revilla and Palomares 2002). Carrion can also act as an alternative food resource for such facultative scavengers when normal prey is not available, particularly during harsh winters that reduce the survival rate and thus availability of regular prey (Selva and Fortuna 2007). These facultative scavengers do share some similar scavenging behaviour qualities such as scavenging alone, having overlapping diets within the same environment, and foraging primarily at night but also at crepuscular and diurnal periods.

A large amount of research into the diet of these scavengers has focused on the Alternative Prey Hypothesis (APH) and how generalist predation affects prey populations. APH claims that a predator will seek an alternative prey when its main prey's population is low (Kjellander and Nordström 2003). Prey-switching behaviour has been observed for both the red fox and Eurasian badger (Kruuk and Parish 1981, 1985; Lindström 1982; Kauhala *et al*. 1998; Leckie *et al*. 1998; Revilla and Palomares 2002; Kjellander and Nordström 2003; Jarnemo 2004). In order to better comprehend the effects of prey-switching behaviour it is essential to identify and understand the foraging behaviour of these predators, more specifically understanding the choices that need to be made and the factors influencing them when scavenging. Understanding the concept of prey switching within the diets of scavengers, along with knowledge of prey populations within the crime scene and surrounding area, can aid interpretations and predictions regarding the likelihood of certain scavenger species seeking carrion and human remains as food sources. Similarly, knowledge of a scavenger's diet and scavenging behaviour can aid police search officers and forensic scientists in interpreting the frequency to which scavengers modify a set of remains and the types and conditions of skeletal elements that may be recovered.

1.4.2.1 Red Fox Foraging Behaviour

The red fox is a solitary scavenger, which is unusual because other predatory members of the Canidae family (e.g. wolf) do scavenge and hunt in pairs or packs (Haglund *et al*. 1989; Willey and Snyder 1989). The fox scavenges alone due to the small size of its prey but has been observed to occasionally hunt in pairs for larger prey such as fawns (Lindström 1982; Jarnemo and Liberg 2005). Red fox hunting methods have been recorded in an ecological study by Jarnemo (2004). Two main hunting methods were observed: searching the ground surface and survey of open areas from edges of the landscape (Jarnemo 2004). The hunting and surveying behaviour of the red fox to travel along topographical features like the forest edge or large rocks allows the fox to remain undetected whilst travelling and allows the fox to gain a larger view of the area it is surveying. A survey by police search officers for such topographical features within and around the crime scene area can indicate key reference points to be searched by police search officers and cadaver dogs. If different scavenger species favour certain topographical features whilst travelling through their home range then there is potential for scavenged remains to be taken to these features for further scavenging or indeed may be accidentally dropped by scavengers whilst travelling.

The foraging behaviour of the fox differs from hunting and surveying behaviour by not following such topographical features. Foraging behaviour instead involves the fox walking through a single area it is searching more than once to increase its chances of acquiring food. During this process the fox will search the ground surface in a non-systematic pattern with its nose lowered to the ground and it will continuously stop and search various spots in that area (Henry 1977). A fox will not only be looking for food items on the ground surface but will also be searching for food caches dug by other foxes; the way in which those caches will be easily found is through urine marking (Henry 1977). Caches are shallow holes (c. 12 cm depth) dug by foxes in which a food item(s) will be buried, covered, and then later retrieved for consumption or transported to a new location (Caraeu *et al*.

2007). Caraeu *et al*.'s (2007) study of arctic foxes identified two types of caches: long-term and short-term. Short-term caches are used by foxes to temporarily hide food whilst continuing to forage for further food items. Caching behaviour provides foxes with the option to further scavenge remains away from deposit sites and at later periods. The removal of remains, at a later date than the initial scavenging period, from caches by foxes can lead to the appearance of skeletal remains in locations within or around the crime scene area that have previously been searched by police search officers, thus scenes should always be searched multiple times. Police search officers need to be aware of the possibility of caches created by foxes within and around the scene so skeletal remains buried at shallow depths are not overlooked.

1.4.2.2 Eurasian Badger Foraging Behaviour

Most research into the foraging behaviour of Eurasian badgers focuses on the availability of earthworms and its effects on badgers' diets. Eurasian badgers' foraging behaviour had been labelled as surface foraging behaviour which sometimes requires light digging to uncover earthworms (Kruuk and Parish 1981). However, as previously mentioned, like the red fox, the Eurasian badger has a varied diet and is able to seek alternative prey when its main prey is scarce. Depending on the alternative prey sought the foraging behaviour of the badger will need to change and compensate for new choices that the individual must make in acquiring its alternative prey. For instance when searching for lagomorphs or larvae at the soil surface as alternative prey, badgers have been observed to dig (Revilla and Palomares 2001).

1.4.3 Recovery Distances of Scavenged Remains

An animal's home range includes the area in which it regularly travels to perform activities such as hunting, foraging, surveying, and lives (e.g. sett) (Jewell 1966), thus the identification of a scavenger's home range can lead to areas within the crime scene where a scavenger may have taken remains. Following an assessment of the scavenger species which may inhabit the crime scene and surrounding area, the delineation of the search boundary can be both hindered and aided by the identification of the home ranges of scavengers within the environment. Identifying a search boundary will inform police search officers of how to adapt search methods in order to improve the efficiency and effectiveness of the search and recovery of scavenged and scattered remains. There is some debate as to how to define a home range because there are a variety of factors that can influence where an animal travels and what actions it undertakes within its home range (White and Harris 1994; Galef and Giraldeau 2001). For example, predation, food competition, or mating reasons causing animals to travel varying distances. Therefore, home range sizes tend to vary and should not be used as the sole deciding factor when delineating a crime scene search area.

1.4.3.1 Red Fox Home Range: Recovery of Scavenged and Scattered Remains

The home range of a red fox can be difficult to identify for various reasons such as a lack of territoriality, non-group style living, seasonal changes, excursions, and floating individuals (Trewhella *et al*. 1988; Doncaster and Macdonald 1991). Canids may disperse to meet individual metabolic needs, search for trophic resources, seasonal or mating reasons, or aggression between dominant and subordinate animals (Christian 1970; Zimen 1976, 1981, 1984; Bekoff 1977; Gittleman and Harvey 1982; Doncaster and Macdonald 1991; Harris and White 1992; White and Harris 1994; Cavallini 1996). These factors not only affect the dispersal behaviour of foxes but can also affect the rate at which scavengers modify a set of remains and the distances to which remains are removed and scattered from the deposit site.

Aggression is predicted to be greater when at the site of food and this will increase as the availability of main food resources diminishes (Doncaster and Macdonald 1991; Hiraldo *et al*. 1991; White and Harris 1994; Revilla and Palomares 2001; Selva and Fortuna 2007). If aggression is present at the deposit site of a set of remains then scavenged elements may be removed to varying distances which provide a scavenger protection from other competing scavengers. This is particularly true for the red fox which does not follow a pattern of group living except when allo-parental behaviour of two parents is adopted for the increased survivability of cubs or for successful reproduction (Cavallini 1996). Intra-specific aggression is expected largely for those facultative scavengers which are solitary foragers, such as the red fox (Doncaster and Macdonald 1991; Hiraldo *et al*. 1991; White and Harris 1994; Revilla and Palomares 2001; Selva and Fortuna 2007). The presence of intra-specific aggression is in addition to inter-specific aggression which can be present when two species' diets overlap within the same environment, such as foxes and badgers. Intra-specific aggression would be expected to be less in scavengers that live in groups, such as the Eurasian badger (Hiraldo *et al*. 1991; Revilla and Palomares 2001; Selva and Fortuna 2007). However, levels of aggression are expected to increase particularly during mating seasons and harsh environmental conditions affecting survivability rates of predator and prey.

1.4.3.2 Eurasian Badger Home Range: Recovery of Scavenged and Scattered Remains

In contrast to the red fox and other mustelids, the Eurasian badger commonly lives in stable social groups called a badger clan (Macdonald *et al*. 2004). A badger clan is made up of several badgers living in the main sett throughout its chambers. Within a single badger territory there is usually one main sett with outliers, in order to maintain spatial distribution of setts and territories, as well as social systems (Macdonald *et al*. 2004). Eurasian badgers utilise hinterland and border latrines to urine mark their territory (Revilla and Palomares 2002; Macdonald *et al*. 2004). Hinterland latrines are located near setts and can be used by every member of a social group (Macdonald *et al*. 2004). Border latrines are used to define territory borders and can be used by different social groups (Macdonald *et al*. 2004). Sett locations are based on a variety of factors, most importantly are soil type and metabolic needs. The location of setts in relation to trophic resources like earthworms will be based on reducing energy costs to obtain such resources.

The ability to sustain social group living has been explained through the Resource Dispersion Hypothesis (RDH) and more specifically through the Food Dispersion Hypothesis (FDH) and the Sett Dispersion Hypothesis (SDH) (Macdonald *et al*. 2004). SDH suggests that territory size of a group is based on the spatial distribution of setts but it does not explain why a sett location has been chosen by a group of badgers (Da Silva *et al*. 1993). RDH implies that the location of a sett will be dependent upon how worm-rich a habitat is, but badgers are only able to access this resource when it is near the soil surface (Da Silva *et al*. 1993). Territory size as being dependent on RDH suggests that there would be a decrease in territory size when habitats change from worm-poor to worm-rich (Da Silva *et al*. 1993). Revilla and Palomares’ (2002) also showed that in areas of low badger density, territorial systems were flexible and urine marking via latrines was concentrated in hinterland latrines and areas of main activity.

Despite social group living, badger groups still have dispersing individuals in search of new territories which may be influenced by factors such as energy constraints, mating seasons, breeding seasons, geology, and other environmental factors. The Eurasian badger displays two types of dispersal behaviour: socio-spatial restructuring and transitional dispersal (Macdonald 1983; Carr and Macdonald 1986; Macdonald *et al*. 2004). Socio-spatial restructuring refers to at least one individual within one social group leaving and joining or creating sub-groups within the same territory possibly due to population growth (Roper *et al*. 2003; Macdonald *et al*. 2004). The dispersal behaviour and variability in home range sizes of scavengers can impair police search officers' attempts to delineate a search area and to identify key reference points. Nevertheless, the identification of hinterland and border latrines can aid in locating the main and outlier setts which are potentially used by both badgers and foxes. The identification of the location of latrines and setts in relation to the suspected deposit site of remains will help in delineating a search area by indicating the home range or territory size of scavengers within and around the area and the accessibility of the deposit site. Additionally, latrine and sett locations are reference points which need to be searched by police search officers for scavenged and scattered remains which have been cached or dropped whilst scavengers travelled to setts, as well as possible caches dug along paths to setts or latrines. The knowledge of species-typical scavenging behaviour and patterns, as well as the characteristics of the environment and topography encompassing a scavenger species' home range, can improve the search, recovery and interpretation of scavenged, disarticulated and scattered human remains.

1.5 THESIS AIMS AND OBJECTIVES

The aim of this thesis is to fill the knowledge and methodology gaps in both the literature and amongst forensic scientists, investigators, and police search officers in the species-typical scavenging behaviour and pattern of the red fox and Eurasian badger. Mammalian scavenger species and their species-typical scavenging behaviour and patterns toward surface deposited vertebrate remains will be identified through the use of field experiments, which employ both direct observation and actualistic methods. Scavenger species-typical utilisation and modification of vertebrate remains will be determined through field experiments and bite mark analysis. The forensic impact of scavenging by red foxes and Eurasian badgers is assessed through direct application to forensic investigations and police-oriented experiments. The objectives of this research are to:

1. Identify mammalian and avian scavenger species of surface deposited vertebrate remains in a Northwest European context;
2. Identify and outline the species-typical scavenging behaviour and pattern of common avian and rodent scavenger species;
3. Identify and outline the species-typical scavenging behaviour and pattern of red foxes and Eurasian badgers;
4. Determine the forensic impact of the species-typical scavenging behaviour and pattern of red foxes and Eurasian badgers;
5. Assess the forensic application of species-typical scavenging studies to forensic investigations;
    a. Provide police search officers with advice on the search, recovery, and interpretation of scavenged human remains in a Northwest European context.

1.6 THESIS STRUCTURE

This thesis analyses the species-typical scavenging behaviour and patterns of Northwest European scavengers, in particular the red fox and Eurasian badger, of surface deposited deer remains with the aim of aiding forensic investigations and physical searches of scenes involving scavenged human remains. Chapter 1 reviews current knowledge in mammalian and avian scavenging of faunal and human remains within the fields of taphonomy, zooarchaeology, paleobiology, paleoecology, taphonomy, archaeology, forensic archaeology, forensic entomology, forensic anthropology, and pathology. Chapter 2 assesses police search officers' experiences and knowledge of cases involving the scavenging of human remains within the U.K. Chapter 3 and 4 identify the common scavenger species to be found in a woodland environment within Northwestern Europe, in particular Britain. These chapters analyse and characterise the species-typical scavenging behaviour and patterns of wild scavengers of surface deposited deer within a woodland environment through the use of direct observation and actualistic methods. In contrast to North America (Rodriguez and Bass 1983; Mann *et al*. 1990; Vass *et al*. 1992; Bass 1997; Spradley *et al*. 2011), human cadavers are not as readily available for scavenging studies within the U.K. due to ethical, planning, and legislative restrictions (McHanwell *et al*. 2008; Cross *et al*. 2009). Human cadavers are instead donated to medical research in the U.K. and tend to be from the elderly and frail (Richardson and Hurwitz 1995), as well as potentially embalmed, thus limiting the ability of forensic studies to research different crime scene scenarios. Animal analogues are commonly used in forensic studies, both in the U.K. and North America, to recreate and analyse crime scene scenarios (Willey and Snyder 1989; France *et* al. 1992; Morton and Lord 2006; Vanlaerhoven and Hughes 2008; Reeves 2009; Cross and Simmons 2010; Simmons *et* al. 2010). Although pigs (*Sus scrofa*) are normally used in forensic studies as human proxies because of similarities in skin and fat qualities (France *et al*. 1992; Morton and Lord 2006; Cross and Simmons 2010), deer were chosen as proxies because this research concentrates on the scavenging, disarticulation and scattering of surface deposited skeletal remains. This research is not focused on the analysis of soft tissue loss, decomposition chemistry, or microbial activity. The elongated skeletal structure of deer is also more similar to the human skeleton than the shorten structure of pigs (Figure 1.5). Additionally, the Department for Environment, Food and Rural Affairs (DEFRA) prohibits the surface deposition of pigs in the U. K. in order to prevent the spread of disease to domestic livestock (DEFRA 2012).

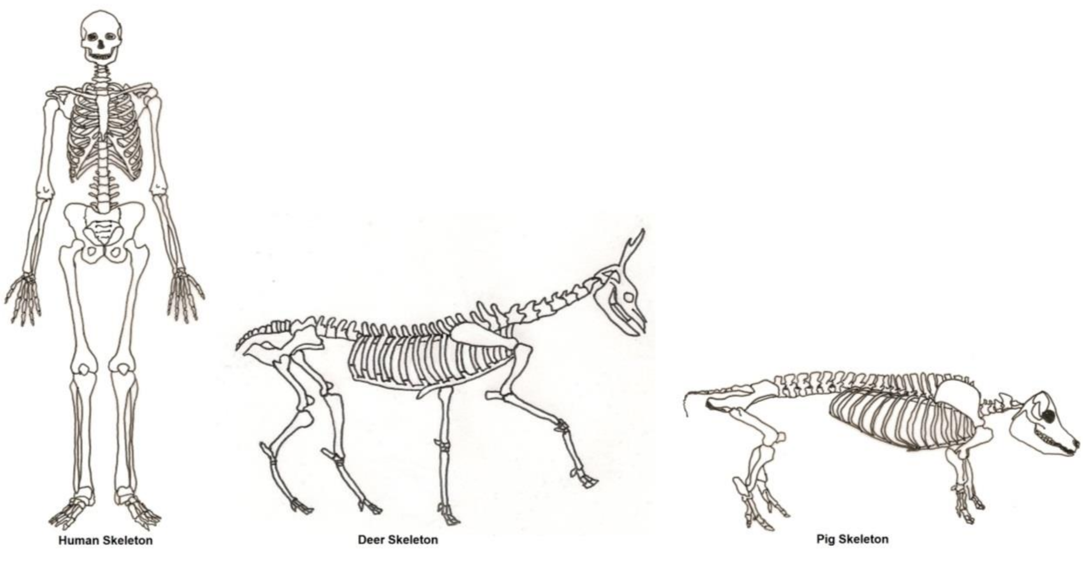

Figure 1.5. Human, deer, and pig skeletal systems.

Chapter 3 presents the scavenging activities of rodent and avian scavengers which modify large-sized carcasses but are not capable of disarticulating and removing large-sized carcasses from deposit sites. Avian and rodent scavenging behaviours affected surface deposited deer and the scavenging behaviour of other scavengers observed at deposit sites hence their relevance to scavenged human remains is discussed.

The largest and most common wild scavengers within Northwestern Europe, especially in Britain, include the red fox and Eurasian badger, hence the focus of this thesis is the forensic impact that red fox and Eurasian badger scavenging has on human remains. Moreover, the scavenging behaviours, dentition, body size, jaw size, bite force, and jaw strength of these two scavengers enables them to heavily modify and transport large-sized carcasses, thus these scavengers are presented in Chapter 4. Chapter 4 examines the scavenging behaviour of captive red foxes and Eurasian badgers for comparison to the observed scavenging behaviour of wild red foxes and Eurasian badgers. The species-typical scavenging behaviour and pattern of captive and wild red fox and Eurasian badger are analysed and characterised. These scavengers' species-typical scavenging behaviours and patterns are analysed and discussed in order to assess the following: the identification and characterisation of Eurasian badger and red fox scavenging behaviours and patterns; the comparison of red fox scavenging to other canid species; the application of species-typical scavenging knowledge to forensic investigations and search methods used by police search officers; and the filling of the gaps in the scavenging knowledge and literature within this region.

Chapter 5 analyses the dimensional data of scavenger-induced bite marks found on recovered scavenged deer remains from field experiments and bones scavenged by captive and domestic scavengers. The benefits of identifying a scavenger species to forensic investigations and physical searches of scenes are discussed. Chapter 6 applies the search methodologies and results from Chapter 3 – 5 to experiments involving the physical search of mock scavenging scenes by police search officers. Finally, Chapter 7 summarises the research methodologies and forensic applications of this thesis. Chapter 7 identifies the common scavenger species to be found within Northwestern Europe and the characteristics of their species-typical scavenging behaviour and patterns. The species-typical scavenging behaviour and pattern of the red fox and Eurasian badger are further discussed and the benefits of such knowledge to future forensic investigations, physical searches of scenes, and studies are presented.

Chapter 2

Scavenging in Northwestern Europe: a survey of U.K. police search officers

2.1 INTRODUCTION

Although there is a gap in scavenging studies and published forensic case studies within Northwestern Europe (Table 1.1; Appendix I, Table A1-1), there are scavenger species within this region capable of modifying human remains. Wild scavengers to be found within this region include rodent, avian, canid and mustelid species (Kruuk and Parish 1981; Doncaster *et al*. 1990; Corbet and Harris 1991; Da Silva *et al*. 1993; Alderton 1994; Todd *et al*. 2000; Reif *et al*. 2001; Revilla and Palomares 2001, 2002; Macdonald *et al*. 1996, 2004; Sterry 2005). More specifically within the U.K., common wild scavengers include wood mouse (*Apodemus sylvaticus*), grey squirrel (*Sciurus carolinensis*), carrion crow (*Corvus corone*), buzzard (*Buteo buteo*), Eurasian badger (*Meles meles*), and red fox (*Vulpes vulpes*) (Chapter 3 – 4). All of these scavengers are capable of causing significant soft tissue damage to surface deposited human remains (Mann *et al*. 1990; Haglund 1992; Rothschild and Schneider 1997; Byard *et al*. 2002; Asamura *et al*. 2004; Morton and Lord 2006; Klippel and Synstelien 2007; O'Brien *et al*. 2007). However, the bite force, jaw strength and body size of foxes and badgers enable them to not only scavenge human remains but also disarticulate and remove skeletal elements from deposit sites (Schmitz and Lavigne 1987; Corbet and Harris 1991; Alderton 1994; Baryshnikov *et al*. 2003; Lee and Mill 2004; Christiansen and Adolfssen 2005; Sterry 2005; Wroe *et al*. 2005; Christiansen and Wroe 2007). Moreover, the dentition and jaw strength of foxes and badgers are capable of fracturing and modifying bone surfaces which can obscure sites of ante- and peri-mortem trauma (Schmitz and Lavigne 1987; Baryshnikov *et al*. 2003; Lee and Mill 2004; Christiansen and Adolfssen 2005; Hillson 2005; Wroe *et al*. 2005; Christiansen and Wroe 2007).

Despite the ability of British avian and mammalian scavengers to scavenge, remove and scatter human remains, information pertaining to scavenging within this region is often based on anecdotal evidence disseminated amongst forensic professionals. Moreover, there is currently no search protocol or formal procedure for conducting searches of human remains or deposit sites that have been modified by animal scavengers (NCPE 2005, 2006). Procedures regarding the search for human remains fall under those of homicide investigation and tend to be based on behavioural, topographical, and geographical analyses, as well as intelligence, related to the crime scene scenario, victim, location, and offender (Harrison and Donnelly 2008). The procedures for homicide investigations do not take into account the impact that scavenging can have on human remains and deposit sites, and, in turn, search methods.

Individuals involved in a physical search at a crime scene can include untrained non-specialist searchers or specialist searchers which are either accredited or licenced by the Association of Chief Police Officers (ACPO) or trained by the National Centre for Policing Excellence (NCPE) (NCPE 2006). Trained and licenced specialist searchers include police search advisers (PolSAs), police search team members, and police search coordinators whose training is focused on using counter-terrorism (CT) search methods for the recovery of evidence related to firearms and explosives, as well as smaller evidence related to forensic examination (e.g. blood, mobile phones) (NCPE 2005, 2006). CT search methods are not based on the search for human remains but are still used and promoted as fully transferrable systematic techniques that can be applied to all crime scenes. To date, the effectiveness of current search methods used by police search officers in the search for scavenged and scattered human remains has not been assessed. Additionally, police search officers' experiences with scavenging have yet to be quantified. This chapter seeks to further highlight the incongruity between the amount of scavenging literature within Northwestern Europe, especially within the U.K., and the impact of scavenging on forensic investigations and physical searches of scenes involving scavenged human remains.

2.2 MATERIALS AND METHODS

Over the course of 164 days, an online survey was made available to police search officers within the U.K. through the National Police Improvement Agency (NPIA) and seminars presented by the researcher to police officers. All information provided by participants was anonymous. A total of 21 open- and closed-ended questions were provided so as to quantify police search officers' different experiences with scavenging (Table 2.1). The first question and questions 11 to13 then 18 to 20 were open-ended questions. Closed-ended questions include questions two to 10 and questions 14 to 17. The survey asked a variety of questions pertaining to police search officers' experiences and knowledge of forensic cases in which scavenging of human remains occurred. Police search officers' knowledge of the extent to which scavengers modified human remains and affected the recovery of skeletal elements were examined. The survey aimed to assess the occurrence of scavenging, scavenger species, and the general effects of scavenging on the recovery of skeletal remains within the U.K., as per police search officers' knowledge.

Table 2.1. The 21 questions provided via an online survey to police search officers and the various answer formats for each question.

Question #	Questions	Answer Format
1	What is your profession?	Comment
2	How many years of experience do you have in your profession?	1-5 years; 5-10 years; > 10 years
3	Have you come across cases where human remains have been scavenged and/or moved by animals?	Yes; No
4	Have you come across cases where human bones have been scavenged and/or moved by animal scavengers?	Yes; No
5	Have you ever been part of a crime scene search for human remains?	Yes; No
6	Have you ever been part of a crime scene search for human remains that did not result in the recovery of all of the set of remains?	Yes; No
7	Have you ever been part of a crime scene search for human remains that used search dogs?	Yes; No
8	During the use of search dogs, were all of the set of remains recovered?	Yes; No

Table 2.1 (continued). The 21 questions provided via an online survey to police search officers and the various answer formats for each question.

Question #	Questions	Answer Format
9	When using search dogs, was the crime scene search affected by the animal scavenging of human remains?	Yes; No
10	Have you ever been part of a crime scene search in which human remains and/or the search were affected by animal scavengers?	Yes; No
11	How was the crime scene search affected by the animal scavenging of human remains?	Comment
12	How were the remains affected by the animal scavenger?	Comment
13	Was the set of human remains buried, deposited as surface remains, or in another way at the crime scene?	Comment
14	Were the remains disarticulated and/or removed from the initial deposit site by an animal scavenger?	Yes; No
15	Was the set of human remains initially deposited as a whole body?	Yes; No
16	Were the human remains initially deposited as dismembered and/or with ante-mortem trauma?	Yes; No

Table 2.1 (continued). The 21 questions provided via an online survey to police search officers and the various answer formats for each question.

Question #	Questions	Answer Format
17	Were animal scavenger species within the search area identified?	Yes; No
18	What animal scavenger species were interpreted as scavenging the set of remains and/or affecting the search?	Comment
19	How were the animal scavenger species identified?	Comment
20	In your opinion, would additional information be beneficial to crime scene searches about different animal scavenger species, how they scavenge, where they are likely to transport remains, and their effects on human remains?	Comment
21	Please enter any additional comments below.	Comment

2.3 RESULTS

A total of 111 individuals participated in the survey. Participants identified their professions as police officer (*n*= 74), police search adviser (PolSA) (*n*= 28), police dog handler (*n*= 7), crime scene manager (*n*= 1), and police technical search assistant (*n*= 1). Of these respondents, five identified themselves as both a police officer and PolSA. However, the general term police officer does describe all of these professions so there is some ambiguity as to how officers participating in the survey labelled their profession because the question was provided as open-ended. More than 81% of participants had over 10 years of professional experience (*n*= 92) and none had less than five years.

One hundred and four responses to questions three and four showed that 63.46% (*n*= 66) had either attended a scene or knew of scenes where animal scavengers affected human remains and, more specifically, skeletal remains (57.69%, *n*= 60). For question five, 89.69% (*n*= 87) of 97 respondents had taken part in a crime scene search involving human remains. Ninety-seven answers to question six indicated that 59.79% (*n*= 58) of participants had been part of a crime scene search in which all of a set of human remains was not recovered. 74% (*n*= 72) of ninety-seven respondents to question seven had been part of a scene search which employed the use of cadaver dogs. Seventy-four (80.43%) of ninety-two responses to question eight showed that the recovery rates of cadaver dogs were negatively affected by scavenging. Similar to question nine, 25% (*n*= 69) of responses indicated that when cadaver dogs were used, search methods and results were affected by scavenging.

When answering questions 10 – 19 participants were instructed to base their answers on their own experience of forensic cases involving scavenging. 53% (*n*= 48) of 90 respondents to question 10 had been part of a search in which human remains and/or search were affected by scavenging. Questions 11-13 were open-ended questions thus it was possible for respondents give multiple answers. Questions 11 and 12 asked participants how scavenging affected human remains and search efforts. According to question 11, the majority of police search officers' experiences (58.33%, *n*= 35) with scavenging resulted in the search area being increased due to the scattering of skeletal remains. Question 12 highlighted that scavengers affected human remains by not only scattering elements (25%, *n*= 15) but also through soft tissue and bone modification (e.g. bite marks) (41.67%, *n*= 25).

Sixty-three responses to question 13 showed that the majority of remains were surface deposited (68.25%, *n*= 43) prior to scavenging (Figure 2.1). As participants' responses for open-ended questions, such as question 13, were not restricted, some responses were given as "N/A" and with no further information by respondents. Thus, "N/A" responses for open-ended questions may mean that the respondent did not have experiences with scavenging and did not feel that the question was applicable to their experiences. 57% (*n*= 35) of 61 answers to question 14 confirmed that human remains were disarticulated and/or removed from deposit sites by scavengers. Interestingly questions 15 and 16 indicated that scavenged human remains were more commonly deposited as a whole body (Yes: 75.41%, *n*= 46) rather than as dismembered (Yes: 18.03%, *n*= 11) prior to scavenging.

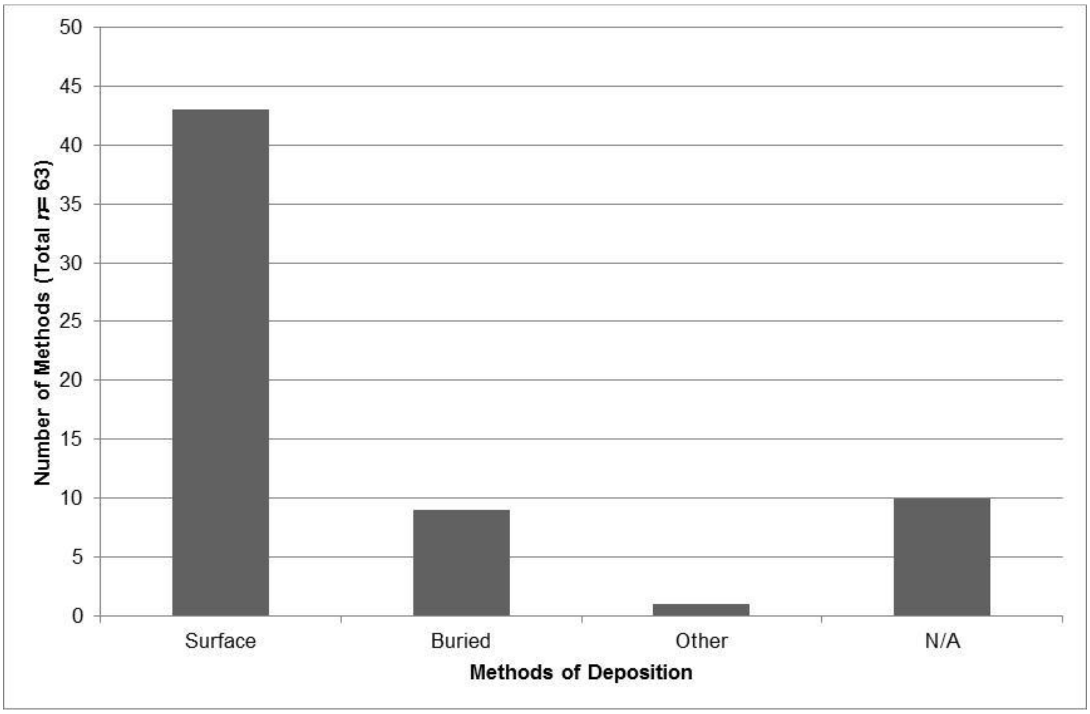

Figure 2.1. The frequency of the methods of deposition encountered by 61 respondents to question 13.

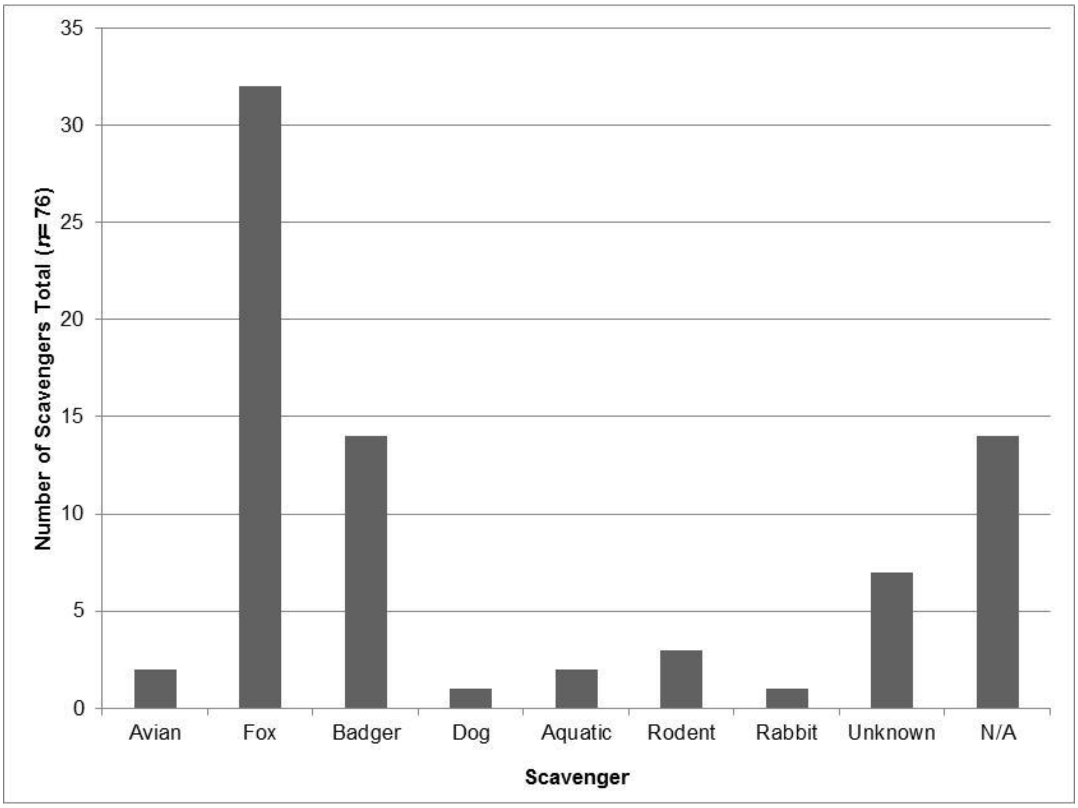

Figure 2.2. The frequency of scavengers interpreted by 61 respondents to question 18.

Questions 17 – 19 focused on the identification of scavenger species. Questions 18 and 19 were open-ended questions so multiple answers could be given by each respondent if they felt it was necessary. Sixty-one responses were received for question 17, of which 66% (*n*= 40) indicated that scavenger species were identified within the crime scene area. Answers for question 18 varied from fox (42.11%, *n*= 35), badger (18.42%, *n* = 14), unknown (9.21%, *n*= 7), rodent (3.95%, *n*= 3), aquatic (2.63%, *n*= 2), avian (2.63%, *n*= 2), dog (1.32%, *n*= 1), rabbit (1.32%, *n*= 1), and not applicable (18.42%, *n*= 14) (Figure 2.2). Fifty-nine responses to question 19 indicated that scavengers were identified by methods which were both varied and subjective (Figure 2.3). The majority of scavengers were identified based on the proximity of remains to badger setts, fox dens and rabbit warrens (16.95%, *n*= 10). Interestingly, 15.25% (*n*= 9) of responses stated that scavengers were not identified.

Question 20 ascertained participants' opinions on the provision of species-typical scavenging knowledge to forensic investigations and physical searches of scenes. 93.33% (*n*= 56) of respondents to question 20 felt that the provision of additional species-typical scavenging information would be beneficial. Question 21 was an additional section of the survey for any comments from participants.

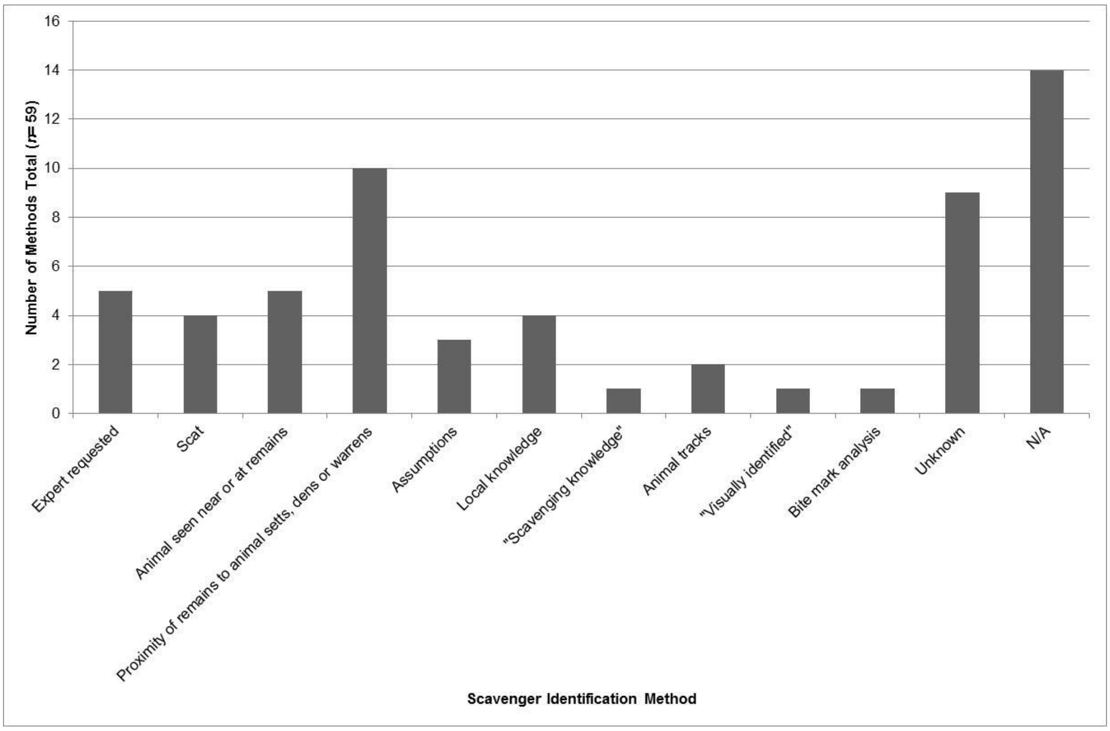

Figure 2.3. The frequency of scavenger identification methods used by 57 respondents to question 19.

2.4 DISCUSSION

This survey is the first time that police search officers' experiences with cases involving scavenging within the U.K. have been assessed. The survey has shown that police search officers are indeed faced with scenes within the U.K. involving the scavenging of human remains. Additionally, the survey has shown that scavengers of this region can affect police search officers' search and recovery efforts of scavenged human remains. Police search officers aim to recover as many skeletal elements of a set of remains for identifications and interpretations related to the individual and investigation, as well as out of respect for the individual's family. Search methods will thus need to be adapted according to factors which affect the crime scene, such as scavenging, so that the highest possible recovery rate of elements is achieved. The gap in the knowledge of scavenger species-typical scavenging behaviour and pattern within this region restricts police search officers' ability to adapt search methods for the optimal recovery of scavenged remains and causes forensic scientists, investigators, and police search officers to undervalue the impact of scavenging on investigations.

In the construction and execution of a search strategy, the senior investigating officer (SIO) must identify the search objectives and priorities, search parameters, required resources, and search methods (NCPE 2006). A forensic examination of a scene will occur prior to a physical search so that the potential for contamination of forensic evidence during a physical search is avoided (NCPE 2006). However, if the search objective is not for human remains but is instead for a location than a physical search may be performed prior to forensic examination (NCPE 2005, 2006). The SIO will consult and work with PolSAs regarding the appropriate search methods depending on the scene, objectives, and parameters (NCPE 2006). However, the current search protocols do not train or advise PolSAs and other specialist searchers in the search for scavenged and scattered human remains.

The survey showed that the search and recovery efforts of specialist searchers were negatively affected by the scavenging, disarticulation, scattering and removal of human remains. Thus, the current search methods, based on CT methods, used by specialist searchers and the search strategy implemented by SIOs need to be adapted for the more effective and efficient search for human remains and deposit sites that have been modified by scavengers. The survey also indicated that cadaver dogs' search and recovery efforts are affected by the scavenging of remains. The use of cadaver or victim recovery dogs to assist police search officers in the search for human remains is common practice (Komar 1999; Brown *et al*. 2002; Blau 2004; Rooney *et al*. 2004; Oesterhelweg *et al*. 2008). However, dogs are not always used in searches and can be adversely affected by factors, such as wind direction (Komar 1999; Brown *et al*. 2002; Blau 2004; Rooney *et al*. 2004; Oesterhelweg *et al*. 2008). This questionnaire does not discredit the added benefit of using dogs in the search for scavenged human remains; instead it highlights the need for dog handlers to be informed of species-typical scavenging information. When dogs are employed in the search of human remains they are led by their handlers in a systematic search method through the scene (Komar 1999; Brown *et al*. 2002; Blau 2004; Rooney *et al*. 2004; Oesterhelweg *et al*. 2008). Handlers knowledgeable of scavenger species-typical scavenging behaviour and patterns would be at an advantage by focusing their dog's search efforts within the scene to reference points associated with scavengers.

According to the survey, police search officers' experiences with scavenged human remains occurred more frequently with surface deposits and human remains deposited as whole rather than buried and dismembered remains. Respondents may have had more experiences with such remains because whole remains would be expected to have a greater chance of being recovered than those deposited as dismembered because the lesser weight of dismembered elements would allow scavengers of certain sizes to remove elements (Clark *et al*. 1997; Komar 1998; Morton and Lord 2006). Dismembered remains or those deposited with trauma expose soft tissue to weather conditions and insect activity which can increase the rate of decomposition of the remains (Bass 1997; Benecke 1998; Campobasso *et al*. 2001; Kulshrestha and Satpathy 2001; Pohjoismäki *et al*. 2010). An increased rate of decomposition can contribute to easier disarticulation and removal of elements by different scavenger species (Clark *et al*. 1997; Komar 1998; Morton and Lord 2006). There is also the possibility that remains recovered and interpreted as surface deposits may have been initially deposited as shallow burials accessed by scavengers. Interestingly, current search protocols refer only to the search of homicide burials and not to homicide surface remains (NCPE 2005, 2006). This is possibly again due to the assumption of fully transferable CT search methods to surface deposited human remains. It is evident in the questionnaire that investigations do include surface deposits, thus whether or not human remains are scavenged current search protocols need to be reassessed for the adaption of search methods for surface remains.

Despite scavengers' abilities to greatly modify human remains and affect search and recovery efforts, the survey suggests that SIOs and police search officers are not incorporating the identification of scavenger species into the majority of investigations. Currently, the identification and interpretation of scavengers may not be included in investigations because of the gap in the literature and knowledge in this region of the effects of scavengers on human remains, thus SIOs are not considering scavenging within their search strategy. Alternatively, SIOs that are including scavenging are potentially limited by the following: absence of search protocol or procedures for searching for scavenged human remains; time and financial constraints; scientific support managers' (SSM) being unaware of available resources or experts on scavenging; and limited numbers of available PolSAs or specialist searchers.

The scavengers most frequently interpreted as the agents altering remains within the police search officers' experiences in this study were foxes and badgers. However, where scavenger species had been interpreted the methods employed appear to have been varied and subjective, thus leading to possible incorrect identifications and interpretations associated with the scavenger and human remains (e.g. trauma) (Ropohl *et al*. 1995; Byard *et al*. 2002). For example, Young *et al*. (2014) presented five forensic cases of scavenged human remains surface deposited within Britain. Within the cases, the identification of scavenger species was based on the presence of typical carnivore damage to bone surfaces (e.g. epiphyseal ends; bite marks). This method of identification is subjective and does not include quantitative methods of analyses for more accurate identifications of scavenger species, taxon, or size, which could indicate specific areas associated with a scavenger to be searched within a scene or the need to extend the scene parameter to maximise the recovery of human remains. The use of subjective, varied, anecdotal and potentially incorrect identification of scavengers can give rise to the dissemination of incorrect knowledge of scavenger species-typical scavenging behaviour and poor adaptation of search methods. The use of an objective and standard identification method, like bite mark dimensional data, along with accurate knowledge of different scavengers' species-typical scavenging behaviour, can indicate key reference points to be searched within and surrounding a scene, as well as guide adaptations to search and recovery methods. Thus, police search officers are also at a disadvantage in the search, recovery, and interpretation of scavenged human remains by not pursuing the identification of scavenger species.

2.5 CONCLUSION

This chapter demonstrates that the scavenging of human remains is widespread within this region and does affect police search officers' search and recovery efforts even with the use of cadaver dogs. The lack of scavenger species-typical and region-specific literature based on the U.K. and to a wider extent Northwestern Europe, as well as the lack of search protocol for scenes of scavenging do not reflect the occurrence and forensic impact of scavenging within this region. Closing this gap in the knowledge of scavenger species within this region enables the more efficient and effective search and recovery of skeletal elements due to more accurate identifications and interpretations of scavengers and their species-typical scavenging behaviour and pattern.

Chapter 3

An experimental study of vertebrate scavenging behaviour in a Northwest European woodland context: rodent and avian scavengers

3.1 ABSTRACT

Vertebrate scavengers can modify surface deposited human remains which can hinder forensic investigations and physical searches. The effects of such scavenging vary between species and regions. Published research into the effects of the scavenging of human remains is dominated by work from North America with few studies covering Northwestern Europe. Forensic scientists, investigators, and police search officers in Northwestern Europe are often left questioning on a basic level as to which scavengers are active and how they might affect human remains. This chapter presents the results of a field study utilising deer (*Cervus nippon*; *Capreolus capreolus*) as surface deposits observed by motion detection cameras in a British woodland. The most common avian and rodent scavenger species recorded included the buzzard (*buteo buteo*), carrion crow (*Corvus corone*), wood mouse (*Apodemus sylvaticus*) and grey squirrel (*Sciurus carolinensis*). The scavenging behaviours observed were affected by seasonality, rates of decomposition and insect activity. Scavenging by buzzards, unlike carrion crows, was most frequent during fall to winter and prior to insect activity. Overall, avian scavengers modified and scavenged soft tissue. Rodents scavenged both fresh and skeletonised remains with grey squirrels only scavenging skeletal remains. Wood mice were most active in winter and scavenged both soft tissue and bone.

3.2 INTRODUCTION

Mustelid and canid scavengers and their scavenging behaviours are discussed in detail in Chapter 4, whilst this chapter focuses on common avian and rodent scavengers in Northwestern Europe including buzzard, carrion crow, grey squirrel, and wood mouse. Avian and rodent scavengers can modify, obscure and remove sites of trauma on both soft tissue and bone which can lead to misinterpretations of the sequence of events that led to the deposition and condition (e.g. rate of decomposition) of human remains (Mann *et al*. 1990; Haglund 1992; Rothschild and Schneider 1997; Byard *et al*. 2002; Asamura *et al*. 2004). Scavenging occurs in a wide variety of rodents such as grey squirrel (Klippel and Synstelien 2007), common rat (*Rattus norvegicus*) (Tsokos and Schulz 1999), African porcupine (*Hystrix africaeaustralis*) (Brain 1981), and golden hamster (*Mesocricetus auratus*) (Ropohl *et al*. 1994). Rodents will scavenge soft tissue from any accessible area on a set of human remains but have been previously recorded to scavenge most often at the hands and face of a body (Haglund 1992, 1997b; Patel 1994; Ropohl *et al*. 1994; Tsokos and Schulz 1999; Komar 2003; Klippel and Synstelien 2007). The prominent upper and lower incisors of rodents produce parallel striations with regular wound margins on soft tissue and bone surfaces (Haglund 1992, 1997b; Patel 1994; Tsokos and Schulz 1999; Klippel and Synstelien 2007). Despite the small body size of some rodent species, the dentition and gnawing behaviour of rodents allow them to access the marrow cavity of bones, either at epiphyseal ends or through the constant gnawing action at the diaphysis (Klippel and Synstelien 2007). In addition to modifying bone surfaces, rodents are capable of transporting skeletal remains dependent on the sizes of the bone and the rodent (Brain 1981; Klippel and Synstelien 2007).

Avian scavenging of human remains is not limited to the modification of soft tissue but can also include damage and removal of bone, personal effects, and hair for nesting (Mann *et al*. 1990; Bass 1997; Komar and Beattie 1998c; Asamura *et al*. 2004). Damage and removal of skeletal elements by avian scavengers will depend on the scavenger size, beak and talon morphology, and the carcass size (Fowler *et al*. 2009; Simmons *et al*. 2010). The modification of bone surfaces typically produces conical punctures caused by avian scavengers' beaks pecking at soft tissue, as well as bone (Komar and Beattie 1998c). Additionally, the effects of vertebrate scavenging on human remains will depend on several factors including the environment, weather conditions, condition and deposition of remains, and length of exposure, as well as particulars of the scavenger species (such as main food source, home range size, intra- and inter-specific aggression) (Gittleman and Harvey 1982; Rothschild and Schneider 1997; McNab 2000; Byard *et al*. 2002; DeVault *et al*. 2004; Wroe *et al*. 2005; O'Brien *et al*. 2007). All of these factors will vary at each crime scene and thus must be considered during a forensic investigation and physical search.

Nevertheless, the majority of research examining vertebrate scavengers from the point of view of their forensic significance has been based on North American environments and scavenger species, such as coyote (*Canis latrans*), wolf (*Canis lupus*) and vulture (Cathartidae) (Haglund *et al*. 1988, 1989; Willey and Snyder 1989; Mann *et al*. 1990; France *et al*. 1992; Haglund 1992; Owsley *et al*. 1992; Haglund 1997a; Komar 1998, 2003; Morton and Lord 2006; Janjua and Rogers 2008; Vanlaerhoven and Hughes 2008; Kjorlien *et al*. 2009; Reeves 2009; Spradley *et al*. 2011) with relatively limited forensic research available based on Northwest European environments or mammalian and avian scavengers of this region and their scavenging behaviours (Coard 2007; Wilson *et al*. 2007; Moraitis and Spiliopoulou 2010; Ruffell and Murphy 2011) (Table 1.1; Appendix I, Table A1-1). Previous studies on scavengers in Northwestern Europe have generally focused on the main components of their diets, home range sizes and the spread of diseases (Doncaster and Macdonald 1991; Baker *et al*. 2000; Revilla and Palomares 2001; Jarnemo 2004; Vicente *et al*. 2007); whilst less attention has been given to the significance of such scavengers for forensic cases involving human remains.

Forensic scientists, investigators, and police search officers questioning what types of scavenging animals are present within Northwest European environments and what those scavengers are capable of doing to human remains are often forced to rely on North American models of scavenging. This situation is based on the assumption that Northwest European scavenger species are likely to have similar effects on human remains to those in North America. Providing information on which scavenger species are present within different environments and regions, as well as their species-typical scavenging behaviours aids forensic scientists, investigators, and police search officers in the implementation of more efficient and effective search and recovery of scavenged human remains, as well as more accurate interpretations based on those recovered remains. The aim of this chapter is to address some of the most commonly asked questions by forensic scientists, investigators, and police search officers in Northwestern Europe regarding avian and rodent scavengers: Which scavenger species are present within a rural and peri-urban environment? What are the effects of scavenging by different scavenger species? Which factors can increase or decrease the frequency of scavenging? What areas on a carcass are different scavengers attracted to and when is such scavenging likely to take place?

3.3 Materials and Methods

Fresh deer carcasses were used as human proxies (Figure 1.5; Chapter 4; Appendix III). Pigs (*Sus scrofa*) are regularly used as human proxies in forensic studies of scavenging (France *et al*. 1992; Morton and Lord 2006) primarily due to the comparative qualities of the skin and fat contents. However, the Department for Environment, Food and Rural Affairs (DEFRA) prohibits the deposition of pigs on the ground surface in the U. K. for the prevention of the spread of diseases amongst domestic livestock (DEFRA 2012). The surface deposition of deer in the U.K. is not restricted by DEFRA because as wildlife they do not pose a threat in the spread of disease to domestic livestock. Deer were chosen as suitable human analogues in this research because the focus of this study is the scavenging, disarticulation and scattering of surface deposited remains rather than the analysis of soft tissue loss, decomposition chemistry, or microbial activity. Additionally, the elongated skeletal structure of deer more closely resembles the human skeletal structure than the skeleton of the pig (Figure 1.5).

Separate deer legs were also used as baits within the experiments. The deer and baits were obtained from an unrelated culling operation which is part of the humane management of wild deer populations within the region. Deer, all of which were aged about 2 years and included both males and females, died as the result of a gunshot wound (.308-calibre; c. 30 mm to 50 mm soft tissue wound) on the right side of the thorax and were surface deposited as fresh for this study with the site of trauma exposed.

The surface deposition of deer legs as baits and whole deer carcasses within a woodland environment located at Bovington, Dorset, U.K. (Figure 3.1), c. 450 m x 550 m, was conducted from November 2010 to July 2011 and utilised 12 baits and five deer carcasses (Chapter 4) (Table 3.1). See Appendix III for all images of deer and baits when deposited. Baits were used as a pilot study to gain an understanding of the field site prior to the deposition of whole deer. The first set of six baits did not include hides or hooves but the second set of six baits did. Baits were deer legs severed at the femur and humerus. The baits and deer were neither covered nor fenced off from the surrounding environment, this allowed for unrestricted exposure to weather conditions, flora, and fauna. Baits in set A were placed an average 25.2 m apart (Figure 3.2). Baits in set B were placed an average 21.6 m apart (Figure 3.2). The whole deer were surface deposited at an average distance of 94 m between each deer (Table 3.1; Figure 3.2). Maps were created using ESRI *ArcGIS* 10 and a base layer map at a scale of 1:2500 (Ordnance Survey 2012).

Baits in set A remained within the site until all baits were scavenged and removed by scavengers. After the removal of set A, baits in set B were deposited and remained on site until removed by scavengers. After both sets of baits were scavenged and removed, Deer 1 was deposited in December and remained on site for the total 210 days of the experiments (Table 3.1). In February, Deer 2 and 3 were deposited c. 100 m apart. After Deer 2 and 3 were scavenged, scattered and removed by scavengers, Deer 4 and 5 were deposited at the same time in March and were placed c. 135 m apart (Table 3.1).

Avian and rodent scavenging activities at baits and deer were recorded using SPYPOINT IR-7 infrared cameras fastened to trees at a height of approximately 55 cm above the ground surface and at a distance of about 1 m from each bait (one camera) and deer at the head and hind (two cameras). Cameras were active during all hours of the experiment in order to record 30 seconds long videos of any motion detected at a vertical angle of 30˚ and up to a distance of 15.24 cm. Recordings were retrieved from cameras during each site visit and were analysed for the presence of scavenger species and their scavenging behaviours during different stages of each deer's exposure and decomposition. The decomposition of each deer was identified according to Galloway *et al*.'s (1989) four stages of decomposition of human remains because this study presents a general description of observed decomposition for surface deposited remains and does not analyse the decomposition chemistry of the deer or buried remains. The state of decomposition and level of scavenging for each carcass were recorded during each weekly site visit. Additionally, photographic recordings were taken of insect activity and evidence of scavengers (e.g. scat, paw prints) at or near deer. Daily temperatures were obtained from the Meteorological Office's Hurn, U.K., weather station (Met Office 2012) (Chapter 4; Appendix III, Figure A3-20).

Figure 3.1. The location of the study site, Bovington, within the U. K.

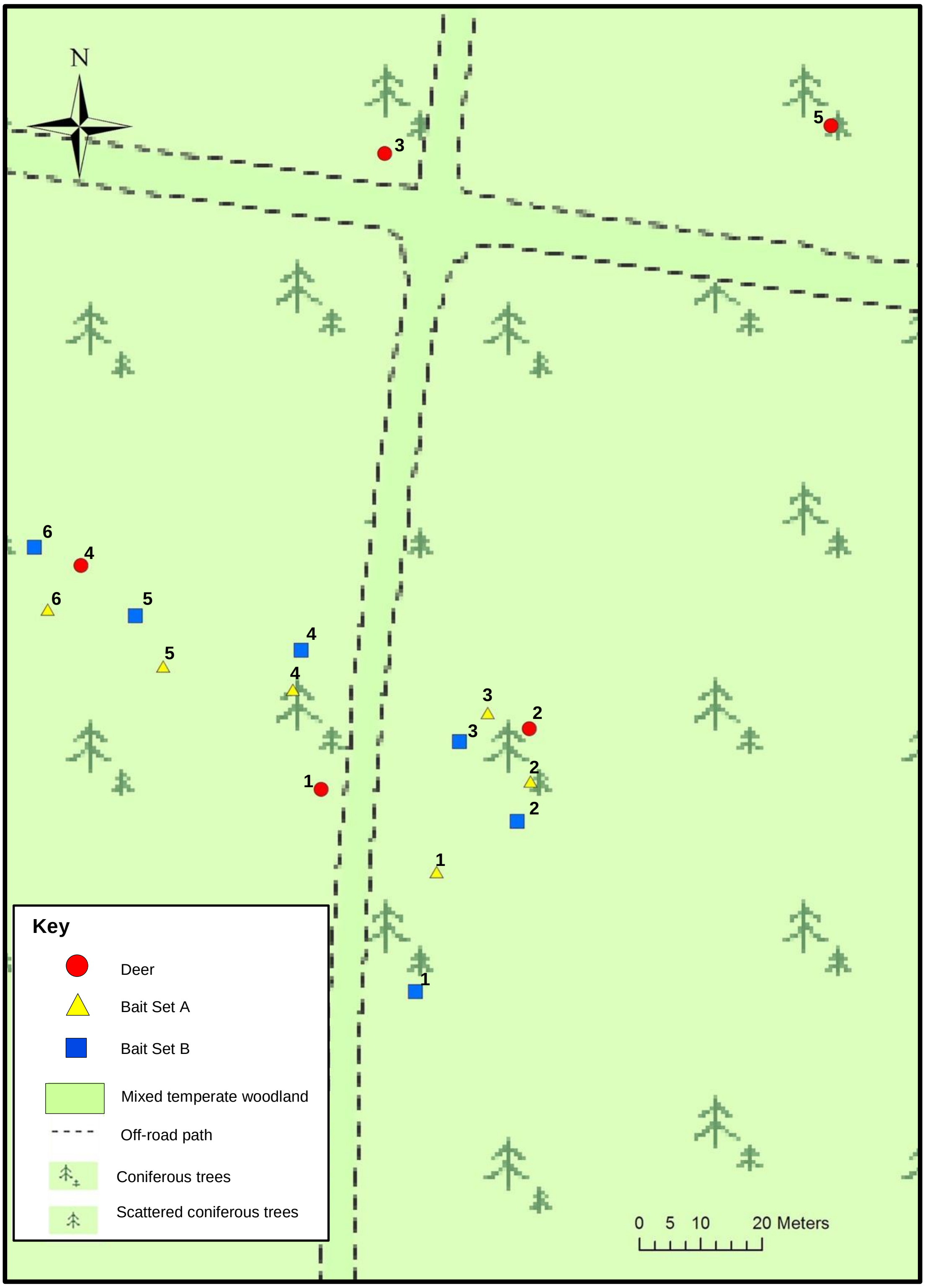

Figure 3.2. A map showing relative locations of and distances between the deposit sites for all baits and deer within the site.

Table 3.1. The weight, month, and year for baits and each deer when deposited. The average temperature during the total number of days of exposure for baits and each deer is also provided (Chapter 4).

Deer #	Weight (kg)	Deposit Month & Year	Total Exposure (Days)	Average Temperature (˚C)
Baits 1A-6A	2	November '10	6	6.13
Baits 1B-6B	6	December '10	6	2.57
1	59	December '10	210	9.51
2	24	February '11	44	7.17
3	24	February '11	8	8.10
4	23	March '11	103	12.58
5	34	March '11	103	12.58
Average	24.57		68.57	
Minimum	2		6	
Maximum	59		210	

3.4 RESULTS

3.4.1 Baits

Baits 1A-6A were surface deposited to test the positioning of cameras on trees and as only one camera recorded scavenging (Bait 3A; only the top of a buzzard's head was visible during scavenging) cameras were repositioned so that baits and scavengers would be more visible. Cameras detected a wider variety of scavenging of Baits 1B-6B which consisted primarily of scavenging by buzzards during daylight and red foxes (*Vulpes vulpes*) at night (Chapter 4). Areas of soft tissue on Baits A and B scavenged by buzzards had a string-like appearance, which was consistent with Asamura *et al*.'s (2004) description of crow scavenging of charred human remains in Japan but was more prominent in the deer legs deposited without a hide than those with a hide (Figure 3.3). No other scavenger species were observed at baits.

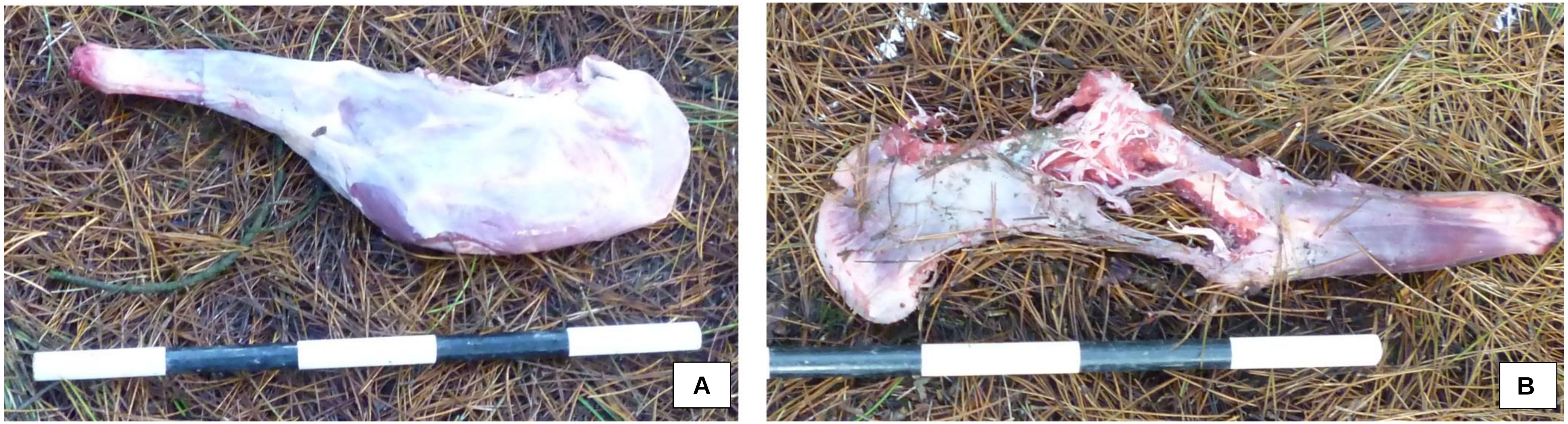

Figure 3.3. Bait 3A, deposited without hide and hoof (A), compared to after it was scavenged by a buzzard (B), which caused scavenged soft tissue to appear string-like (demarcated by arrows).

3.4.2 Deer Case Studies

In total, avian scavengers were observed and recorded at or near deer in 214 video recordings (107 minutes) and rodent scavengers in 52 recordings (26 minutes). Wood mice were observed scavenging at a carcass when it was still in the early stages of decomposition (57.89% of all wood mice scavenging events) prior to bloating but were also recorded scavenging when the carcass had become skeletonised (42.11%) (Table 3.2). Wood mice scavenging activities were nocturnal (Table 3.3) and recorded as occurring all over the carcass but were concentrated at the gunshot wound (GSW) located at the thorax (29.03%) (Table 3.4). Wood mice scavenged deer during all seasons but scavenged more frequently during colder seasons.

Grey squirrels were only recorded during daylight (Table 3.3) and scavenging at later stages of decomposition when remains were skeletonised (Table 3.2). Grey squirrels were observed scavenging and travelling through deposit sites during all seasons that deer were deposited. Scavenging by grey squirrels was evenly spread across the head (28.57%), neck (28.57%) and thorax (28.57%) but was also observed at the hind end (14.29%) of the deer (Table 3.4).

Table 3.2. Percentage of recorded scavenging events per scavenger species during each stage of decomposition for all deer. Stages of decomposition based on Galloway *et al*. (1989), as the descriptions of the stages are general.

Stages of Decomposition	Wood Mouse	Grey Squirrel	Robin	Crow	Buzzard	Total scavenging events
1.Fresh	57.89% (n=11)	0	0	25.83% (n=39)	100% (n=54)	45.22% (n=104)
2. Early Decomposition (e.g. discolouration and bloating; maggot activity)	0	0	0	23.84% (n=36)	0	15.65% (n=36)
3. Advanced Decomposition (e.g. moist soft tissue decomposition; some bone exposure and mummification)	0	0	0	49.01% (n=74)	0	32.17% (n=74)
4. Skeletonisation	42.11% (8)	100% (n=5)	100% (n=1)	1.32% (n=2)	0	6.69% (n=16)
5. Extreme decomposition	0	0	0	0	0	0
Total count of scavenging events	19	5	1	151	54	230

Table 3.3. Percentage of recorded scavenging events at all deer that occurred during day and night per scavenger species. Sunrise and sunset times for each day deer were exposed were obtained from Time and Date AS (2012).

Animal Species	Scavenging events after sunrise	Scavenging events after sunset	Total
Crow	100% (n=151)	0	151
Buzzard	100% (n=54)	0	54
Wood Mouse	0	100% (n=19)	19
Grey Squirrel	100% (n=5)	0	0
Total scavenging events of all scavengers observed	91.70% (n=210)	8.30% (n=19)	229

Table 3.4. Percentage of recorded scavenging events according to different locations on the whole deer at which each scavenger species scavenged.

Animal Species	Site of Trauma (GSW)	Head	Neck	Front Limbs	Thorax	Abdominal Cavity	Hind End	Hind legs	Total for all locations
Crow	14.39% (n=40)	6.47% (n=18)	7.19% (n=20)	10.43% (n=29)	3.96% (n=11)	12.95% (n=36)	18.35% (n=51)	26.26% (n=73)	278
Buzzard	79.66% (n=47)	8.47% (n=5)	0	0	10.17% (n=6)	1.69% (n=1)	0	0	59
Wood Mouse	16.13% (n=5)	12.90% (n=4)	16.13% (n=5)	9.68% (n=3)	29.03% (n=9)	6.45% (n=2)	3.23% (n=1)	6.45% (n=31)	31
Grey Squirrel	0	28.57% (n=2)	28.57% (n=2)	0	28.57% (n=2)	0	14.29% (n=1)	0	7
Total for all scavengers	24.53% (n=92)	7.73% (n=29)	7.20% (n=27)	8.53% (n=32)	7.47% (n=28)	10.40% (n=39)	14.13% (n=53)	27.73% (n=104)	375

Avian scavenging predominantly involved buzzard and carrion crow but other species, such as jay (*Garrulus glandarius*) and robin (*Erithacus rubecula*), were observed at the carcass deposit site following the removal of the remains by larger scavengers. The robin was observed searching the soil underneath where the deer had been deposited so it was recorded as having scavenged because it had the potential to remove either fur or insects related to the deer. The two instances where a jay was recorded it was stationary near a deer's deposit site (at least 4 m) so it was not identified as scavenging.

Buzzard scavenging was only observed in daylight hours (Table 3.3) and was primarily concentrated at the site of trauma (79.66%) for the removal of soft tissue but was also observed at the head (8.47%) of deer (Table 3.4). Additionally, buzzards were only present in the early stages of decomposition prior to any bloating of the carcass and before increased insect activity (Table 3.2). Buzzards were only observed scavenging in colder seasons (late fall to late winter). In contrast to buzzards, scavenging by carrion crows was observed for all months in which deer were deposited and during all stages of decomposition but did increase in warmer months and when deer were in an advanced stage of decomposition (49.01%) (Table 3.2). Similarly to buzzards, scavenging by carrion crows was limited to daylight hours (Table 3.3). Carrion crows not only removed soft tissue from the head (6.47%), GSW (14.39%), hind end (18.35%) and limbs (36.69%) of deer (Table 3.4) but also plucked fur from around the gunshot wounds on Deer 4 and 5 (Figure 3.4).

Figure 3.4. The still image taken from a video recording at Deer 5, showing two carrion crows removing fur, soft tissue and insects from the carcass, as well as collecting fur from the ground surface.

Table 3.5. The total number of video recordings of each animal species visiting each deer.

Animal Species	Deer 1	Deer 2	Deer 3	Deer 4	Deer 5	Total
Crow	3	0	4	46	155	208
Buzzard	49	0	7	0	0	56
Wood Mouse	21	0	0	0	1	22
Grey Squirrel	15	0	4	10	1	30
Robin	1	0	0	0	0	1
Jay	0	0	0	0	0	0
Total Count	89	0	15	56	157	317

Table 3.6. Percentage of recorded scavenging events of each scavenger species scavenging per deer.

Animal Species	Deer 1	Deer 2	Deer 3	Deer 4	Deer 5	Total percentage of scavenging events for all deer
Crow	2.70% (n=2)	0	12.50% (n=1)	100.00% (n=41)	100.00% (n=107)	65.65% (n=151)
Buzzard	63.51% (n=47)	0	87.50% (n=7)	0	0	23.48% (n=54)
Wood Mouse	25.68% (n=19)	0	0	0	0	8.26% (n=19)
Grey Squirrel	6.76% (n=5)	0	0	0	0	2.17% (n=5)
Robin	1.35% (n=1)	0	0	0	0	0.43% (n=1)
Total Count	n=74	n=0	n=8	n=41	n=107	n=230

3.4.2.1 Deer 1

Scavenging of Deer 1 occurred only when the deer was in a fresh stage of decomposition and skeletonisation. Wood mice were observed scavenging in 90.48% of recordings; grey squirrels in 33.33%; buzzards in 95.92%; and carrion crows in 66.67% of videos showing each scavenger at Deer 1 (Table 3.5-3.6). Overall, buzzards (63.51%, n = 47) were the most frequent scavenger of Deer 1 other than foxes (Chapter 4; Table 3.5-3.6). Wood mice scavenged when the deer was both fresh (57.89%) and skeletonised (42.10%). Grey squirrels and carrion crows only scavenged when the deer was skeletonised, whereas buzzards only scavenged when the deer was fresh.

After a time of exposure of approximately 33 hours, a wood mouse was recorded biting and removing soft tissue from the GSW area (Figure 3.5-3.6). Scavenging by wood mice at the GSW was recorded on three subsequent days of exposure prior to the arrival of a buzzard on the 8th day of exposure, around midday, which perched on top of the thorax of the carcass and removed soft tissue from the GSW (Figure 3.7). Additional scavenging by wood mice was observed at night on the 10th day and was followed on the 11th by scavenging of the deer by a buzzard during daylight. As Deer 1 was exposed for a total of 210 days, additional scavenging by carrion crow, wood mouse, and grey squirrel was observed during later stages of decomposition, in particular, once skeletonised. A jay and robin were recorded, separately, at the deposit site but were not recorded pecking at the carcass. The final scavenger observed at Deer 1 was a grey squirrel scavenging the skeletonised innominates on the 128th day of exposure.

Figure 3.5. A still image from video recordings showing a wood mouse (demarcated by an arrow) scavenging at the gunshot wound site on Deer 1.

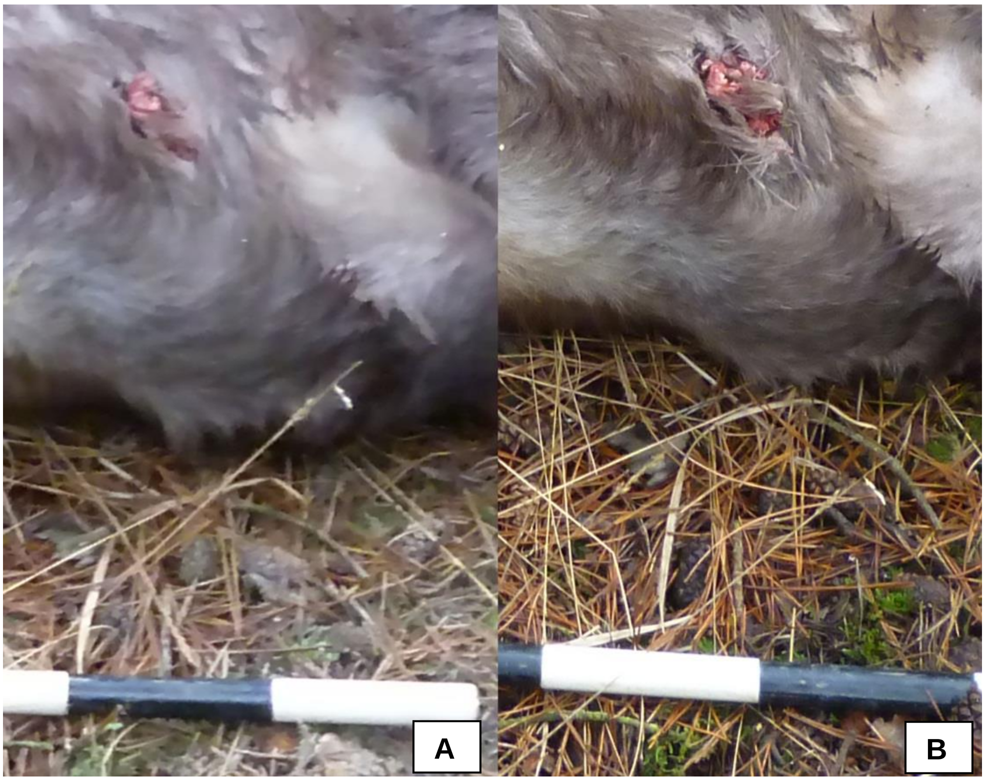

Figure 3.6. The appearance of the GSW on the thorax of Deer 1 prior to wood mouse scavenging (A). The modified soft tissue of the GSW of Deer 5 after wood mouse scavenging (B).

Figure 3.7. A buzzard recorded scavenging from the gunshot wound on Deer 1.

3.4.2.2 Deer 2

No avian or rodent scavengers were recorded at Deer 2 (Table 3.5). The scavenging, disarticulation, scattering and removal of the deer only involved fox activity (Chapter 4).

3.4.2.3 Deer 3

There were no observations of rodent scavengers at Deer 3 prior to the scavenging, disarticulation, scattering and removal of the deer on its seventh day of exposure within a 24 hour period by a fox (Chapter 4). Scavenging of Deer 3 only occurred whilst the deer was in a fresh stage of decomposition. All recordings from Deer 3 of buzzards showed them scavenging from the deer. Carrion crows were observed scavenging in 25.00% of videos of carrion crows at or near the deer (Table 3.5-3.6).

On Deer 3's second day of exposure, a buzzard was recorded for c. 15 minutes scavenging the GSW located on the thorax of the deer but was not observed scavenging at any other point in the deer's exposure. Scavengers, such as carrion crows and grey squirrels were observed investigating the soil surface of the deposit site after the removal of the deer by the aforementioned fox.

3.4.2.4 Deer 4

Carrion crows were recorded in 41 videos (20 minutes 30 seconds) taken at Deer 4 and were observed scavenging in 89.13% of videos (Table 3.5-3.6). Carrion crows only scavenged whilst the deer was in an advanced stage of decomposition. No buzzards were observed at the deer. The only rodents recorded were grey squirrels but they did not scavenge the deer.

On the 7th day of exposure, a carrion crow was observed at the deer but did not scavenge. Scavenging by carrion crows did not begin until the 22nd day and was focused primarily at the hind end and hind legs of the deer which had soft tissue trauma previously caused by a fox (Chapter 4). Scavenging by carrion crows also occurred at the exposed soft tissue at the abdominal cavity which was also caused by fox scavenging (Chapter 4). Carrion crows were recorded removing soft tissue and maggots from the abdominal cavity prior to the desiccation of the deer (Figure 3.4). On the 45th day of exposure, carrion crows were recorded scavenging from the head of the deer. The final observation of carrion crows scavenging from Deer 4 was on the 56th day and was concentrated at the desiccated remains of the ribcage and head (Figure 3.8).

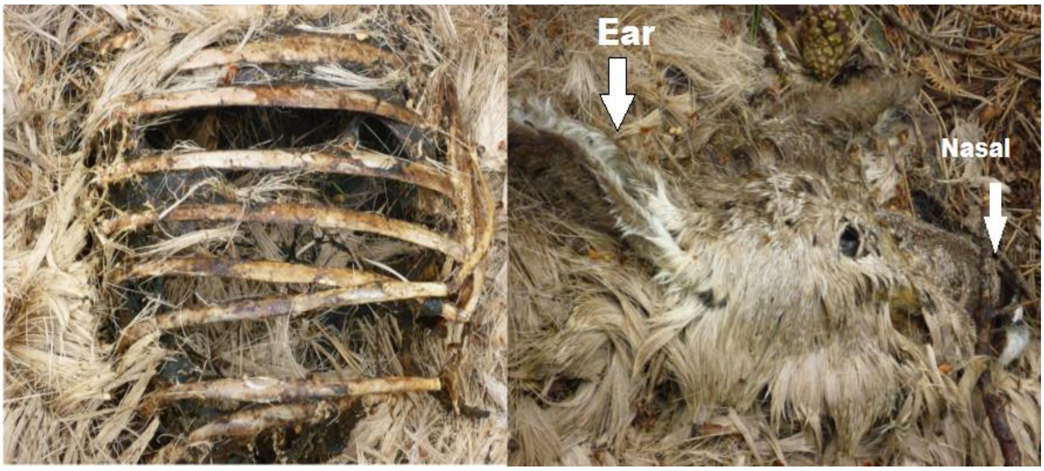

Figure 3.8. The desiccated ribcage and head of Deer 4 were also scavenged by carrion crows.

3.4.2.5 Deer 5

Carrion crows, grey squirrels and wood mice were observed at or near Deer 5 but not all were recorded scavenging. No buzzards were observed at the deer. There was only one video showing a grey squirrel and one video showing a wood mouse near the deposit site. Carrion crows were recorded scavenging in 69.03% of videos showing carrion crows at Deer 5 (Table 3.5-3.6). Carrion crows scavenged when the deer was fresh (36.45%), in an early stage of decomposition (38.32%), and skeletonised (25.23%).

Scavenging by carrion crows began on the 3rd day of exposure and involved one carrion crow scavenging at the hind legs, front legs, and head of the deer whilst another carrion crow searched the ground surface near the deer (Figure 3.9-3.11). The head of the deer was further scavenged by carrion crows on the 5th day and included the removal of the eyes and part of the tongue (Figure 3.9). From the 6th day onwards, carrion crows were recorded scavenging and removing fur, soft tissue, and maggots from the GSW area, as well as searching the soil near the deer (Figure 3.10). Blowflies continued on the 15th day to access the thoracic cavity of the deer via the GSW and oviposit (Figure 3.12). On the 28th day, carrion crows were also observed scavenging from the dorsal side of the deer where additional insect larvae were located (Figure 3.12). The final recording of carrion crow scavenging was on the 41st day. On the 84th day, a jay was recorded near Deer 5 but was not scavenging from the deer.

Figure 3.9. The eye of Deer 5 was removed by carrion crows and the tongue was scavenged.

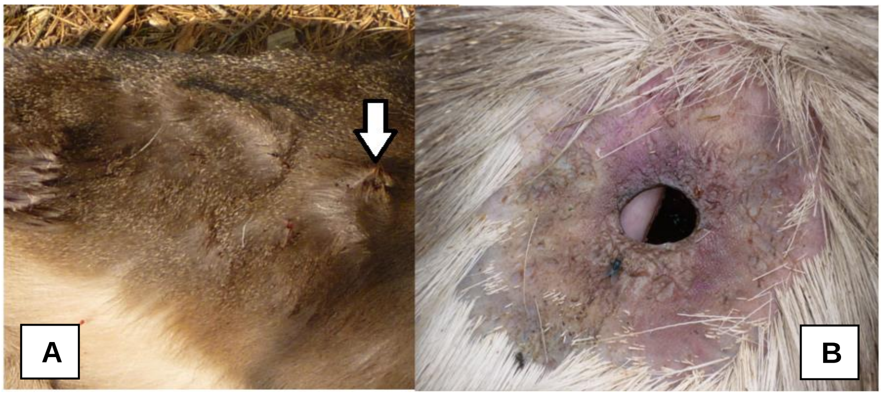

Figure 3.10. The gunshot wound area on deer when first deposited (A). Prior to removing soft tissue or insects from gunshot wounds, carrion crows were recorded removing fur from around the entry site of gunshot wounds on deer and produced the pictured effect on Deer 4 and 5 (B).

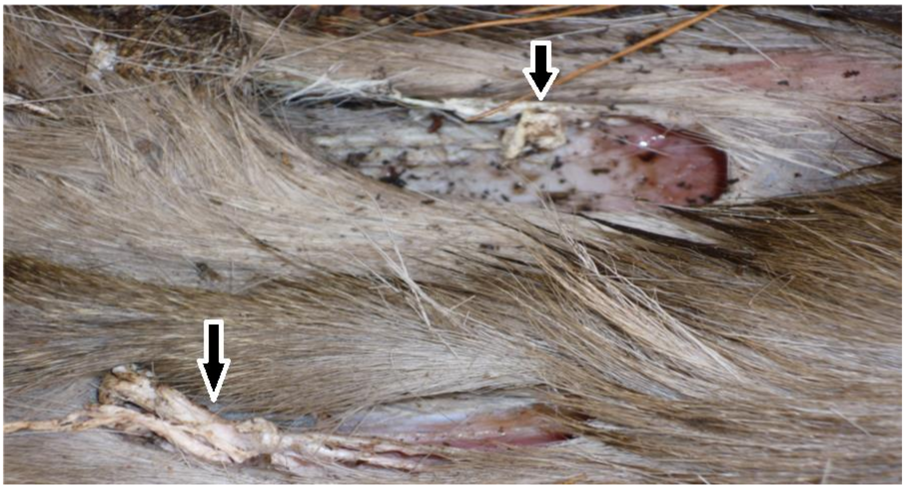

Figure 3.11. Scavenging by carrion crows at the hind legs of Deer 5 also created a string-like effect in soft tissue (demarcated by arrows).

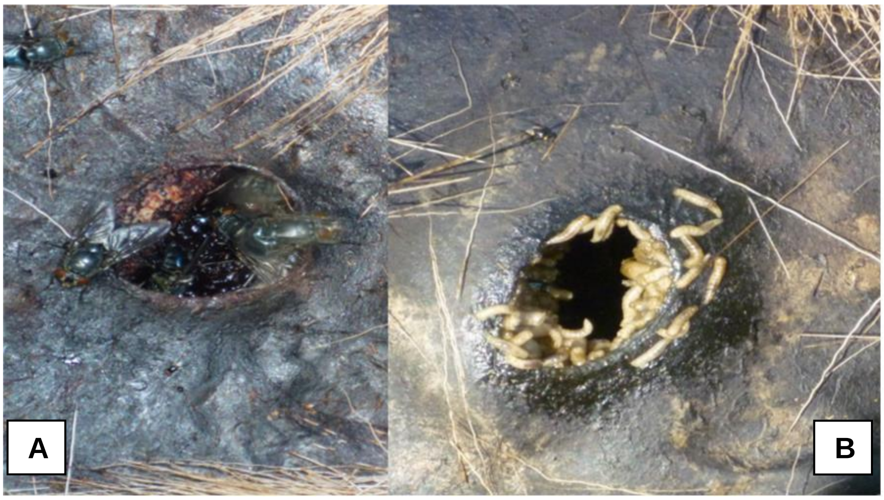

Figure 3.12. Thoracic and abdominal cavities of Deer 5 at the site of trauma (gunshot wound) with Calliphoridae accessing and ovipositing on the 15th day of exposure (A) and maggot activity on the 28th day of exposure (B).

3.4.3 Ungulates as Taphonomic Agents

Sika deer were also observed present near all of the deposited deer carcasses and occasionally walking through deposit sites. All live deer were observed eating vegetation near carcasses and sniffing the soil surface near the deposit site (within 2 m). Deer were never observed scavenging from the carcasses.

3.5 DISCUSSION

Buzzard, carrion crow, wood mouse and grey squirrel were the only observed avian and rodent scavengers of deer remains. These scavengers' behaviours and patterns were affected by seasonality, insect activity, decomposition, and trauma. Colder temperatures may have affected the availability of main food sources for scavengers and as a result caused an increase in the frequency of scavenging by those seeking an alternative food source (Da Silva *et al*. 1993; Leckie *et al*. 1998; Reif *et al*. 2001). Moreover, colder temperatures will have hindered insect activity and slowed the rate of decomposition of carcasses (Rodriguez and Bass 1983; Galloway *et al*. 1989; Vass *et al*. 1992; Micozzi 1991; Campobasso *et al*. 2001; Megyesi *et al*. 2005; Amendt *et al*. 2007; Cross and Simmons 2010; Simmons *et al*. 2010) which may have provided certain scavenger species with a more desirable fresh carcass. Warmer temperatures contributed to an increased level of insect activity and thus increased rates of decomposition at carcasses (Rodriguez and Bass 1983; Galloway *et al*. 1989; Campobasso *et al*. 2001; Cross and Simmons 2010). These increased rates limited the time available to some scavengers to obtain a fresh carcass but also provided other scavengers, such as carrion crows, with an insect rich carcass.

There was no overall pattern observed as to when scavenging began at each carcass nor did the onset of scavenging appear to have an effect on the length of time a single scavenger spent actively scavenging a carcass. Interestingly, during this study there was never more than one species of scavenger present at the carcass at a single time. Possible reasons for this limited number of scavengers at the carcass may be inter-specific aggression (Macdonald 1983; Doncaster and Macdonald 1991; Revilla and Palomares 2002; Selva and Fortuna 2007). Buzzards were mostly observed as solitary scavengers but when two buzzards were present at a deer or bait there were signs of intra-specific aggression. Carrion crows were instead observed more often in pairs and without intra-specific aggression. Wood mice were only observed as solitary scavengers at deer, whereas grey squirrels were observed scavenging alone approximately as often as they were in pairs.

The avian and rodent scavengers in this region caused both soft tissue and skeletal damage but did not cause widespread scattering and removal of skeletal elements. Avian scavenging exposed a greater proportion of soft tissue than rodent scavenging and contributed to increased insect activity and rates of decomposition, which affected the scavenging behaviour of other scavengers (Chapter 4).

3.5.1 Rodent Scavenging

Previous studies that have focused on rodent scavenging at earlier stages of decomposition have failed to identify the scavenging activities and effects of wood mice on remains (Mann *et al*. 1990; Haglund 1992; Patel 1994; Tsokos and Schulz 1999; Komar 2003). In contrast to previous studies that have examined wood mice diet (Watts 1968; Ouin *et al*. 2000; Todd *et al*. 2000), the results from this study have shown the presence of large size carrion in the wood mouse diet. Wood mice proved to be amongst the first scavengers present at the carcass after deposition, prior to any bloating. Wood mouse scavenging of soft tissue was concentrated at the site of trauma but was also seen at the genital region and head of deer. It is important to note that wood mouse activity was also observed when deer were skeletonised but this was not as frequent as in the earlier stages of decomposition and occurred over the entire skeleton. Results of wood mice from this field study are consistent with baiting studies conducted by Jonathan Reynolds (personal communication, 02 March 2011), Game and Wildlife Conservation Trust 2011, in which wood mice were observed as the first scavengers present at sites of lamb carrion prior to any avian scavengers. Rodent scavenging of soft tissue is characterised by even wound margins, crenulated edges, and parallel lacerations produced by the incisors of rodents (Patel 1994; Tsokos and Schulz 1999) (Figure 3.13).

Figure 3.13. Rodent scavenging produced parallel striations at the ends and shaft of a deer femur.

In addition to these characteristics, rodent scavenging is often identified by the presence of rodent fur or faeces, however, the larger the size of the rodent the easier it is to identify such characteristics. The wood mouse is a relatively small rodent in comparison to the more commonly studied scavenging of rats, thus the absence of easily identified evidence of rodent scavenging such as soft tissue damage (e.g. crenulated edges), faeces and fur of the wood mouse has the potential to lead to misinterpretations of trauma obscured by wood mouse scavenging. Scavenging at the site of trauma by a wood mouse can modify the size of the trauma, for example widening a gunshot wound or stab wound, or, in contrast, create a site of trauma in soft tissue. The identification of wood mouse scavenging can assist in more accurate interpretations of trauma, deposit sites (e.g. indoor vs. outdoor; rural vs. urban) and how the body was deposited (e.g. trauma exposed or not exposed; surface vs. buried; textiles or larger item prohibiting access by small scavengers).

Scavenging by wood mice and grey squirrels at later stages of decomposition was observed and is consistent with a number of studies that have researched the effects of rodent scavenging on human remains (Milner and Smith 1989; Mann *et al*. 1990; Haglund 1992; Klippel and Synstelien 2007; Janjua and Rogers 2008). Unlike wood mice, grey squirrels were only observed when deer were skeletonised and scavenged from all areas of the skeleton. In addition to scavenging, grey squirrels were frequently observed running through deposit sites in pairs. The interest of rodents in skeletal remains has been attributed to the necessity of rodents to wear down their incisors and to obtain nutrients (Haglund 1992; Klippel and Synstelien 2007). Within this study, the small size of wood mice and grey squirrels in relation to carcass sizes prohibited the transportation of deer as whole and skeletonised. Likewise, the scavenging behaviour of these rodent species did not modify the condition of deposit sites.

3.5.2 Avian Scavenging

Within North American forensic studies of avian scavenging, the predominant avian scavengers discussed are vultures (Reeves 2009; Spradley *et al*. 2011). Griffon vulture (*Gyps fulvus*), Egyptian vulture (*Neophron percnopterus*), and Cinereous vulture (*Aegypius monachus*) inhabit Mediterranean and Eastern Europe regions, as well as Asia, whereas within Northwestern Europe buzzards are amongst the more common larger avian scavengers (Reif *et al*. 2001; Gavashelishvili and McGrady

2006; Moreno-Opo *et al*. 2010). Despite this, the species-typical scavenging behaviour and effects of buzzard scavenging on a set of remains have yet to be examined. Interestingly, some North American and Australian forensic studies have observed the scavenging and/or presence of ravens (*Corvus corax*), and magpies (*Pica pica*) (Komar and Beattie 1998c; O'Brien *et al*. 2007) at human remains. These avian scavengers are present within Northwestern Europe (Mason and Macdonald 1995; Amar *et al*. 2010) but were not observed at any of the deer during this study.

Scavenging by buzzards is concentrated at sites of trauma on a carcass, from which the buzzard will scavenge soft tissue. In this study, buzzards were observed primarily perched on top of the remains near the area at which they were scavenging. Additionally, buzzards were not observed scavenging skeletal remains. The colder temperatures of winter months, which contributed to a delay in the rate of decomposition of a carcass, provided buzzards with a carcass that remained fresh for a longer period of time in comparison to deer deposited in warmer months, as a result buzzard scavenging activity was observed more frequently in the colder months whilst deer were still in a fresh state. These observations were consistent with ecological studies in Poland on the scavenging of deer, boar, bison and livestock by buzzards (Selva *et al*. 2003, 2005). Buzzards did not transport any skeletal elements or disarticulated remains from deposit sites, nor did they modify deposit sites whilst scavenging deer.

In contrast to buzzards observed within this study, carrion crows displayed more variety in their scavenging behaviours. Scavenging by carrion crows occurred at all areas on a deer but was characterized by the initial scavenging of sites of trauma and the head, in particular the eyes and tongue. Interestingly, carrion crows first removed fur from the GSW prior to removing soft tissue. Carrion crows also consumed insects and removed fur from the carcass and soil. Previous studies have identified the removal of hair by birds from a human body for use as nesting material (Bass 1997; Rodriguez 1997; Komar 2003) and within this study the removal of fur from the deer carcass and the soil surface was interpreted as also being used for nesting. Unlike buzzards, carrion crows did modify deposit sites through the scattering of fur around the site and light digging or clearing of the ground surface with their beaks for insects and potentially scattered soft tissue.

Areas of soft tissue on the deer scavenged by buzzards and carrion crows, like the baits, had a string-like appearance, which was consistent with Asamura *et al*.'s (2004) description of crow scavenging (Figure 3.3, 3.11). The damage to soft tissue and bone by buzzards and carrion crows not only has the potential to remove sites of trauma but to also affect the patterns of decomposition seen on a human body by exposing soft tissue and internal cavities to weather conditions and insects. In contrast to all other scavengers observed during this study, the level of scavenging by carrion crows was not deterred by increased insect activity. Carrion crows were observed eating maggots from the gunshot wound, catching blowflies mid-air, eating insects in the soil, collecting fur and eating soft tissue at all stages of decomposition. The scavenging by carrion crows of Deer 4 and 5 exposed soft tissue, which is known to contribute to an increase in insect activity (Mann *et al*. 1990; France *et al*. 1992; Campobasso *et al*. 2001; Matuszewski *et al*. 2010). Within this study, insect activity by Calliphoridae appeared to increase once the carrion crows had removed the fur from around the site of trauma, thus giving additional access to the thoracic and abdominal cavities for oviposition. Large maggot masses were observed in both Deer 4 and 5 at the thoracic cavity and specifically at the gunshot wounds at which maggots were visibly exiting (Figure 3.12). Maggots were observed to a much lesser extent at the hind legs where carrion crows had removed some soft tissue and within the mouth. Cross and Simmons' study (2010) identified blowflies as being primarily attracted to the heads of the pigs where volatile gases were released and less attracted to sites of trauma (gunshot wounds) for oviposition. The lack of scavenging of the pig carcasses may have influenced the preference of natural orifices for oviposition over gunshot wounds. In contrast, the scavenging of the gunshot wounds on deer by carrion crows appeared to have given blowflies easier access to the thoracic cavity because of the removed fur and exposed soft tissue, thus blowflies were concentrated at the thorax. Oviposition in that location allowed the maggots to use the skin of the deer, like that of human remains (Bass 1997), as protection against sunlight and other adverse conditions.

3.5.3 Ungulates as Taphonomic Agents

It is important to note that deer are known to scavenge dry bones, a behaviour termed osteophagia, caused by a nutritional dysfunction in which an animal is deficient in phosphorous (Cáceres *et al*. 2011). Deer were not observed scavenging bones in this study. There is, however, the potential of modification to surface remains by ungulates due to trampling which can cause movement and fracturing of bones (Olsen and Shipman 1988; Lyman 1994; Yeshurun *et al*. 2007).

3.6 CONCLUSION

This study found buzzard, carrion crow, wood mouse, and grey squirrel to be the most common avian and rodent scavengers within a British woodland environment. At each set of remains there were no observations of more than one scavenger species. Intra-species aggression during scavenging was only observed with buzzards. There was no transportation of deer or removal of disarticulated remains from deposit sites by any of the observed avian and rodent scavengers. The only feature transported from the deer and deposit sites by these scavengers was fur by carrion crows for nesting.

Buzzards and wood mice scavenged a set of remains more frequently when remains were still in a fresh stage of decomposition. Buzzards scavenged only soft tissue from remains and concentrated at sites of trauma. Wood mice focused their scavenging efforts at sites of trauma whilst remains were fresh, whereas scavenging occurred over the entire set of remains once skeletonised. In contrast, carrion crows scavenged and removed soft tissue, fur, and insects from sites of trauma, hind end, and head of remains, as well as searched the ground surface. Carrion crows scavenged during all stages of decomposition but were observed scavenging more often when deer were in early and advanced stages of decomposition when there was increased insect activity. Grey squirrels were recorded scavenging only when deer remains were skeletonised, this occurred over the entire skeleton. The time at which scavenging occurred differed between each scavenger. Buzzards, carrion crows and grey squirrels only scavenged during daylight, whereas wood mice were only recorded scavenging at night.

All of these scavengers displayed different scavenging behaviours and patterns, preferring to scavenge at different times of the day, at different stages of decomposition and different weather conditions. The identification of scavengers and their species-typical scavenging behaviours can aid in the search of scavenged remains, as well as interpretations of trauma, condition and deposition of a human body. Studies, such as this, which provide species-typical scavenger behaviours and region specific knowledge are needed in forensic investigations and searches to improve the search, recovery, and interpretation of scavenged remains.

Chapter 4

An investigation of red fox (*Vulpes vulpes*) and Eurasian badger (*Meles meles*) scavenging, scattering and removal of deer remains: forensic implications and applications

4.1 ABSTRACT

Within Northwestern Europe, especially the U.K., the red fox (*Vulpes vulpes*) and the Eurasian badger (*Meles meles*) are the largest wild scavengers capable of modifying and scattering a set of remains through scavenging. Knowledge of the region-specific and species-typical scavenging behaviours of scavengers within the crime scene area and surroundings can aid in more efficient and accurate interpretations. This study has used actualistic methods and direct observations to outline the scavenging behaviours of foxes and badgers. In addition to observing captive scavengers, scavenging by wild foxes and badgers of six surface deposited baits and five deer carcasses (*Cervus nippon*; *Capreolus capreolus*) in a woodland was observed and analysed. Foxes were found to scavenge more frequently than badgers and to have a pattern of scavenging that differs to badgers and larger sized canids.

4.2 INTRODUCTION

In 2011, there were 1,271 reported cases of missing persons in the U. K. and of those 267 resulted in fatalities. A total of 51.69% occurred in rural or peri-urban locations thus exposing such human remains to wild scavengers with the potential to greatly modify remains (Perkins *et al*. 2011). Within cases of surface deposition of human remains, vertebrate scavenging can modify, remove and scatter soft tissue and skeletal elements, as well as obscure sites of trauma on soft tissue and bone. Knowledge of the region-specific and species-typical scavenging behaviours of those scavenger species within the crime scene area/surroundings can aid in more efficient and accurate interpretations of the crime scene. Likewise, a consideration of scavengers and their scavenging behaviours will enable a more effective strategy for the search and recovery of any missing skeletal elements that have been scavenged, disarticulated and scattered by scavengers. Maximising the recovery of human remains will contribute towards calculating the number of individuals, the identification of the deceased, the assessment of trauma, establishing manner of death, post-mortem interval (PMI), the interpretation of the deposition site, and any third party involvement.

Within Northwestern Europe and specifically within Britain, the red fox and the Eurasian badger, henceforth referred to as fox and badger within this chapter, are the most common wild scavengers which have the potential to rapidly modify and disperse a set of remains through scavenging and disarticulation. Avian scavengers, such as carrion crow (*Corvus corone*) and buzzard (*Buteo buteo*), are also common scavengers in this region (Chapter 3). However, they disperse remains to a lesser extent than foxes and badgers, as well as produce a different pattern of modification through scavenging (Chapter 3). Foxes and badgers are facultative, generalist, scavengers that are widespread in Northwestern Europe and exist in the same woodland environments where they sometimes co-habit in badger setts (Corbet and Harris 1991; Alderton 1994; Macdonald *et al*. 1996, 2004; Sterry 2005). Research exploring the scavenging of human remains by the fox has so far been limited, despite an estimated population of 240,000 adult foxes and the addition of 425,000 cubs per year in Britain alone (Game & Wildlife Conservation Trust 2012). Similarly, despite an estimated population of 300,000 badgers in Britain, as well as numerous ecological studies conducted on their diet and their social living system, published research investigating the scavenging of human remains by badgers is rare (Kruuk and Parish 1981; Da Silva *et al*. 1993; Macdonald *et al*. 1996, 2004; Revilla and Palomares 2001, 2002; Roper *et al*. 2003; Sterry 2005; Game & Wildlife Conservation Trust 2013). Moreover, the issue as to the frequency and extent of badger scavenging of human remains is a highly contested topic. Accounts of fox and badger scavenging and their effects on human remains are frequently discussed amongst forensic professionals but these interpretations of scavenging are frequently based on anecdotal evidence. Thus, forensic professionals, such as police search officers, forensic archaeologists, and forensic anthropologists, may often ask questions such as: What level of scavenging of surface deposited human remains should be expected by foxes and badgers? When do foxes and badgers scavenge (e.g. weather; degree of decomposition; time of day)? What body areas are scavenged primarily and to what extent? What skeletal elements are likely to be missing or recovered once scavenged? Where and how far to search for scavenged and scattered remains?

The aims of this chapter are to describe the species-typical scavenging behaviours of foxes and badgers and to determine: 1) how foxes and badgers modify surface deposited remains/bodies; 2) how and when foxes and badgers scavenge, scatter and remove soft tissue and skeletal elements; 3) what skeletal elements are scavenged, scattered and removed by foxes and badgers; as well as which elements are scattered; 4) how experimental studies of scavenged deer can be applied to the search, recovery, and interpretation of scavenged human remains. This was achieved through experimentation and observations of both captive and wild foxes and badgers.

4.3 MATERIALS AND METHODS

For this study, a total of 258 food items including fresh and dry pig bones (*Sus scrofa*) and fresh soft tissue were presented to seven captive foxes and three captive badgers whose subsequent scavenging behaviours were observed and recorded. The scavenging behaviours of wild foxes and wild badgers were also recorded in field experiments involving the deposition of six deer legs as baits, followed by the individual deposition of five whole deer over a period of 216 days. Wild badgers were observed at or near a set of remains in a total of 12 video recordings whereas wild foxes were recorded 435 times by infrared motion detection cameras.

Deer were chosen as human proxies for this study because human cadavers are not available for scavenging studies within the U.K. due to ethical, planning, and legislative restrictions (McHanwell *et al*. 2008; Cross *et al*. 2009). If human cadavers were available to taphonomic research, such as scavenging, there would still be limitations in recreating crime scene scenarios involving victims of different ages and health because the majority of donated cadavers are elderly, frail, and embalmed (Richardson and Hurwitz 1995). In both North America and the U.K., animal analogues are commonly used in forensic studies to recreate and analyse crime scene scenarios due to the lack of access to human cadavers (France *et al*. 1992; Morton and Lord 2006; Vanlaerhoven and Hughes 2008; Reeves 2009; Cross and Simmons 2010; Simmons *et al*. 2010). Pigs are often used as animal analogues in forensic research (France *et al*. 1992; Morton and Lord 2006) because of similarities in the skin and fat qualities of pigs and humans (Figure 1.5). However, in the U.K. the surface deposition of pigs is restricted by the Department for Environment, Food and Rural Affairs (DEFRA) because it poses a threat to domestic stock and wildlife (DEFRA 2012). Unlike pigs, deer can be surface deposited in the U.K. because as wildlife they do not pose a threat in the spread of disease to domestic livestock, thus allowing forensic research of crime scenes involving surface depositions. Since the focus of this research is the scavenging, disarticulation and scattering of surface deposited remains with an emphasis on damage and transportation of skeletal elements by scavengers rather than the analysis of soft tissue loss, decomposition chemistry, or microbial activity, deer were chosen as human proxies.

Five fresh deer carcasses, received as part of a surplus of a culling operation unrelated to the research which aims to manage wild deer populations in a humane manner, were deposited on the ground surface of the site. See Appendix III for images of all deer at the time of their deposit on site. Each deer died as the result of a gunshot wound (.308-calibre) on the right side of the trunk and when deposited as fresh for this study the wound was left exposed. Gunshot wounds ranged from about 30 mm to 50 mm in diameter at the entry site in the soft tissue.

4.3.1 Behaviour of captive foxes and badgers

The scavenging behaviours of captive foxes and badgers were observed and recorded on a Panasonic SDR-S50EB-H digital camcorder from November 2010 to February 2012. All food items presented to captive and wild scavengers were between 15 g to 59 kg and split into seven weight categories. Captive scavengers were presented with items assigned to either category 1 (15 g ≥ or < 45 g), 2 (45 g ≥ or ≤ 80 g), 3 (250 g ≥ or < 600 g) or 4 (600 g ≥ or ≤ 1 kg). Items weighing between 600 g to 1 kg were provided as two per scavenger and items weighing 15 g to 600 g were provided three to four per scavenger present. Behaviours were recorded during each feeding session. A single session was defined as beginning when food was deposited and ended when all scavengers in an enclosure showed no further behaviours and returned to a dormant state.

In total, seven foxes were observed at the Wildwood Trust, Kent, U.K., and at the New Forest Wildlife Park, Ashurst, U.K. The Wildwood Trust allowed direct observations of captive foxes. The fox enclosure housed five foxes, aged from 3 – 10 years. The fenced enclosure had a natural woodland ground surface with some vegetation, trees, and tree stumps, as well as various shelters for the foxes that face towards the public path for viewing. The foxes were fed a variety of foods that include mice, chicks, rats, pigeons, fish, chicken, and dog food (wet and dry). The fenced enclosure at the New Forest Wildlife Park housed two foxes (age range of 2-3 years) in an area containing various wooden shelters and sand pits. The enclosures at both sites allowed the researcher to have unrestricted views of the foxes at all times. The badger enclosure at the Wildwood Trust housed three badgers with ages ranging from 6 months to 13.5 years. The enclosure consists of an indoor viewing area which is part of a larger underground sett that connects to the outer area of the enclosure which is fenced. Badgers could be directly viewed in the outer and inner enclosure except for inside sett tunnels. Due to the crepuscular behaviours of badgers, some of the badgers within the enclosure did not become active until the early hours of the morning, during which food items were removed and taken down into setts as identified by keepers. The badgers were fed on a diet of dog food (wet and dry), chicks (*Gallus gallus domesticus*), and rabbits (*Oryctolagus cuniculus*). For this study, foxes and badgers were provided with fresh domestic pig bones (varied skeletal elements) obtained from a butcher and dry roast ham bones (femora about 30.5 cm in length) in addition to their regular diet.

4.3.2 Behaviour of wild foxes and badgers

The scavenging behaviours of wild foxes and badgers were observed and recorded at Bovington, Dorset, U.K. from November 2010 to July 2011 (Figure 4.1). The site at Bovington was about 450 m x 550 m of temperate mixed forest of spruce (*Picea* spp.), pine (*Pinus* spp.), oak (*Quercus* spp.) and birch (*Betula* spp.). Ground cover includes a mix of greater tussock sedge (*Carex paniculata*), bramble (*Rubis fruticosus*), and bracken (*Pteridium aquilinum*) (Figure 4.2). Wild scavengers received food items, baits or whole deer, labelled as either category 5 (1 kg ≤ or ≥ 7 kg), 6 (23 kg ≤ or ≥ 35 kg), or 7 (59 kg). Wild animals' scavenging behaviours within the experiment site were observed and recorded with a single SPYPOINT IR-7 infrared camera secured to a tree overlooking deposited remains (Appendix III, Figure A3-19). The cameras were set up at a height of 55 cm above the ground surface and were able to detect and record motion at a vertical angle of 30˚ and up to 15.24 cm away. The cameras were set to remain active over all hours and were set to record 30 seconds long video clips when motion was detected. The delay between each detection of motion was set to the minimum setting of one minute.

Prior to the deposition of complete deer carcasses for this study, a small pilot study was conducted using deer legs as baits (category 5) in order to assess the environment and wildlife present, in particular the presence of foxes and badgers within the site. Deposited baits and deer were neither covered nor fenced in any way, this was to allow full access and exposure to the environment, weather conditions, insects and vertebrate scavengers. All six baits had their hides and hooves intact. Baits were accompanied with a single motion detection infrared camera secured to a tree overlooking each bait. Following the removal of all baits from the site by scavengers, Deer 1-5 were then surface deposited within the site at different times over a total period of 210 days (Table 4.5; Figure 4.3). Deer 1 was deposited in December and remained on site until the final day of the experiments (Table 4.5). Deer 2 and 3 were deposited on the same day in February and were placed c. 100 m apart. Following the removal and scavenging of Deer 2 and 3 by scavengers, Deer 4 and 5 were deposited on the same day in March and were placed c. 135 m apart (Table 4.5). In contrast to the baits, two motion detection infrared cameras were fastened separately to two trees facing each deer (1 m from the hind end and the head) so that any animal activity occurring from either end of the deer could be observed and recorded as it occurred.

Figure 4.1. The location of the field study site, Bovington, within the U. K.

Figure 4.2. The mixed temperate woodland environment, during the autumn of 2010, of the experiment site at Bovington, U.K.

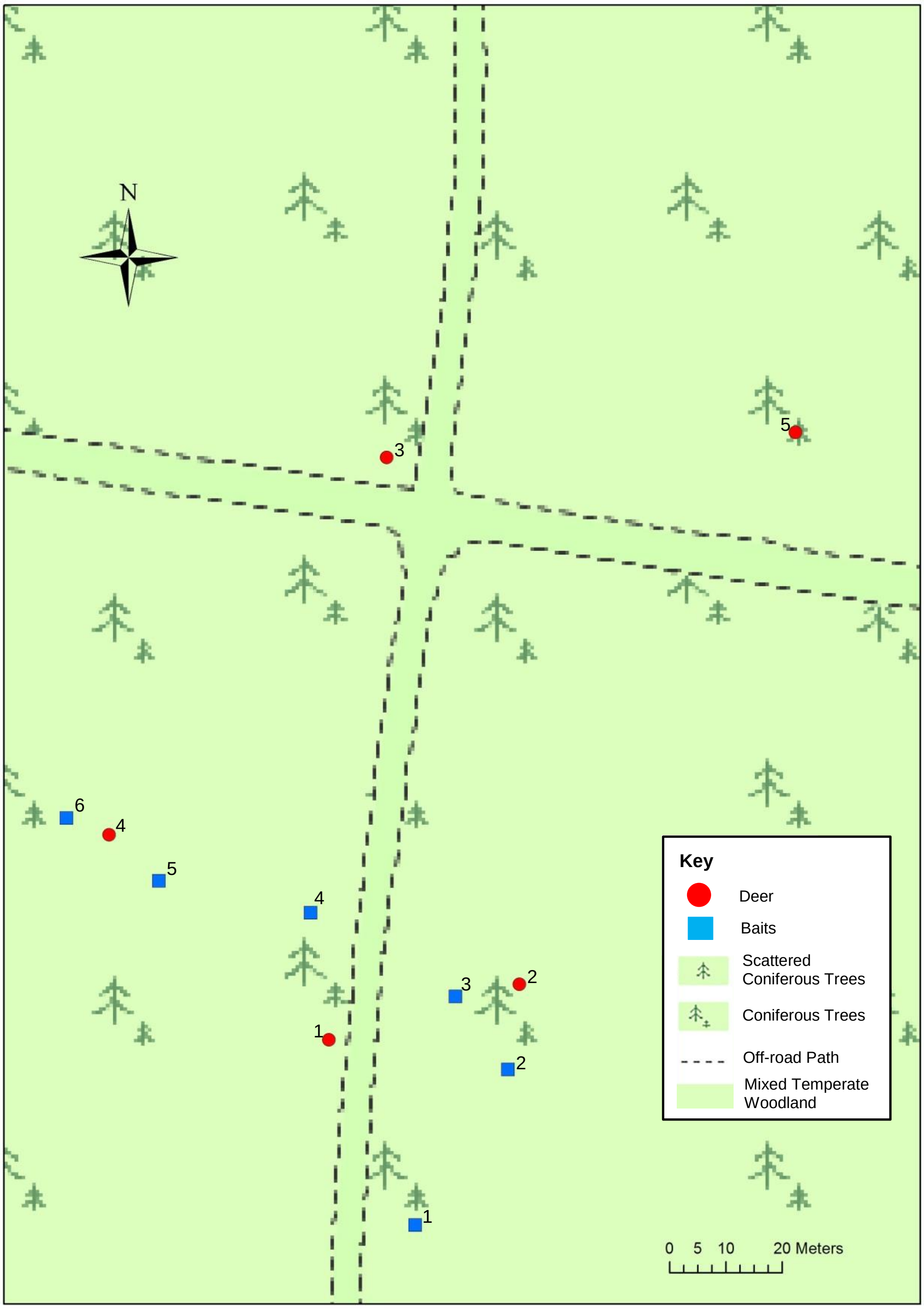

Figure 4.3. The map shows deposit sites for each bait and deer within the field site.

During weekly site visits, the rate of decomposition and level of scavenging for each bait and deer were observed, described, and recorded. The identification of different stages of decomposition was based on Galloway *et al*.'s (1989) description of four stages of decomposition of a body because this study gives a general description of decomposition rather than an analysis of decomposition chemistry, soft tissue loss, or microbial activity. Photographs were also taken of any skeletal finds or evidence of scavengers (e.g. fur, scat, and paw prints). Daily temperatures and monthly total rainfall measures over the length of the experiment were obtained from the Meteorological Office's Hurn, U.K., weather station (Met Office 2012) (Appendix III, Figure A3-20). Recordings from the motion detection cameras were also retrieved at every visit and analysed off-site for the presence of scavengers, weather, time of day, areas on a bait or deer targeted by scavengers, and scavenger behaviours at or near deposit sites. When it was evident that a carcass had been scavenged, disarticulated or scattered, a site search was conducted over an area of about 150 m^2 that included the deposit site. Site searches pertaining to Baits 1-6 included one searcher whilst searches for Deer 1-5 involved three additional searchers, all with osteological experience, walking through the area using a link method search, similar to the police search method of winthropping, which relies on adjusting your direction based on the identification of cues or reference points that will lead to the recovery of finds (Humprey *et al*. 2010).

In this study the link method involved identifying signs of drag marks in the soil, scattered or clumped fur, animal scat, depressed vegetation, thick vegetation, disturbed soil for caches, and setts. Upon the discovery of a find, photographic and location recordings were taken. The locations of finds, such as fur, soft tissue and bones, and the movement of a whole carcass from its primary deposit site by scavengers, were recorded using a Leica FlexLine TS06 total station and mapped using ESRI *ArcGIS* 10 and a base layer ordnance survey map at a scale of 1:2500 (Ordnance Survey 2012).

Scavenged bones were left where they were found to allow for the recording of further scavenging and movement of that skeletal element by scavengers. However, if the left and right bones of a skeletal element were located, then the disarticulated and most heavily chewed bone of that element was collected by the researcher to ensure a sample of scavenged bone was available for future analysis on bite marks. The recovery rates, excluding these collected bones, per skeletal elements for all deposited deer has been calculated, as well as the overall recovery rates of skeletal elements for all deposited deer. Additionally, the total recovery rate of skeletal elements per deer was recorded.

4.3.3 Statistical Methods

All statistical analyses were completed using PASW Statistics version 18. Separate chi-square tests were used to compare captive badger and fox scavenging, wild badger and fox scavenging, and wild fox scavenging versus different stages of decomposition. Full factorial multinomial logistic regression was performed twice: first, to analyse the relationship between the weight of deer, a deer's stage of decomposition, outside temperature, the time of exposure of a deer, and whether a wild fox scavenged or did not scavenge a deer; and second, to analyse the relationship between the same variables and whether a wild fox tried to remove or did not try to remove a deer from its deposit site. Binary logistic regression was employed separately to analyse the relationship between the condition (e.g. dry or fresh) of food, the weight of a food item, and whether a captive badger scavenged or did not scavenge, or tried to move or not move an item. Binary logistic regression was also used to analyse the relationship between the condition (e.g. dry or fresh) of food, the weight of a food item, and whether a captive fox scavenged or did not scavenge; moved or did not move; and cached or did not cache an item.

Recovery rates for the total of five deer were calculated individually as 20 categories of skeletal elements. All rates are presented as a percentage of each recovered category or body area per individual deer regardless if recovered as either fragmented or whole. A Kruskal-Wallis test was used to compare the distribution of recovery distances of scattered remains of each deer. Following the Kruskal-Wallis test, *post hoc* Mann-Whitney tests were conducted to further compare the recovery distances of scattered elements from each deer. A Bonferroni correction (0.05/4=.0125 level of significance) was used to avoid inflating the Type I error caused by the use of four Mann-Whitney tests.

4.4 RESULTS

See Appendix IV for a detailed outline of video recordings of scavengers' activities and for observed insect activity.

4.4.1 Behaviour of captive foxes and badgers

The most common behaviours displayed by the observed captive foxes included the following: picking up food items either for scavenging or caching, scavenging, caching items, and investigating (e.g. sniff or lick) food (Table 4.1). Scavenging is defined here as an animal using their dentition to tear, remove, masticate, or break down soft tissue and bone. To a lesser extent, captive foxes were also observed to search the ground surface of the enclosure and to pick up but not move items from the deposition site (Table 4.1).

Prior to any scavenging, foxes were observed investigating (e.g. sniff or lick) food items without making any bites, which sometimes lead to the item being picked up and moved by an individual fox to a different location from where it was initially deposited and then placed into a shallow hole dug (c. 12 cm depth) in the soil (referred to as a cache). Weight (p=.07) and the state of the food (dry or fresh) (p=.59) did not have a significant effect on whether a fox did or did not cache an item (R^2=.02, $x^2(2) = 3.85$, p=.15). Likewise, weight (p=.09) and the state of the food (dry or fresh) (p=.13) did not significantly affect whether a fox moved or did not move food (R^2=.03, $x^2(2) = 5.90$, p=.05). Foxes were recorded placing one or more food items into a single cache which was then covered in soil shovelled by the fox's nose and often concealed by loose twigs or leaves (Figure 4.4). Foxes were observed to scent mark some caches. When a fox uncovered a cache dug by another fox, including those which were scent marked, no signs of aggression between foxes were recorded. Instead, displays of aggression were only observed between foxes when items from categories 1-2 (15 g - 600 g) were present on the ground surface and yet to be scavenged or removed by a fox from its deposit site. When food was deposited into enclosures, foxes were observed to scavenge 44.7% of the time. The condition of a food item (fresh or dry) when deposited into the foxes' enclosure did not make a significant impact as to whether a fox scavenged the item or not (p=1.00). However, the weight (p=.03) of the item deposited did have a significant effect as to whether a fox scavenged the item or not, such that as weight increased a fox was more likely to scavenge (R^2=.10, $x^2(2) = 14.48$, p=.001).

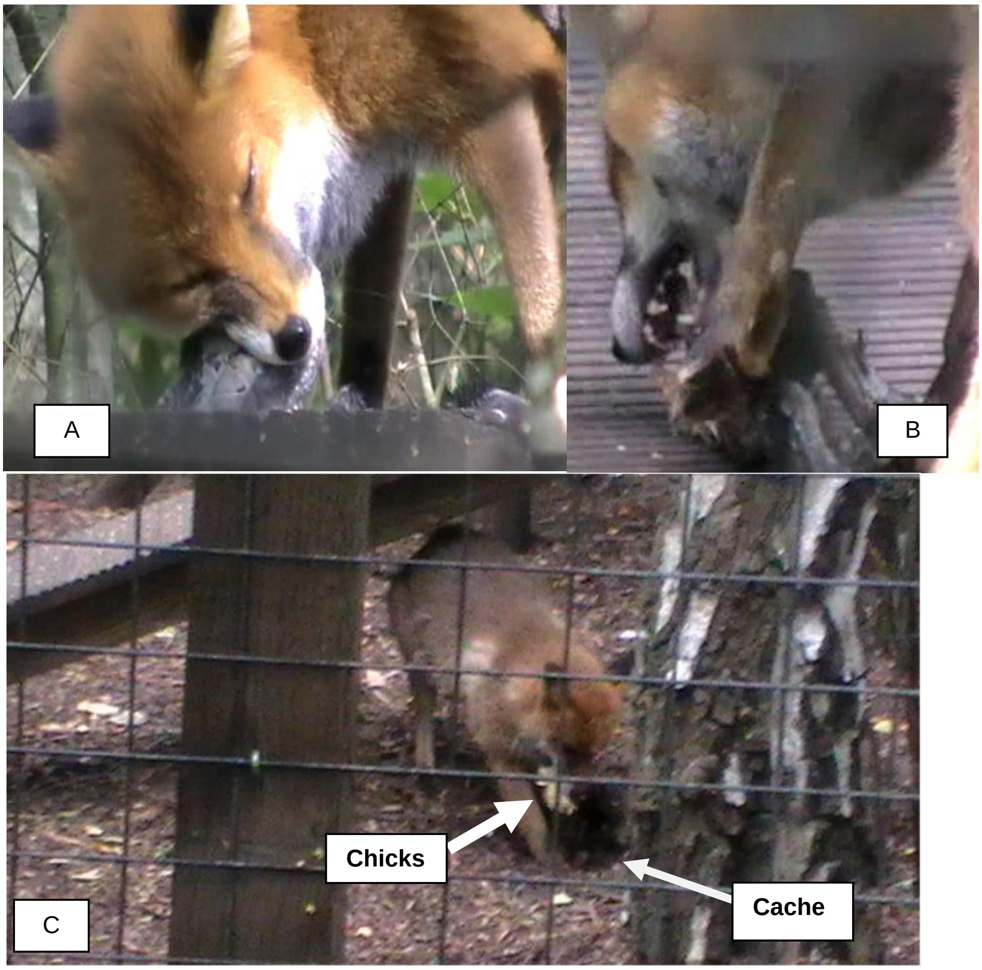

Figure 4.4. A captive red fox scavenges black chicken (A; B). A captive red fox with two chicks in its mouth whilst digging a cache in which the chicks were placed (C).

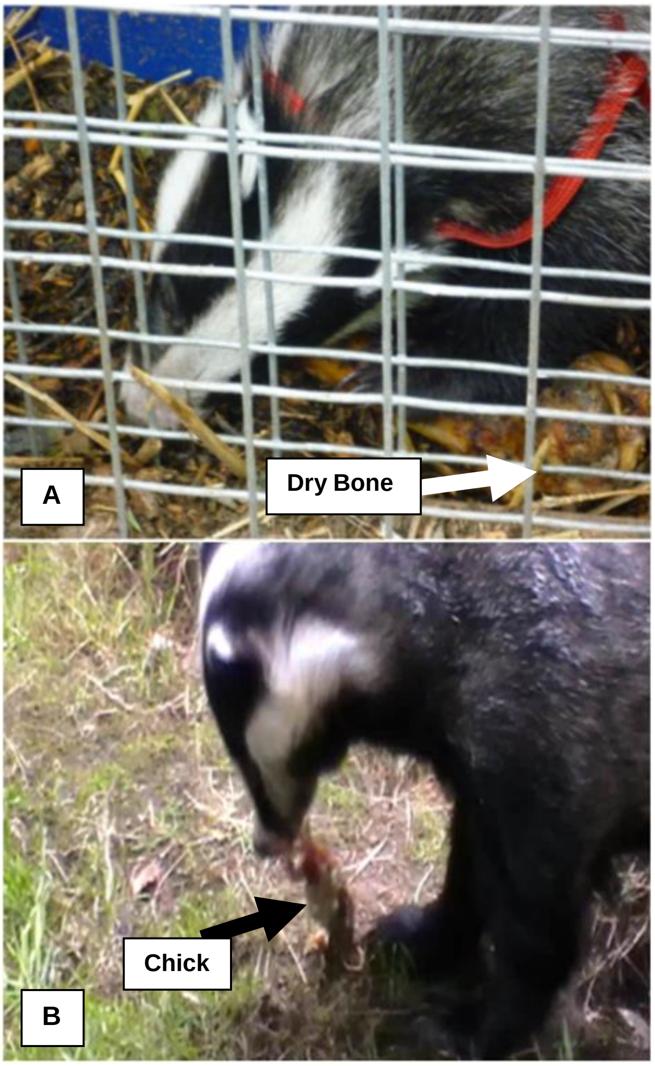

Figure 4.5. A captive Eurasian badger scavenging a dry pig femur (A) and another captive badger scavenging fresh chicks (B).

Captive badgers were observed to scavenge 87.8% of the time when food was present within the badgers' enclosure (Figure 4.5). Unlike foxes, there were no observations of captive badgers caching food items, displaying aggression (when food was present), or scent marking food items. Badgers scavenged food at deposit sites more frequently than moving items to be scavenged away from deposit sites (Table 4.2). Weight (*p*=.58) and the state of the food (dry or fresh) (*p*=1.00) did not have a significant effect on whether a badger moved or did not move an item (R^2=.25, $x^2(2) = 7.71$, *p*= .02). However, the state of the food (*p*=.01) did significantly affect whether a badger scavenged or did not scavenge, such that the fresher the item the less likely a badger would scavenge. The weight (*p*=.23) of the food item did not significantly affect badger scavenging (R^2=.10, $x^2(1) = 7.06$, *p*=.01). Badgers were significantly more likely to scavenge food items when deposited into enclosures than foxes (x^2 (1) = 42.66, *p*< .001).

Table 4.1. The observed occurrences of the different scavenging behaviours displayed by captive red foxes per deposited food category.

	Category 1 (15 g ≥ or < 45 g; dog food, mice, chicks)		Category 2 (45 g ≥ or ≤ 80 g; fresh pig bones)		Category 3 (250 g ≥ or < 600 g; dry pig bones, pigeon, rats)		Category 4 (600 g ≥ or ≤ 1 kg; rabbit, chicken)		Total	
Behaviours	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**
Approaches (no biting)	0	0	0	0	0	0	0	0	0	0
Investigates food item (sniffs or licks)	5.58	13	52	13	29.63	8	0	0	11.93	34
Bites (no picking up item & no scavenging)	1.29	3	0	0	0	0	0	0	1.05	3
Bites & picks up food item (and moves or drags item)	32.62	76	12	3	22.22	6	0	0	29.82	85
Picks up a food item but does not move or drag it from deposit site	6.44	15	4	1	0	0	0	0	5.61	16
Scavenging (tearing s.tissue,breaking down of bone, mastication & consumption)	25.75	60	0	0	0	0	0	0	21.05	60
Cautious (Jumps back; skiddish)	0	0	0	0	0	0	0	0	0	0
Scent or urine marks food item or remains	0.43	1	4	1	0	0	0	0	0.70	2
Uncovers a cache, removes food item	0.43	1	0	0	0	0	0	0	0.35	1
Walks around enclosure nose to ground surface, foraging	6.87	16	12	3	3.70	1	0	0	7.02	20
Caches one food item in one hole	12.45	29	12	3	33.33	9	0	0	14.39	41
Caches more than one food item in one hole	3.43	8	0	0	0	0	0	0	2.81	8
Digs a cache but does not deposit food	1.29	3	0	0	0	0	0	0	1.05	3
Uses paws to hold down food item or remains	1.29	3	0	0	0	0	0	0	1.05	3
Uses paws to scrape away soft tissue or remove part of remains	0.86	2	0	0	0	0	0	0	0.70	2
Displays aggression at food site or with food in mouth	0	0	0	0	0	0	0	0	0	0
Displays aggression not at food site but when food is present in the enclosure or site	0.43	1	4	1	0	0	0	0	0.70	2
Scent or urine marks cache	0.86	2	0	0	11.11	3	0	0	1.75	5
Total		233		25		27				285

Table 4.2. The observed occurrences of the different scavenging behaviours displayed by captive Eurasian badger per deposited food category.

	Category 1 (15 g ≥ or < 45 g; dog food, mice, chicks)		Category 2 (45 g ≥ or ≤ 80 g; fresh pig bones)		Category 3 (250 g ≥ or < 600 g; dry pig bones, pigeon, rats)		Category 4 (600 g ≥ or ≤ 1 kg; rabbit, chicken)		Total	
Behaviours	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**
Approaches (no biting)	0	0	0	0	0	0	0	0	0	0
Investigates food item (sniffs or licks)	0.47	1	0	0	16.67	1	0.90	1	0.89	3
Bites (no picking up item & no scavenging)	0	0	0	0	0	0	0	0	0	0
Bites & picks up food item (and moves or drags item)	1.87	4	50	3	0	0	2.70	3	2.97	10
Picks up a food item but does not move or drag it from deposit site	24.30	52	0	0	0	0	19.82	22	21.96	74
Scavenging (tearing s.tissue,breaking down of bone, mastication & consumption)	45.33	97	0	0	33.33	2	37.84	42	41.84	141
Scent or urine marks food item or remains	0	0	0	0	0	0	0	0	0	0
Takes food item down into sett/den	0	0	50	3	0	0	0	0	0.89	3
Walks around enclosure nose to ground surface, foraging	8.88	19	0	0	0	0	18.92	21	11.87	40
Searching soil (includes removing soil finds); digs ground surface for foraging	0	0	0	0	0	0	0	0	0	0
Uses paws to hold down food item or remains	7.01	15	0	0	33.33	2	8.11	9	7.72	26
Uses paws to scrape away soft tissue or remove part of remains	12.15	26	0	0	16.67	1	11.71	13	11.87	40
Displays aggression at food site or with food in mouth	0	0	0	0	0	0	0	0	0	0
Displays aggression not at food site but when food is present in the enclosure or site	0	0	0	0	0	0	0	0	0	0
Total		214		6		6		111		337

4.4.2 Behaviour of wild foxes and badgers

Wild badgers were not observed to scavenge any of the surface deposited deer or baits, whereas wild foxes were observed to scavenge both baits and deer. Badgers were only recorded at night walking past or slowly approaching and investigating deer weighing 23 kg-35 kg (category 6), as well as searching (e.g. sniffing with nose lowered and light digging) the ground surface near the deer deposit site both when deer were in an early decomposition stage and skeletonised (Figure 4.6). Badgers were also recorded clearing and taking bedding to sett entrances (Figure 4.7). There were no recordings of wild badgers making any bites to the remains. Badgers and foxes were not observed in any recordings simultaneously at or near a bait or deer but were recorded at different times using the same paths through the site.

Figure 4.6. Two wild badgers walking near skeletonised remains of Deer 5 and pausing to investigate a collection of thoracic vertebrae located under ferns.

Figure 4.7. Prior to the deposition of Deer 5, a badger was recorded carrying dry grass into its sett.

Fox behaviours recorded at bait sites were not included in statistical analyses as the cameras captured animal activity at only three baits and were thus repositioned for the deer. Wild foxes were recorded scavenging deer in 76.6% of all video recordings. Foxes were not observed present near or at deer until the remains had been exposed for an average length of 11.2 days, a minimum of two days, and a maximum of 17 days (Table 4.5). Certain behaviours that were observed with captive foxes were not directly observed with wild foxes, such as caching, taking items down setts and dens, or scavenging that occurred away from the deposit sites where cameras had been setup overlooking the deposited remains and sites. The behaviours recorded most frequently of wild foxes included the following: investigating, scavenging, walking past sites, approaching remains, as well as failed and successful attempts to remove or drag deer (Table 4.3). Prior to scavenging a bait or deer, individual foxes were observed walking past and approaching deposit sites more than once, followed by investigating the remains. Foxes first investigated deer that had been exposed an average length of 11.8 days, a minimum of two days, and a maximum of 20 days (Table 4.5). The investigation of remains either involved just the sniffing or licking of remains but would often include a quick bite and release, as well as jumping back (e.g. cautious) from deer prior to scavenging (Figure 4.8). Foxes most frequently approached and investigated the hind end and hind legs of deer first. Individual foxes were also recorded attempting to remove whole baits and deer carcasses from deposit sites prior to scavenging and if successful, the fox would drag the bait or deer from the deposit site (Figure 4.9). Removal or attempts to remove deer by foxes first occurred on average when deer were exposed for 20.4 days, a minimum of seven days, and a maximum of 33 days (Table 4.5). The most common area on deer at which foxes tried to bite and drag the deer from the deposit site were the hind legs (66.67%), both as fresh and skeletonised. Weight (p<.001), the time of exposure (p<.001), and stage of decomposition (p<.001) of the deer did have a significant effect as to whether a fox did or did not try to remove a whole deer. As the length of exposure and stage of decomposition increased foxes were less likely to remove deer from deposit sites. Additionally, the larger the carcass weight when deposited the less likely foxes were to remove the whole deer from the deposit site. However, temperature did not have a significant effect (p=.61) (R^2=.10, $x^2(6)$=43.16, p<.001). If a fox was unable to remove the whole bait or deer from the site then scavenging would commence at the deposit site until a fox was able to remove remains.

Figure 4.8. A fox approaches and investigates the hind of Deer 1.

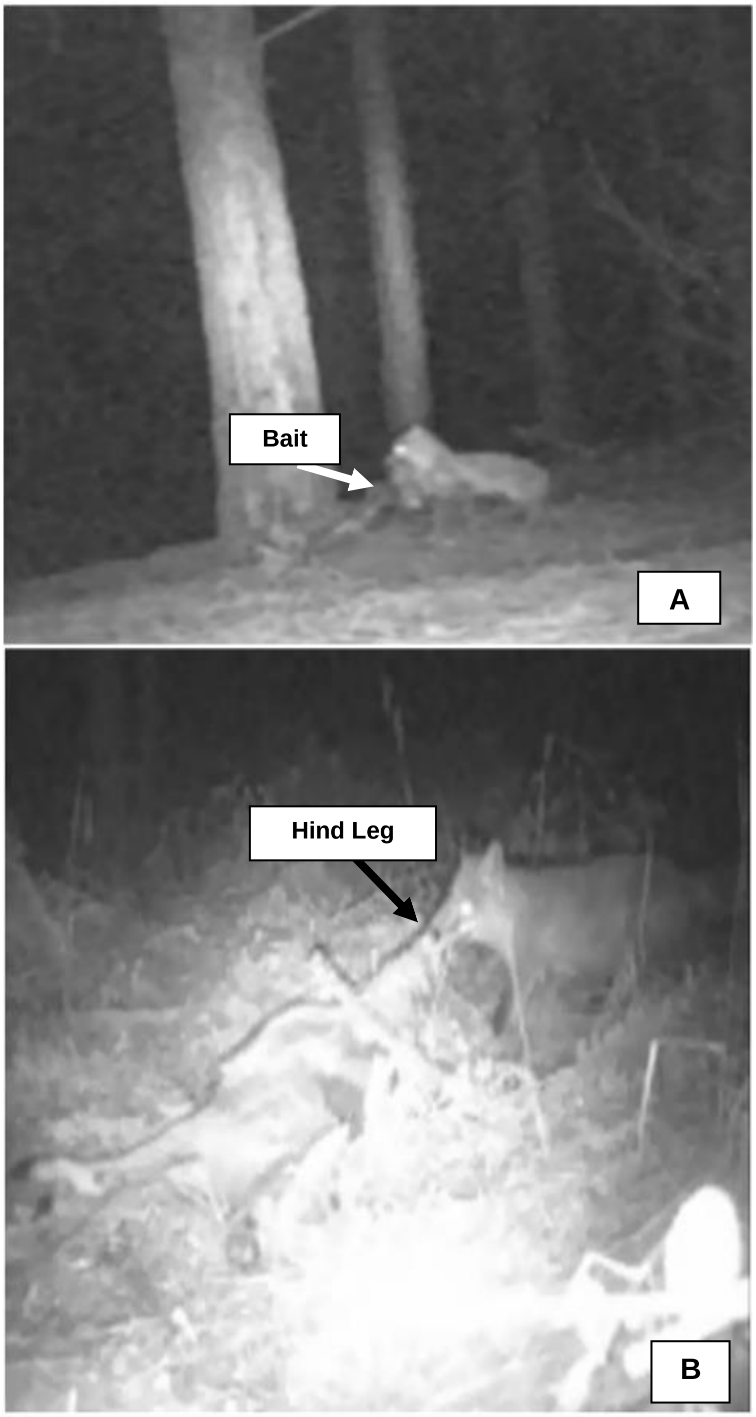

Figure 4.9. A fox picks up and carries a bait (6 kg) away from its deposit site (A); a fox bites and drags Deer 3 (24 kg) by the hind leg away from its deposit site (B).

Figure 4.10. A fox runs and pounces onto another fox that is scavenging soft tissue that it had removed from the deer.

Table 4.3. The observed occurrences of the different behaviours displayed by wild red foxes recorded present or near deer remains and deposit sites.

	Baits		Deer 1		Deer 2		Deer 3		Deer 4		Deer 5			
	Category 5 (1 kg ≤ or ≥ 7 kg)		Category 7 (59 kg)		Category 6 (23 kg ≤ or ≥ 35 kg)		Category 6 (23 kg ≤ or ≥ 35 kg)		Category 6 (23 kg ≤ or ≥ 35 kg)		Category 6 (23 kg ≤ or ≥ 35 kg)		Total	
Behaviours	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**
Approaches (no biting)	7.14	4	5.44	32	0	0	2.86	1	1.79	1	0	0	4.92	38
Investigates food item (sniffs or licks)	10.71	6	6.46	38	13.04	3	14.29	5	12.50	7	25.00	3	8.03	62
Bites (no picking up item & no scavenging)	1.79	1	0.34	2	0	0	2.86	1	5.36	3	0	0	0.91	7
Bites & picks up food item (and moves item)	7.14	4	0.34	2	0	0	0	0	1.79	1	0	0	0.91	7
Bites & drags item (or attempts to drag)	0	0	2.38	14	8.70	2	20.00	7	3.57	2	8.33	1	3.37	26
Picks up a food item but does not move or drag it from deposit site	1.79	1	0.17	1	13.04	3	0	0	0	0	0	0	0.65	5
Scavenging (tearing s.tissue,breaking down of bone, mastication & consumption)	16.07	9	52.38	308	17.39	4	37.14	13	28.57	16	33.33	4	45.85	354
Picks up fur from soil	0	0	0.17	1	0	0	0	0	0	0	0	0	0.13	1
Cautious (Jumps back; skiddish)	3.57	2	1.19	7	0	0	2.86	1	5.36	3	8.33	1	1.81	14
Scent or urine marks food item or remains	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trampling remains	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Walks around nose to ground surface, foraging	7.14	4	0.17	1	0	0	0	0	0	0	0	0	0.65	5
Searching soil (includes removing soil finds); digs ground surface for foraging	0	0	1.02	6	0	0	5.71	2	7.14	4	16.67	2	1.81	14
Walks or runs past (food item or remains)	23.21	13	5.61	33	26.09	6	8.57	3	7.14	4	8.33	1	7.77	60
Stationary at or near remains and not scavenging (in view)	7.14	4	7.99	47	8.70	2	2.86	1	12.50	7	0	0	7.90	61
Uses paws to hold down food item or remains	14.29	8	15.65	92	0	0	0	0	0	0	0	0	12.95	100
Uses paws to scrape away soft tissue or remove part of remains	0	0	0.51	3	0	0	0	0	0	0	8.33	1	0.52	4
Displays aggression at food site or with food in mouth	0	0	0.17	1	0	0	0	0	0	0	0	0	0.13	1
Removes fur from remains (directly)	0	0	0	0	13.04	3	2.86	1	14.29	8	8.33	1	1.68	13
Total		56		588		23		35		56		14		772

There were no recordings of more than one fox scavenging a carcass or bait at a single time for any category of remains. If an additional fox was present near the same carcass or bait the number did not exceed two. When two foxes were present, one fox would be scavenging and removing soft tissue from the carcass whilst the other fox sat or lay down watching the other fox scavenge. Once the previously scavenging fox left the carcass, the stationary fox would then slowly approach the deer, investigate, and begin scavenging. Displays of aggression between foxes were only observed in a single scavenging event between two foxes. Whilst one fox removed and masticated soft tissue away from the carcass but within 2 m of the deposit site, an additional fox ran and leapt at the scavenging fox, followed by both foxes running out of view of the camera (Figure 4.10). Once both foxes were out of view, another fox slowly approached the deer and eventually began scavenging the deer. The onset of scavenging of deer by foxes occurred when deer were exposed for an average length of 18 days, a minimum of three days, and a maximum of 33 days until scavenging commenced (Table 4.5). Scavenging by foxes was observed more frequently after sunset (96.58%) but was also seen during the day (3.42%) (Table 4.4).

The thoracic cavity was observed to be the area of deer most often scavenged (74.55%), however, it is important to note that a large proportion of recordings of scavenging in this area was with Deer 1, which was the only deer scavenged by an unaccompanied dog that randomly appeared within the site. See Appendix III for Tables A3-1 to A3-5 which present the results for the locations affected on each deer carcass by fox scavenging and investigating. The dog was recorded scavenging and opening the thoracic cavity of that deer first (Figure 4.11). The dog was only present at the deer and deposit site for a total of five hours and 57 minutes, of which the dog scavenged for one hour and 30 minutes. For all other deer, foxes scavenged more often from the hind legs and hind end (70.21%) (Appendix III, Tables A3-1 to A3- 5).

Scavenging by foxes was observed during all stages of decomposition except for extreme decomposition as no deer reached that stage (Table 4.6). Foxes were more likely to scavenge deer that were in an early stage of decomposition (86.69%; Table 4.6) than later stages ($x^2(3) = 17.94$, $p<.001$) and without insect activity. Whether or not a fox scavenged from a deer was significantly affected by the time of exposure ($p=.03$) and stage of decomposition ($p=.02$) of the deer but was not by the weight of the deer ($p=.99$) or the outside temperature, such that as length of exposure and the stage of decomposition increased foxes were less likely to scavenge ($p=.22$) ($R^2=.06$, $x^2(6)=23.03$, $p=.001$). Seasonal temperatures did affect the rate of decomposition of deer and the presence of insect activity which in turn affected fox scavenging. Nonetheless, foxes were recorded scavenging throughout all seasons but in varying frequencies (Figure 4.12-4.17). Foxes were also recorded re-scavenging and re-scattering deer remains that had already been scavenged, disarticulated and scattered by previous foxes (Figure 4.12-4.17). The final recordings of foxes scavenging occurred when deer were exposed an average length of 55.6 days, a minimum of seven days, and a maximum of 106 days (Table 4.5). The final observations of foxes present or near deer were on average when deer were exposed for 63 days, a minimum 32 days, and a maximum 106 days (Table 4.5).

Table 4.4. The recorded occurrences of nocturnal (after sunset) or diurnal (after sunrise) wild red fox scavenging of baits or whole deer.

Deposited Remains	Scavenging events after sunrise*		Scavenging events after sunset*		Total	
	%	n	%	n	%	n
Baits	0	0	100.00	14	4.35	14
Deer 1	3.37	9	96.63	258	82.92	267
Deer 2	0	0	100.00	7	2.17	7
Deer 3	0	0	100.00	15	4.66	15
Deer 4	6.67	1	93.33	14	4.66	15
Deer 5	25.00	1	75.00	3	1.24	4
Total	3.42	11	96.58	311		322

*Sunrise and sunset times for each day deer were exposed were obtained from Time and Date AS (2012).

Figure 4.11. A dog removes fur and soft tissue from the gunshot wound area on Deer 2 (A); the dog turned the deer about 90˚ whilst opening the thoracic cavity and removing soft tissue (B).

Table 4.5. The month and year of deposit, total exposure time, and average temperature during the total length of exposure for each bait and deer within the experiment. The first and final recordings of a wild red fox as present at each bait and deer. The first and final occurrences of red fox investigations and scavenging behaviours, based on video recordings, towards each deposited bait and deer.

					First Fox Present	First Fox Investigation	First Fox Bite	First Fox Attempt to Drag	Final Fox Present	Final Fox Bite
Deer #	Weight (kg)	Deposit Month & Year	Total Exposure (Days)	Average Temperature (˚C)	Exposure (Days)	Exposure (Days)	Exposure (Days)	Exposure (Days)	Exposure (Days)	Exposure (Days)
Bait 1-6	6	December '10	6	2.57	2	2	2	2	6	5
1	59	December '10	210	9.51	2	2	3	10	106	106
2	24	February '11	44	7.17	16	16	27	32	32	31
3	24	February '11	8	8.10	7	7	7	7	32	7
4	23	March '11	103	12.58	17	20	20	20	57	46
5	34	March '11	103	12.58	14	14	33	33	88	88
Average	32.80		67.71		9.67	10.17	15.33	17.33	53.50	47.17
Minimum	6		6		2	2	2	2	6	5
Maximum	59		210		17	20	33	33	106	106

Table 4.6. The stages of decomposition at which wild red fox scavenging occurred. The stages of decomposition are based on Galloway et al. (1989) because this is used to present a general description of the observed decomposition of deer.

	Deer 1		Deer 2		Deer 3		Deer 4		Deer 5		Total	
Stages of Decomposition	%	n	%	n	%	n	%	n	%	n	%	n
1.Fresh	94.38	252	0	0	100.00	15	0	0	0	0	86.69	267
2. Early Decomposition (e.g. discolouration and bloating)	0	0	100.00	7	0	0	0	0	0	0	2.27	7
3. Advanced Decomposition (e.g. moist soft tissue decomposition; maggot activity; some bone exposure and mummification)	0	0	0	0	0	0	100.00	15	50.00	2	5.52	17
4. Skeletonisation	5.62	15	0	0	0	0	0	0	50.00	2	5.52	17
5. Extreme decomposition	0	0	0	0	0	0	0	0	0	0	0	0
Total	86.69	267	2.27	7	4.87	15	4.87	15	1.30	4		308

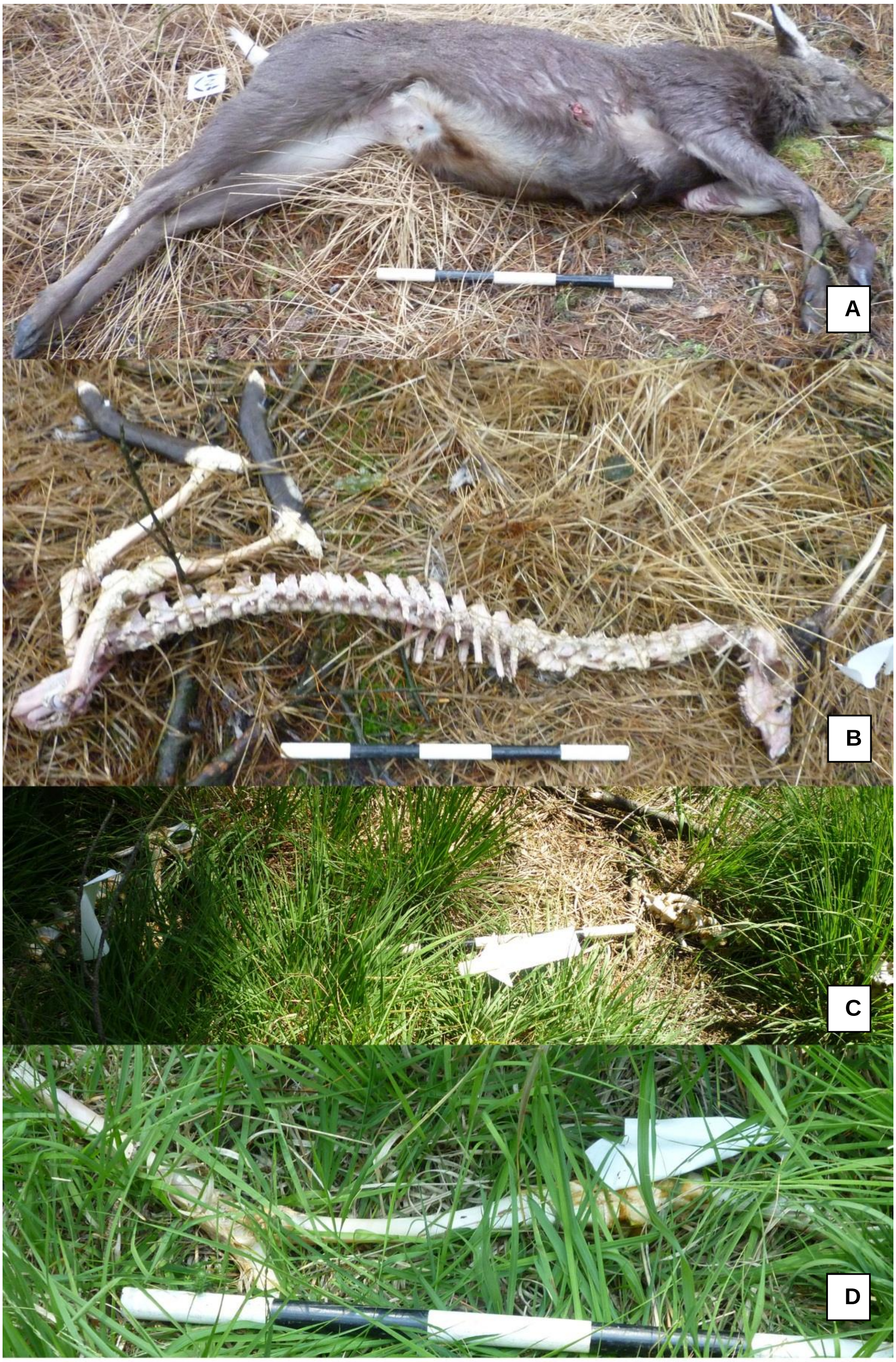

Figure 4.12. Deer 1 at different stages of its scavenging and exposure: time of deposit (A); after 31 days including scavenging by a dog and various foxes (B); final day of exposure, 210 days, showing the effects of further re-scavenging and scattering by foxes (C,D).

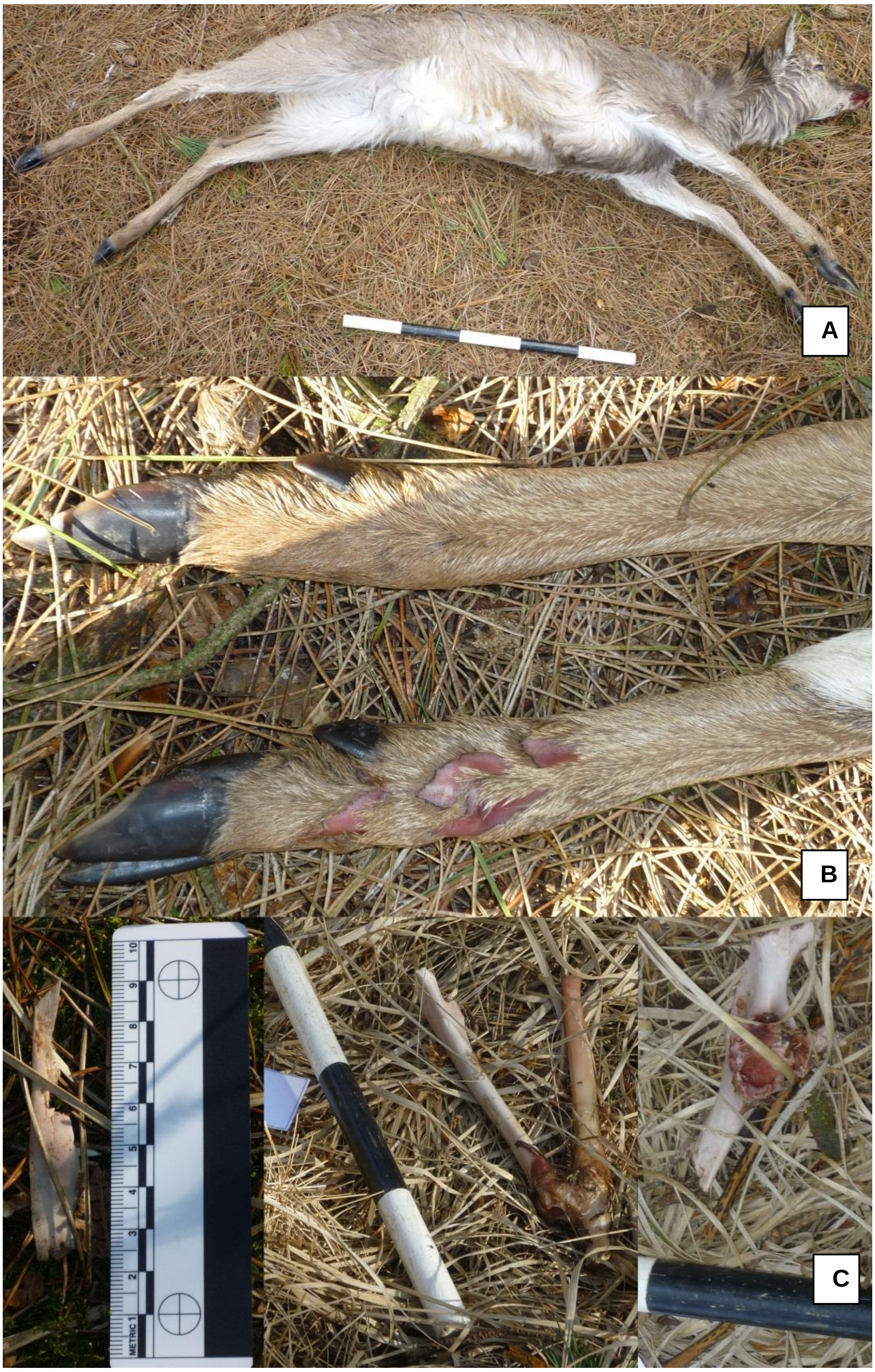

Figure 4.13. Deer 2 at different stages of scavenging: time of deposit (A); on the 27th day of exposure, a fox investigated and quickly picked up and dropped the hind leg (B); after fox scavenging on the 31st day, scavenged bones (rib; tibia & metatarsal; innominates) were recovered (C).

Figure 4.14. Deer 3 is shown here at the time of its deposit (A) and after only the 7th day, scavenging by foxes within a 24 hours period resulted in small rib fragments (B).

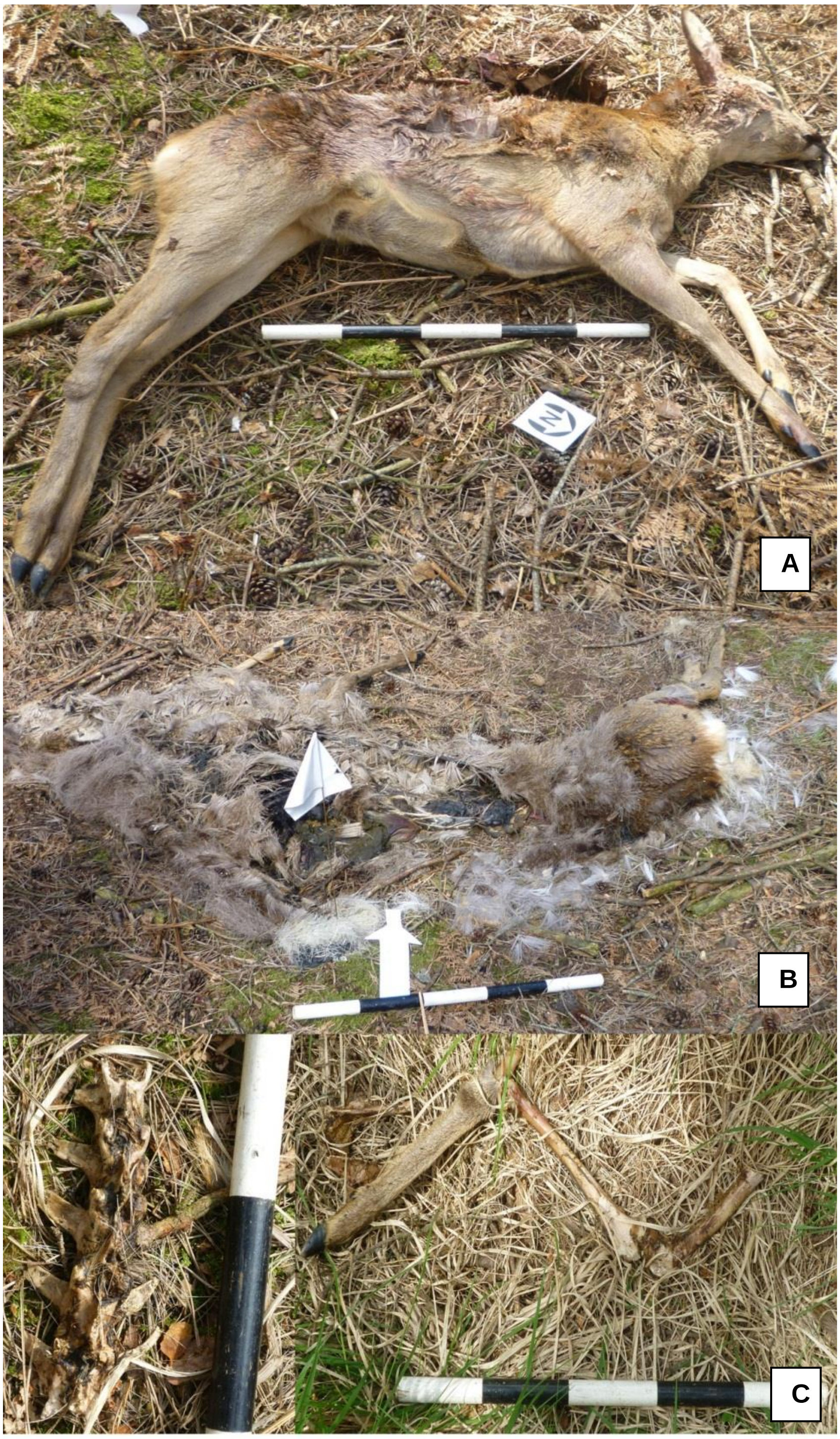

Figure 4.15. Deer 4 at different stages of scavenging and decomposition: time of deposit (A); after increased temperatures and insect activity for 20 days, a fox pulled at the hind legs and stretched the abdominal cavity (B); scavenging of the hind end on the 39th day resulted in the recovery of lumbar vertebrae and hind leg (C).

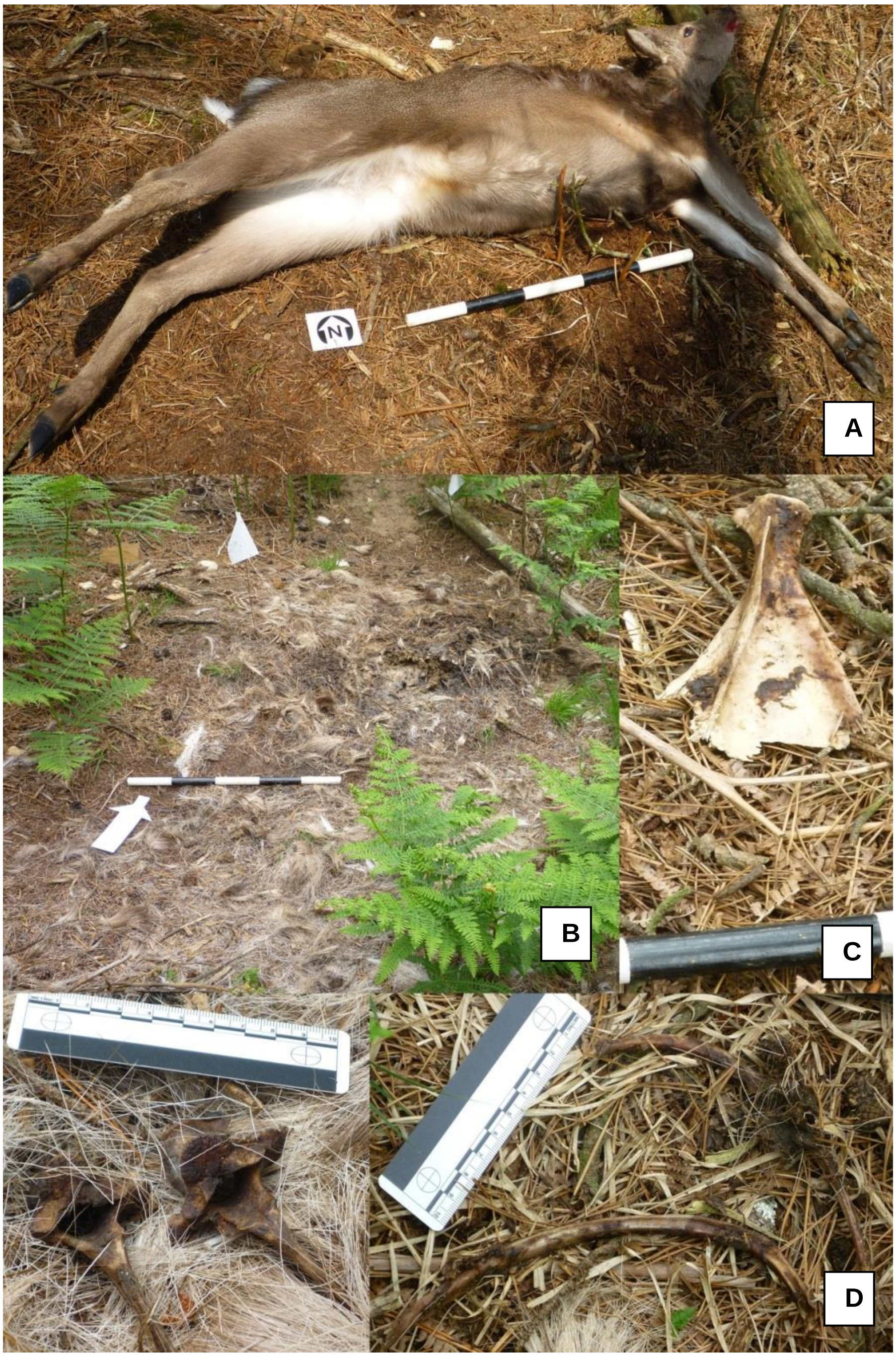

Figure 4.16. Deer 5 is shown here when it was deposited (A); after the departure of a maggot mass followed by fox scavenging (B); and scattered scavenged bones (scapula; thoracic vertebrae; ribs) (C,D).

Figure 4.17. A fox scavenging the previously scavenged sternal ends of the skeletonised Deer 1 (A); a fox attempting to remove Deer 1 from its deposit site by its skeletonised hind leg (B).

4.4.3 Scene investigation, search, and recovery: scattering and dispersal of scavenged surface remains

Scavenged and scattered remains were primarily recovered within a 45 m radius (Figure 4.18). The maximum distance of recovery of a skeletal element, a metacarpal with phalanges articulated, was 103.54 m (Deer 1) from a primary deposit site and the maximum distance of scattered fur was 41.98 m (Deer 3) (Figure 4.18-4.26). The mean distance of recovery for scattered bone was 18.13 m (SD = 15.51) from the deposit site and for fur, 10.00 m (SD = 7.47) (Figure 4.19-4.20). The scatter pattern of scavenged and disarticulated remains led 80% of the time towards either areas of high and thick vegetation, a dense collection of fallen trees, or sett entrances (Figure 4.22-4.26).

The distribution of distances of recovered scattered skeletal elements for Deer 1-5 were significantly different (H (4)= 25.07, p < .001). Deer 1's distribution of distances was significantly different to Deer 2 (U= 24, r= -.67) and Deer 3 (U= 50, r= -.40), however, it was not significantly different to Deer 4 (U = 444, r= -.04) and Deer 5 (U= 470, r= -.09). These findings support results within this experiment, that Deer 2 and 3, deposited at the same time, were not affected by extreme weather temperatures like Deer 1, 4 and 5, nor were they scavenged by a large sized canid (e.g. dog) like Deer 1. Deer 1, 4 and 5's recovery rates were also higher than those of Deer 2 and 3, possibly due to the effects of extreme temperatures associated with either decelerated decomposition and insect activity or increased insect activity and rates of decomposition, as well as the effect of dog scavenging on fox scavenging behaviours (Table 4.6-4.7).

Overall the five deer deposited within the field site, ribs were recovered in 100% of searches, as whole and fragmented (Table 4.7). Other commonly recovered elements were innominates in 70% of searches (60% not including collected innominates), as well as the cranium (40% not including collected crania) and vertebrae in 60% (Table 4.7). Front and hind limbs were both recovered in 40% of searches, however, the individual skeletal elements of the hind limbs were found more often than those of the front limbs (Table 4.7). Deer 4 (81.82%) and Deer 1 (63.64%) had the highest recovery rate of skeletal elements. The recovery rates for Deer 2 and Deer 5 were 21.21% and 30.30%, both of which deer had the longest PMI of all deer prior to the onset of a fox scavenging. Deer 3, which was successfully removed as whole by a single fox from the deposit site and was fully scavenged and disarticulated within a 24 hours period, had the lowest recovery rate of just 3.03% and primarily consisted of small rib fragments (2 cm - 5 cm) (Figure 4.9; 4.14).

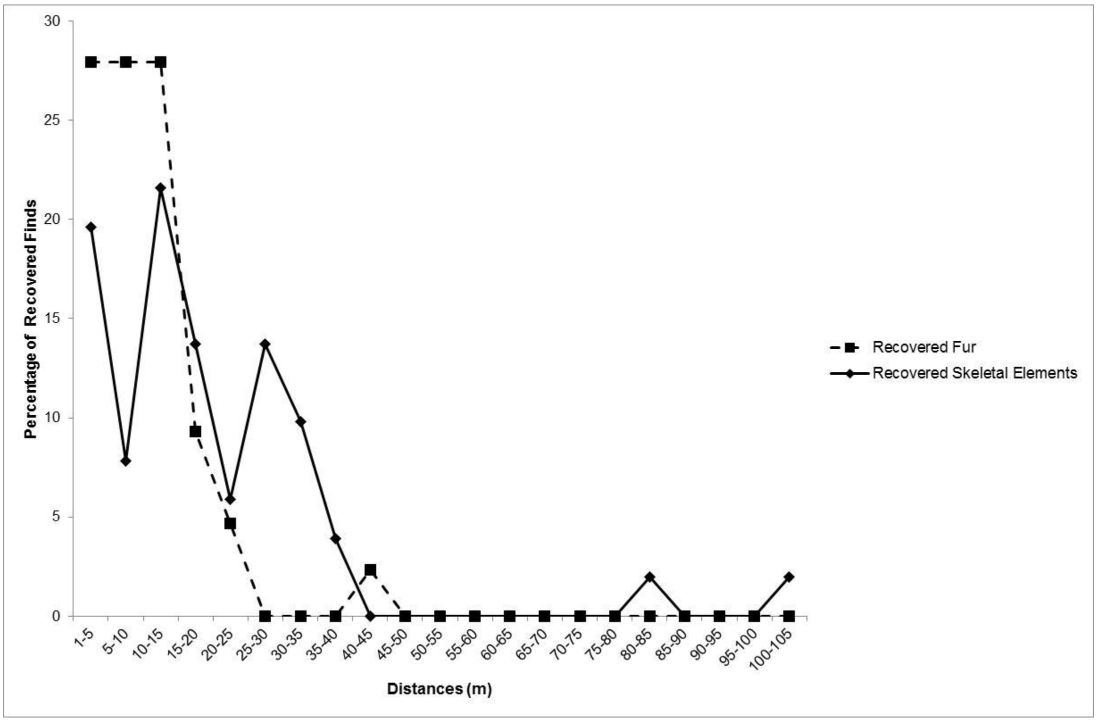

Figure 4.18. The distribution of the recovery distances of scattered bones and fur.

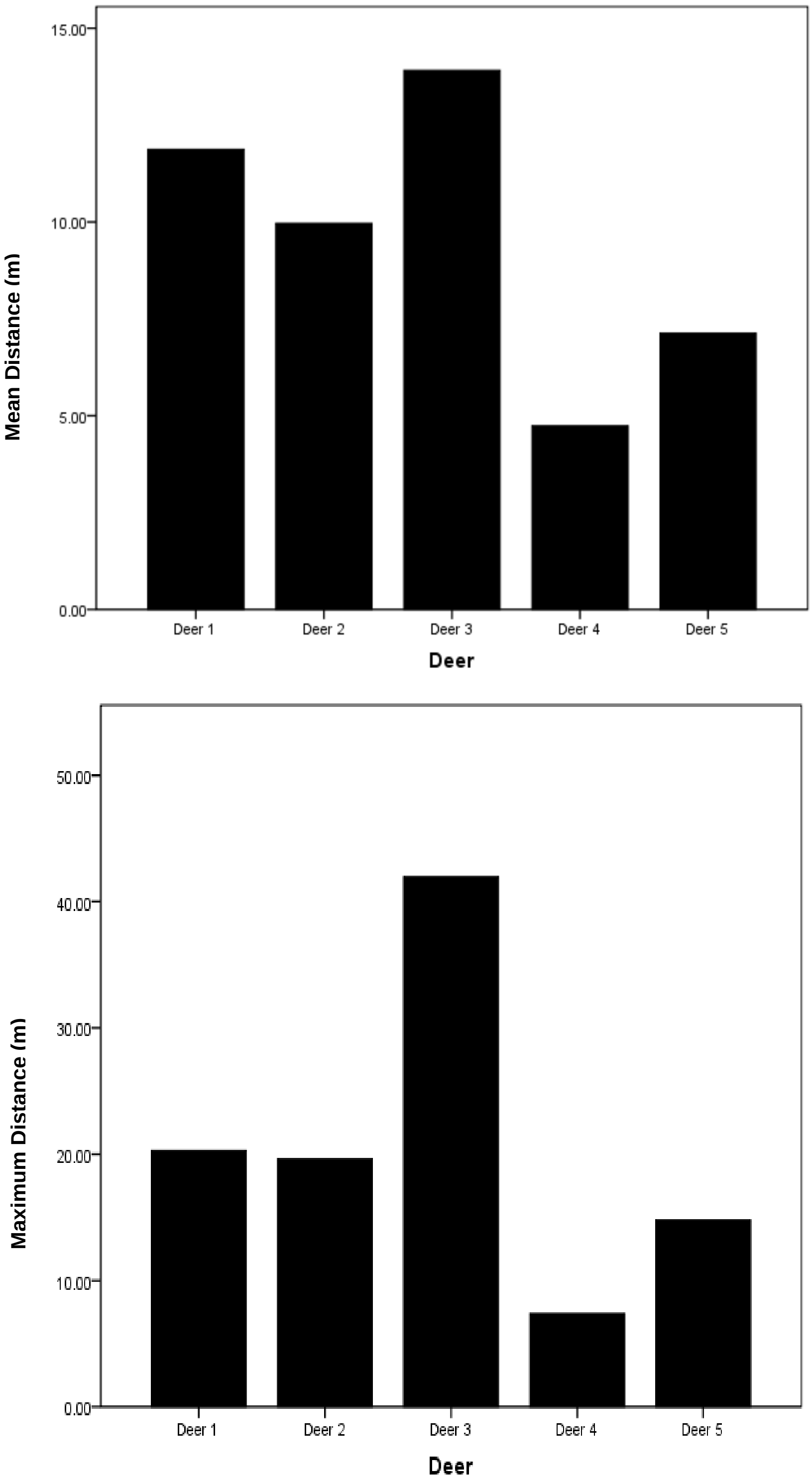

Figure 4.19. The mean and maximum distances of scattered fur.

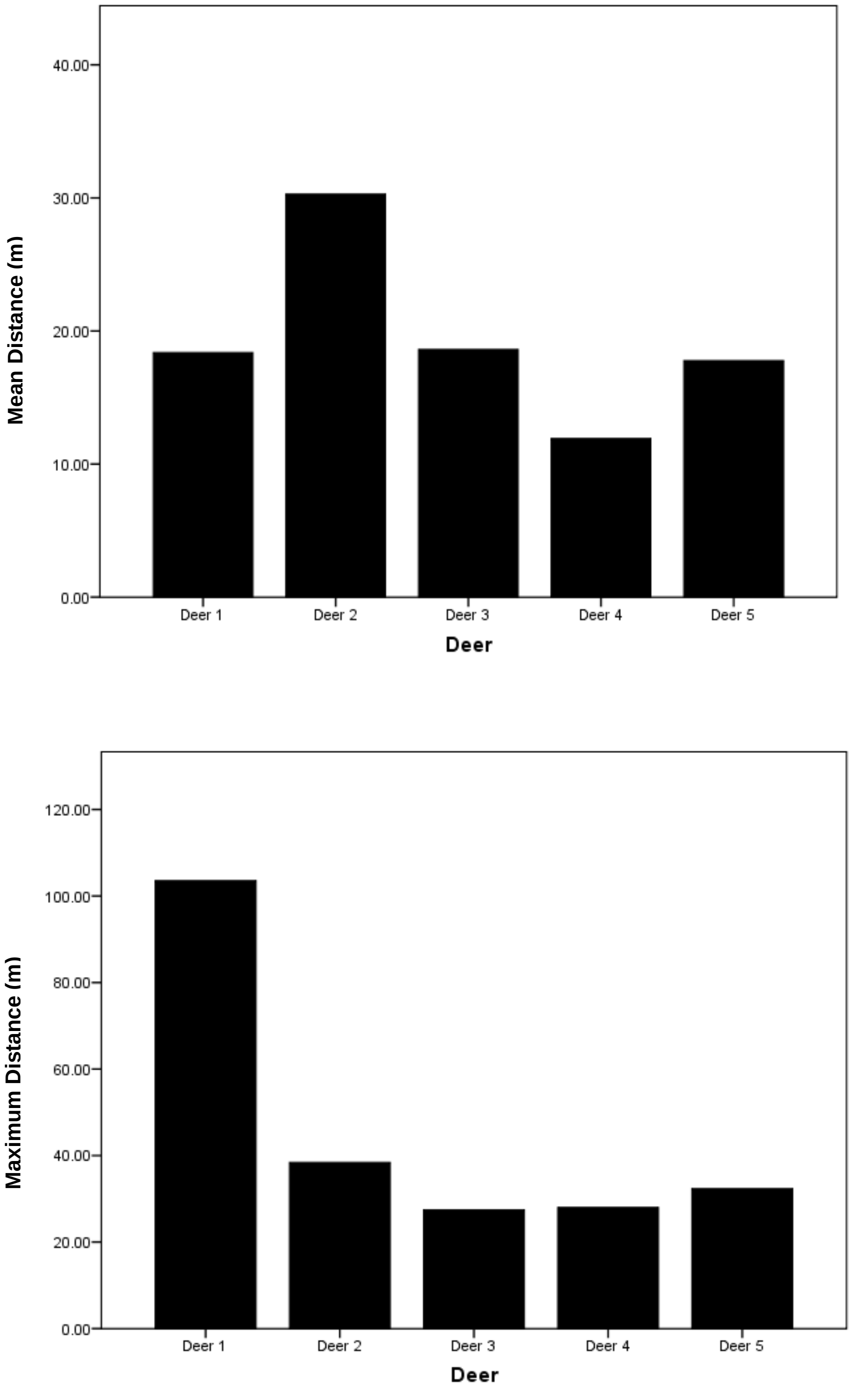

Figure 4.20. The mean and maximum distances of scattered bones.

Figure 4.21. A cached metacarpal from Deer 1 located c. 103 m North of the primary deposit site.

Table 4.7. The recovery rate, excluding those removed from the site and not exposed for further scavenging and scattering, and the overall recovery rates per skeletal elements from Deer 1-5.

Skeletal Elements	Recovery Rate Excluding Previously Recovered Elements %	Overall Recovery Rate %
Cranium	40	60
Mandible	40	40
Cervical Vertebrae	60	60
Thoracic Vertebrae	60	60
Lumbar Vertebrae	40	40
Sacrum	0	0
Scapula	40	50
Ribs	100	100
Sternum	20	20
Humerus	30	30
Ulna	20	20
Radius	20	20
Carpals	30	30
Metacarpal	40	40
Phalanges	35	35
Innominates	60	70
Femur	40	40
Tibia	40	40
Tarsals	50	50
Metatarsal	30	30

4.4.3.1 Deer 1

A site visit and search on the 31st day of exposure revealed the partial disarticulation and scattering of Deer 1 (Figure 4.12). The partially skeletonised remains of the deer had been moved by scavengers southwest a distance of 15.07 m from the initial deposit site (Figure 4.22). In relation to the deposit site, rib fragments were recovered a maximum 12.66 m away and the mandible 8.9 m. Fur was found scattered in both a northwest and southwest direction but was more prevalent towards the south (Figure 4.22). The maximum distance from the deposit site that fur was found was 20.29 m. The lower hind legs (metatarsals and phalanges) and between the antlers of the deer were the only areas that retained soft tissue and fur. The sternum, front limbs, and scapulae were not recovered. The southward direction of scattering of remains led towards a collection of overturn trees and exposed tree roots located 9.26 m from the scavenged remains (Figure 4.22). Examination of the tree collection revealed the presence of fox scat and accumulated deer fur at the base of trees. The nearest sett entrance was 24.27 m northeast of the primary deposit site (Figure 4.22). On the 58th day, a cached metacarpal with articulated phalanges was located 103.54 m North of the primary deposit site (Figure 4.21). Based on the condition of the soft tissue, as well as the time of exposure between Baits 1-6 and Deer 1, the find was interpreted as belonging to Deer 1. Further movement of the remains by scavengers was not observed during site searches until the 108th day of exposure. The hind legs of the deer were no longer lying straight but were instead bent towards the head of the deer and the entire remaining set of remains appeared slightly twisted. On the 163rd day, the skeleton of Deer 1 was separated at the fourth thoracic vertebrae with the front and lower halves of the deer approximately 90 cm apart. The hind legs were further disarticulated and scattered a maximum distance of 3.06 m from the remainder of the skeleton but 13.05 m from the first deposit site. The cached metacarpal was no longer present on the 197th day due to scavenging. The overall recovery rate for all skeletal elements of Deer 1 was 63.64%.

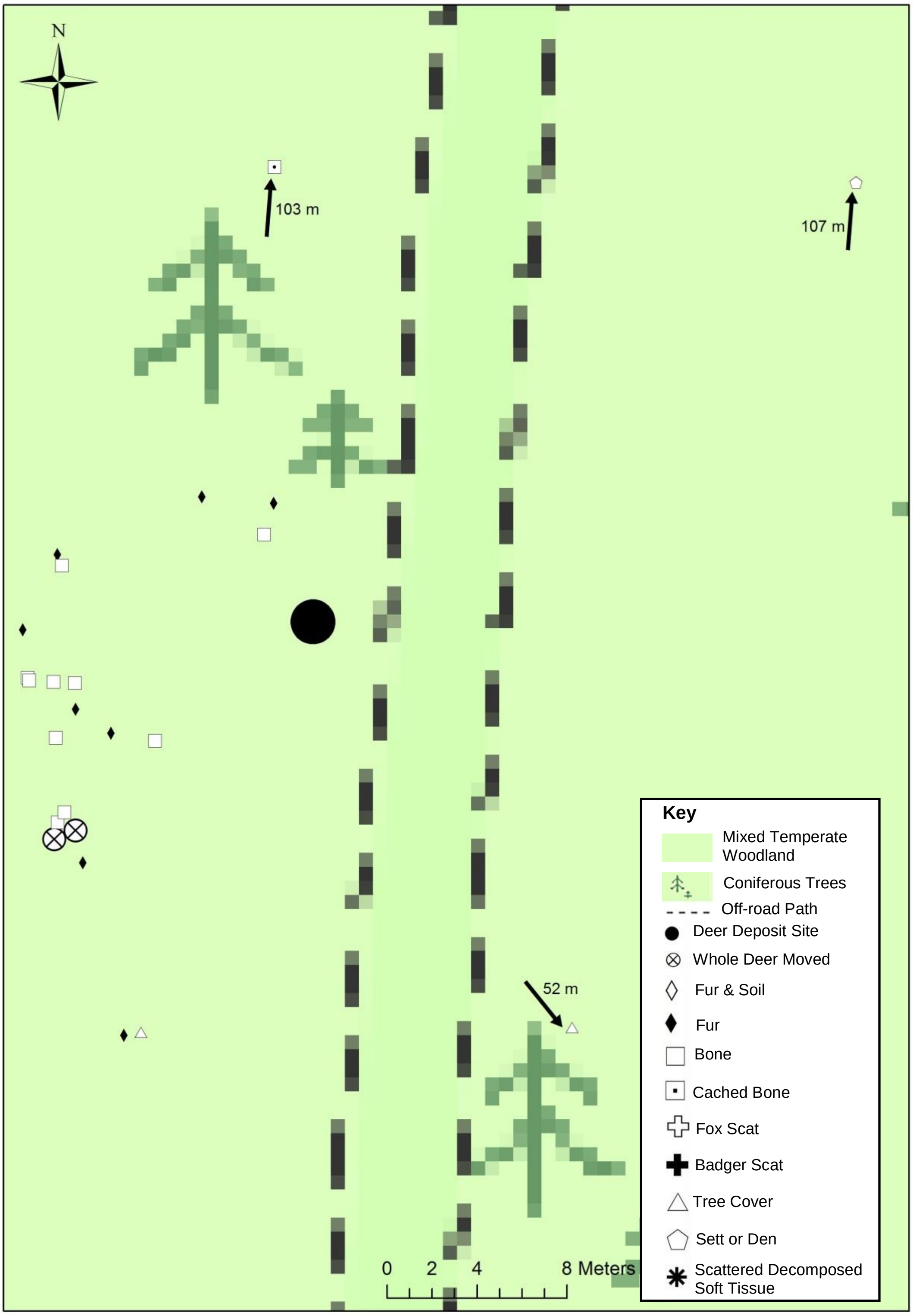

Figure 4.22. Scatter map for Deer 1 showing deposit sites, setts, scavenged and scattered bones, and scattered fur.

4.4.3.2 Deer 2

On the 30th day of exposure, scavenging of Deer 2 was first observed during a site visit. The deer, slightly bloated with a swollen mouth, was moved 10 cm towards the West by a fox. Four patches of exposed skin were visible on the right hind leg but had no soft tissue damage or removal. A site visit on the 44th day revealed the full scavenging, disarticulation and scattering of the deer (Figure 4.13). Leading from the deposit site was evidence of drag marks in the soil, scattered fur, and fox faeces. The maximum distance fur was scattered was 19.62 m. The pattern of scattered fur and soil marks led in a southward direction (Figure 4.23). Recovered remains included rib fragments (maximum distance to deposit site 26.53 m), a right scapula fragment (26.36 m), an articulated but fractured right tibia and metatarsal (31.22 m), a right femur shaft (38.41 m), and the right side of the pelvic girdle (30.93 m) (Figure 4.23). The scattered remains did not lead towards any sett entrances but did lead towards higher vegetation in comparison to the ground cover of the deposit site. The pattern of scattering, in fact, led away from the nearest sett entrance located 11.36 m East of the deposit site. Additionally, towards the South of the deposit site there was an increase in collections of fallen tree branches approximately 46 m from the deposit site but 7 m from the recovered femur shaft. The recovery rate of all skeletal elements for Deer 2 was 21.21%.

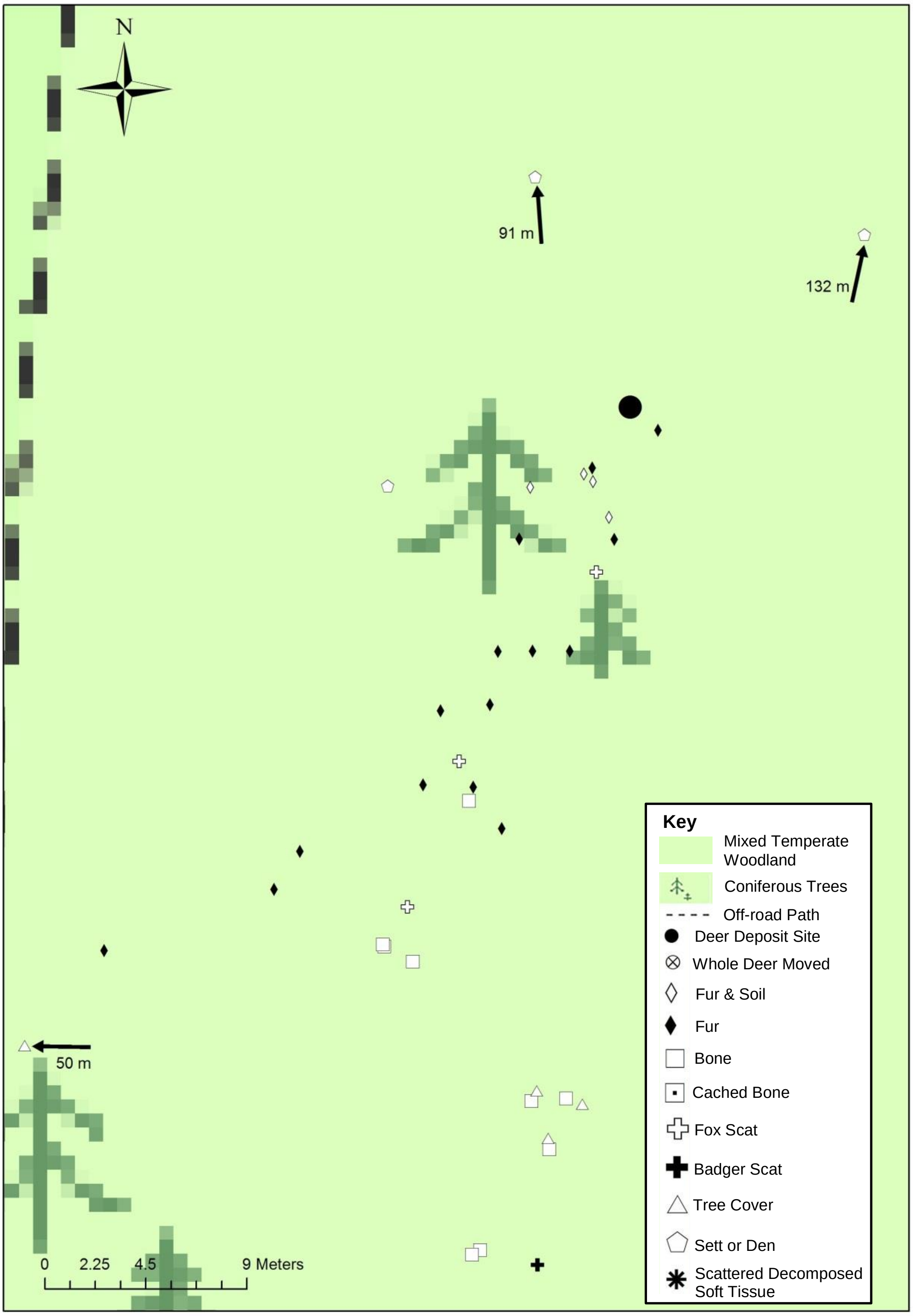

Figure 4.23. Scatter map for Deer 2 showing deposit sites, setts, scavenged and scattered bones, and scattered fur.

4.4.3.3 Deer 3

The site was visited on the 8th day of exposure, during the site search the only recovered finds included scattered fur and rib fragments (Figure 4.14). Witness accounts by site wardens confirmed the presence of the whole carcass during daylight on the 7th day. The maximum distance to which fur was located was 41.98 m to the southwest and the maximum distance for rib fragments was 27.41 m (Figure 4.24). The pattern of scatter of rib fragments and fur led towards the northeast where there was an increase in the number of active and inactive badger setts (Figure 4.24). No fox faeces were identified near any finds, however, badger faeces was located 20.88 m from the deposit site and 4.49 m to the nearest rib fragment. Rib fragments were located both along the unpaved car track, fallen tree branches, and areas of higher vegetation. A cached rib fragment was located at the base of a tree, 27.41 m from the deposit site (Figure 4.24). Further northeast, approximately 65 m from the deposit site, larger and more active badger setts were located. Examination of the sett entrances revealed older scavenged bones from other animal species (e.g. cow, badger, and fox) deposited at the entrances and some concealed within soil heaps. Additionally, trails of dry vegetation leading down into setts were also observed. No other remains were located for Deer 3. However, on the 44th day a deer skull was located 81 m southeast of the deposit site. The skull was completely skeletonised with some staining and the ground surface underneath the skull was moist with some evidence of a fungal type growth. Also, located nearby was a heavily scavenged and bleached fragmented left mandible. The skull may have belonged to Deer 3, however, there was not enough evidence to confirm this. Thus the skull was not included in calculations of recovery rates or average distances of recovery for the skull. The total recovery rate of skeletal elements, not including the aforementioned skull, was 3.03%.

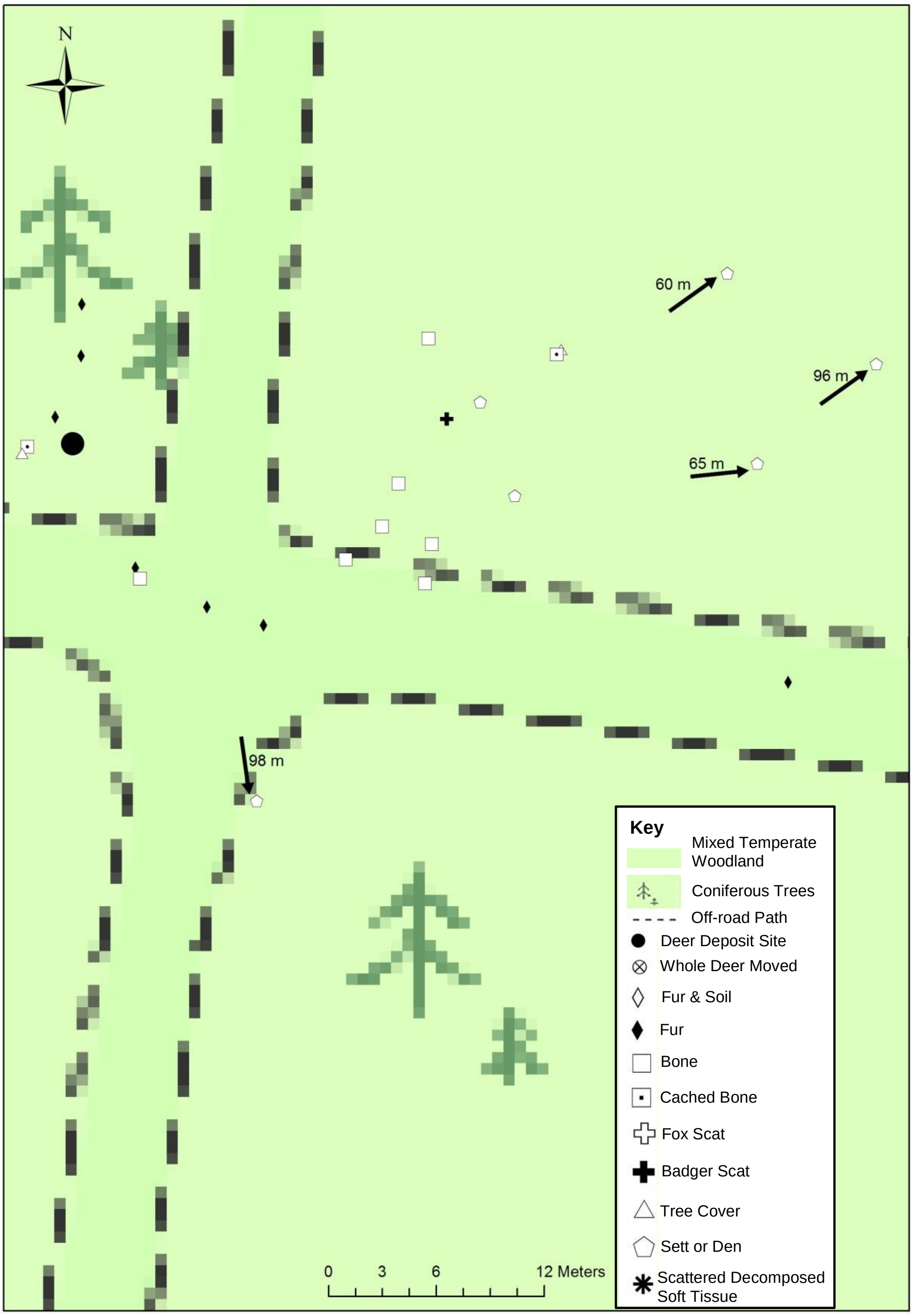

Figure 4.24. Scatter map for Deer 3 showing deposit sites, setts, scavenged and scattered bones, and scattered fur.

4.4.3.4 Deer 4

Scavenging of Deer 4 by foxes was not evident in site visits until the 20th day of exposure. The deer had been pulled at the right hind end by a single fox which resulted in the deer being separated at the first lumbar vertebrae (Figure 4.15). The hind end had an area of exposed red soft tissue where the fox had pulled at the deer and removed soft tissue. The front half of the deer, inclusive of head to the ribcage, remained in its deposited location whilst the lower half was moved 50 cm East. All skeletal elements were still present within the deposit site. Decomposing, darkened, soft tissue from within the thoracic and abdominal cavities was stretched out and exposed, including a large maggot mass. Scattered fur outlined the deer carcass. On the 43rd day, the lower half of the deer, which included lumbar vertebrae, pelvic girdle, sacrum, coccyx, and lower hind legs, had been removed from the deposit site by a fox. All other skeletal elements from the top half of the deer were not scavenged. Fur was scattered in a northwest direction at a maximum distance of recovery of 7.38 m. Recovered skeletal elements included an articulated pelvic girdle and sacrum (16.49 m), articulated lumbar vertebrae (16.49 m), and a right articulated hind leg (19.81 m) (Figure 4.15, 4.25). All of the scattered bones were removed by the researcher except for the articulated hind leg which was left in the site to allow for further scavenging and movement by scavengers. The hind leg was recorded on day 56 as having moved a further 8.19 m West of the deposit site (Figure 4.25). The leg was found further disarticulated with the femur moved an additional 3.86 m West and the articulated tibia and metatarsal 3.45 m on the 103rd day of exposure (Figure 4.25).The pattern of scattering of fur and skeletal elements did not lead towards any setts or dens nor did it lead towards areas of higher vegetation in comparison to the deposit site. The nearest sett was 69.76 m away towards the East (Figure 4.25). However, to the southwest of the deposit site there was an area of low vegetation and less dense tree cover. The total recovery rate of skeletal elements for Deer 4 was 81.82%.

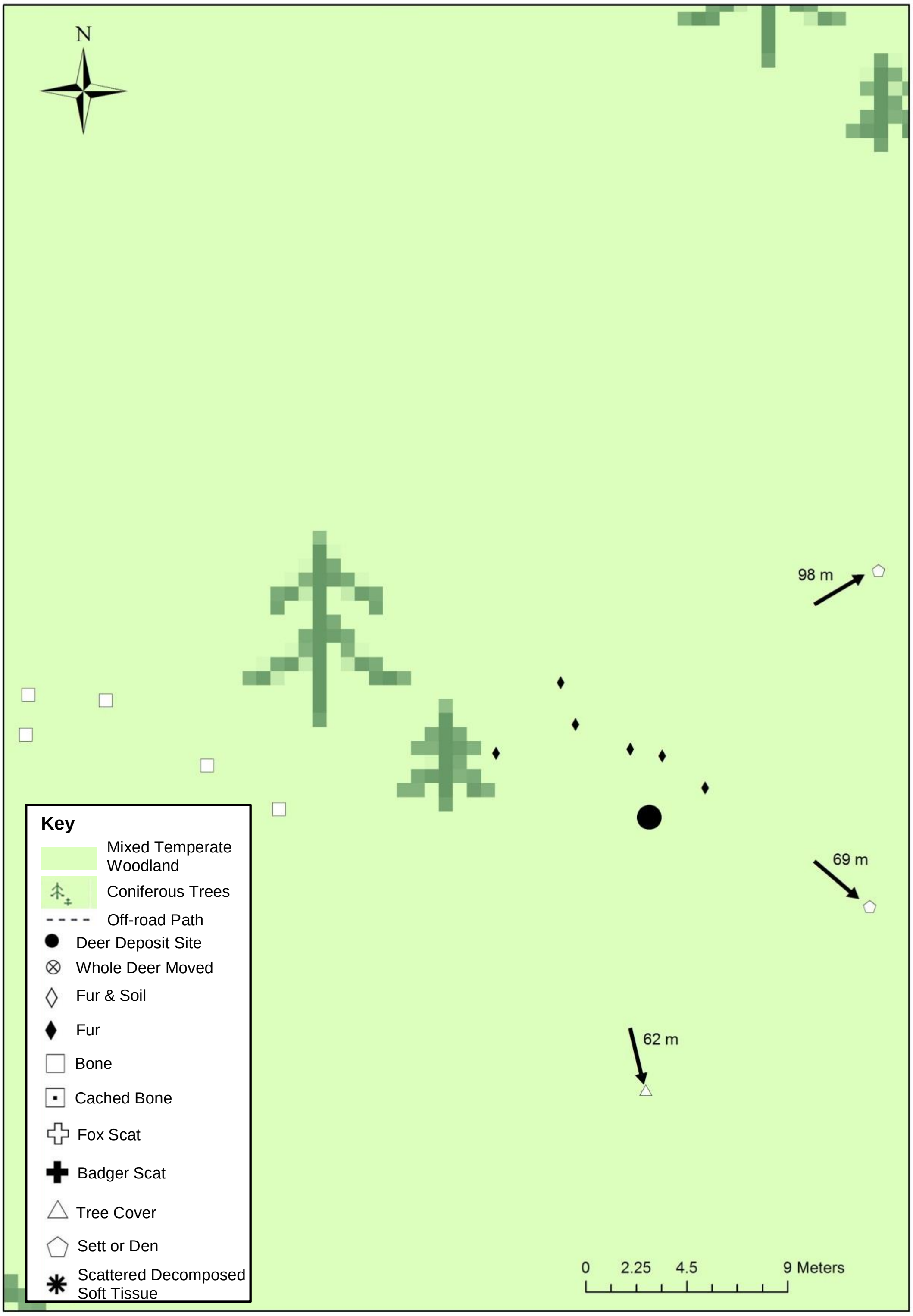

Figure 4.25. Scatter map for Deer 4 showing deposit sites, setts, scavenged and scattered bones, and scattered fur.

4.4.3.5 Deer 5

On the 20th day of exposure, the bloated and discoloured carcass of Deer 5 did not appear to be scavenged by foxes except for a possible small movement or rotation of the right hind leg. The deer was in an advanced stage of decomposition on the 35th day, such that a maggot mass previously present within the thoracic and abdominal cavities was no longer present, and the overall state of the carcass was drier and flatter in appearance. The left hind leg was still articulated to the deer but was pulled slightly away from the carcass and the front left leg had been removed. A site search on that day did not result in the recovery of the front leg. Fur was also found scattered within 2 m of the deposit site and collected near the hind legs of the deer against a fallen tree where two fox paw prints were visible. Heavy scavenging by foxes was visible on the 56th day. The entire deer had been scavenged and scattered away from the deposit site except for a small collection of decomposed soft tissue from the thoracic cavity which held a thoracic vertebrae and a rib (Figure 4.16). Fur was scattered and found at a maximum distance of 14.79 m (Figure 4.26). Within 2 m of the deposit site scavenged bones were recovered which included thoracic vertebrae, a cervical vertebra, the left scapula, and ribs. However, these elements and others were also found at farther distances. The maximum distance at which ribs were recovered was 5.32 m, scapula at 10.95 m, cervical vertebra at 7.54 m, and ox coxae at 29.8 m (Figure 4.26). The left and right ox coxae were separated by a distance of 29.46 m and the scapulae at 9.63 m (Figure 4.26). A small but active badger sett entrance was located 4.90 m northeast of deposit site. The site search also resulted in the identification of large active setts both to the West and northeast about 23 m of the deposit site (Figures 4.26, 4.27). One sett entrance contained scattered pheasant (*Phasianus colchicus*) feathers and another had fox faeces within the entrance. All scattered elements were removed from the site by the researcher except for the left scapula, the right os coxae, one cervical vertebra, and three ribs which were left within the site to allow for further scavenging. Additional scavenging was observed on the 63rd day, all skeletal elements within 2 m of the deposit site had been slightly moved or removed from the site by foxes. Elements removed by foxes included the left scapula, a rib, and a cervical vertebra. Located within 2 m to the southwest of the deposit site was a fox faeces near a scavenged rib. A small rib fragment was located at a sett entrance at 4.90 m. Moreover, a single rib was recovered at 5.33 m leading towards the larger setts to the northeast. These additional ribs and rib fragments could not be distinguished from ribs identified on the 56th day, thus it is possible that the ribs could have been the previous ribs but scavenged and moved to a new location by scavengers. At 21.34 m northwest from the deposit site, a scavenged cervical vertebra and two temporal bone fragments were recovered (Figure 4.26). These bones were found 8.55 m from an active badger sett and latrine. The only skeletal elements removed from the site that day by the researcher were the cervical vertebra and temporal bones. All other elements were left on site. On the 76th day of exposure, an articulated front leg was located 25.18 m from the deposit site amongst thick bracken and fox faeces (Figure 4.26). There was no other evidence of scavenging of the previous skeletal elements. The front leg was left on site to allow for any further scavenging. The leg was found to have been moved two additional times on the 83rd day by 5.78 m and on the 90th day by 1.37 m (Figure 4.26). In comparison to the 76th day, on the 83rd day the leg appeared to have less soft tissue and was disarticulated on the 90th day. The overall recovery rate for Deer 5 was 30.30%.

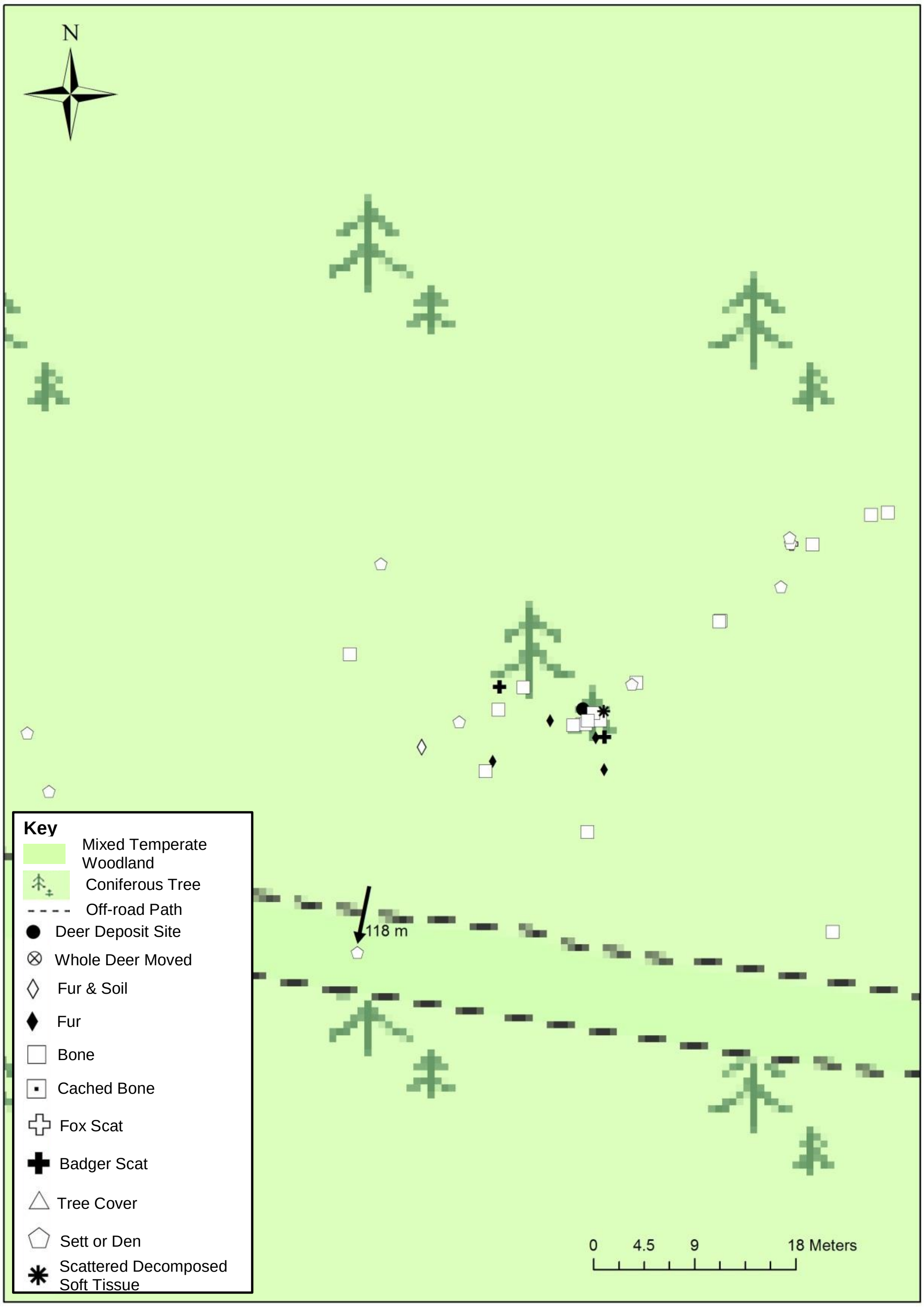

Figure 4.26. Scatter map for Deer 5 showing deposit sites, setts, scavenged and scattered bones, and scattered fur.

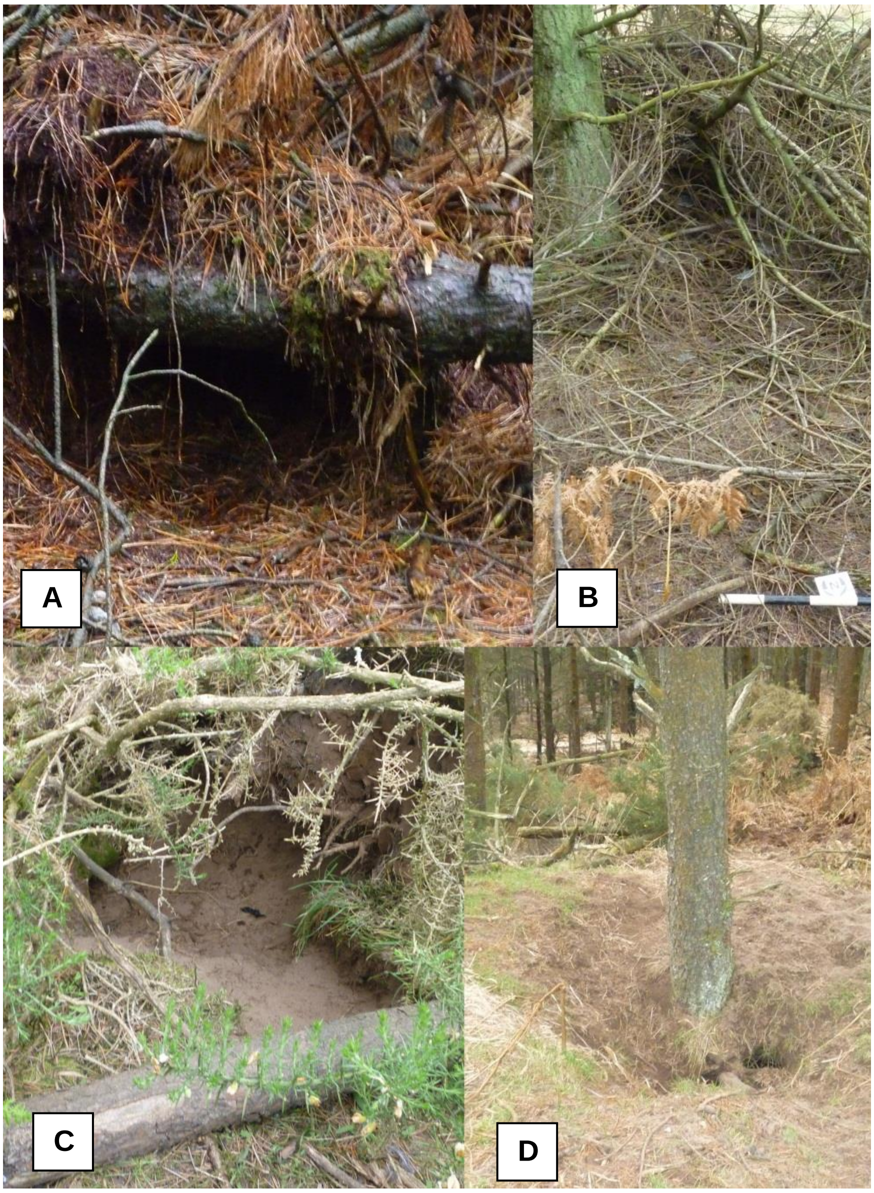

Figure 4.27. Typical areas foxes take scavenged remains to: overturned tree (A); thick collection of fallen branches (B); thick bracken (C); active badger sett (D).

4.5 DISCUSSION

The observations, comparisons and analyses of badger and fox scavenging behaviour and patterns towards deer remains, as well as comparison of wild and captive scavengers' behaviour, provide insight into the modification and transportation of human remains by the red fox and Eurasian badger. The search and recovery of scavenged and scattered deer remains has identified key reference points at which scavenged deer and human skeletal elements can be recovered, as well as the condition and types of elements that police search officers are likely to recover. The application of these results to the scavenging of human remains also aids forensic investigations in the more accurate interpretations of deposition environments, condition of remains, and time of exposure.

Foxes are more likely to scavenge surface deposited human remains than badgers in a rural or peri-urban environment within Britain. Scavenging by foxes is most frequent during colder seasons for a variety of reasons such as low trophic resources, delayed rate of decomposition of remains, and decreased insect activity. Foxes avoid scavenging remains whilst there is increased activity or will concentrate scavenging from areas on a body where there is less insect activity. Once insect activity has decreased and remains have begun to dry, foxes will scavenge at a faster rate.

Foxes' scavenging behaviour towards deer remains indicated that a fox will first try to remove a whole carcass via the extremities from the deposit site. If a fox is unable to remove the remains then it will proceed to scavenge and disarticulate remains at the deposit site so that smaller elements can be transported. Scavenging by foxes is initially focused at the extremities and less likely at the site of trauma (e.g. gunshot wound). Foxes will further scavenge, scatter, and consume transported remains or cache them. Caching allows foxes to hide scavenged remains from other scavengers and to re-scavenge, re-scatter, and consume remains at a later date. Foxes will also re-scavenge, re-scatter, and cache remains from original and new deposit sites (Figure 4.17). The majority of scavenged and scattered elements for deer remains scavenged by foxes were recovered within an 18 m – 45 m radius from the original deposit site. Scattered remains were most commonly found at areas of thick and high vegetation, badger setts or fox dens, fallen trees, and collections of tree branches.

4.5.1 Badgers versus foxes

Although wild badgers were not observed scavenging any deer remains, observations of captive badgers did show that badgers do scavenge both fresh remains with soft tissue and dry skeletal remains, as well as take items down into setts. Captive badgers were found to scavenge more frequently than both wild badgers and captive foxes. The inclusion of captive badgers within this study allowed for normally crepuscular activities of badgers to be observed. Captive foxes were observed to scavenge food less frequently than wild foxes due to a stable diet of provided food. However, studying captive foxes allowed for fox scavenging activities that occur away from deposit sites, such as caching and further scavenging, to be recorded. Both captive and wild foxes tried to remove food items or baits and deer prior to any scavenging.

The diet of wild badgers relies primarily on invertebrates such as earthworms (L. terrestris) and beetles (Kruuk and Parish 1981; Revilla and Palomares 2001; Macdonald et al. 2004). When earthworm density in a badger's territory is low it will need to seek alternative resources to meet its metabolic needs (Da Silva et al. 1993; Leckie et al. 1998; Kjellander and Nordstrom 2003; Sidorovich et al. 2011). Within this field study, the lack of any observations of wild badgers scavenging from the deer carcasses and the recordings of badgers digging the ground surface suggest that the badgers' main prey met their metabolic needs. Badgers enter a state of torpor or semi-hibernation during winter and are most active from spring to fall, whereas foxes are active year-round (Gittleman and Harvey 1982; Doncaster and Macdonald 1991; Alderton 1994; Kowalczyk et al. 2003). Likewise, scavenging activity can be increased due to imminent breeding seasons and semi-hibernation which will require higher metabolic needs (Christian 1970; Von Schantz 1984; Zimen 1984; Harris and White 1992; White and Harris 1994; Cavallini 1996; O'Brien et al. 2007).

The diets and environments of badgers and foxes are known to overlap but the main diet of foxes relies more on small mammals and birds (Von Schantz 1984; Lindström 1989; Trewhella et al. 1991; Leckie et al. 1998; Sadlier et al. 2004). Foxes, like badgers, can also seek alternative food sources when their main sources are low (Carr and Macdonald 1986; Da Silva et al. 1993; Leckie et al. 1998; Kjellander and Nordstrom 2003; Macdonald et al. 2004; Selva and Fortuna 2007). Foxes were recorded in this study scavenging baits and deer during all seasons that remains were deposited but badgers were not observed scavenging any remains.

There were also no observations of badgers and foxes acting aggressively towards each other at or near remains despite both species recorded using the same paths at different times. The experiment site may have provided enough trophic resources that there was no competition between these species over access to baits or deer. Alternatively, it may be a reflection of a low badger or fox population density.

4.5.2 Scavenging behaviour and pattern of the red fox

The pattern of scavenging and utilisation of a deer carcass by foxes in this study differs to that of domestic dogs (*Canis familiaris*), coyotes (*Canis latrans*) and wolves (*Canis lupus*). Foxes are solitary scavengers, whereas, wild dogs, coyotes and wolves hunt and scavenge in packs (Haglund et al. 1989; Carr and Macdonald 1986; Harris and White 1992; White and Harris 1994; Jarnemo 2004). The larger body size, jaw strength and pack advantages to hunting, enable these larger canids to hunt larger sized carcasses (Schmitz et al. 1987; Baryshnikov et al. 2003; Lee and Mill 2004; Christiansen and Adolfssen 2005; Wroe et al. 2005; Christiansen and Wroe 2007). Within this study on deer carcasses, foxes were observed scavenging from all accessible areas of a carcass at various stages but was concentrated first on the extremities and/or areas of a carcass that were still within the early stages of decomposition and not at the head, neck or site of trauma.

A red fox's species-typical scavenging pattern is as follows: after multiple visits and investigations to the carcass, the fox will slowly approach the point of the body that is farthest from the head where there is the risk of a bite, in this study this point was the hind end or hind legs of deer. The fox will then proceed to make non-invasive bites to the remains, which has the potential to cause damage to the surface of the skin. A fox will then try to transport the remains from its deposit site for further scavenging and disarticulation of remains where there is less of a chance of inter- or intra-species aggression and competition for a food source. In contrast, larger canids (e.g. coyotes and wolves) focus on scavenging remains where they are deposited (Haglund et al. 1989; Willey and Snyder 1989; Haglund and Reay 1993). The sequence of scavenging for foxes then continues from the hind to front limbs, followed by the thorax which includes the scavenging, disarticulation and scatter of vertebrae, ribs, sternum, and scapulae. The final stage of fox scavenging cannot be generally described as total disarticulation but instead partial to complete disarticulation followed by the re-scavenging and re-scattering of skeletal elements (Figure 4.28; 4.17).

This pattern of fox scavenging differs to Willey and Snyder's (1989) study on the scavenging of deer by captive timber wolves in North America in which wolves concentrated first at a site of trauma, if present, and tore soft tissue from the face and neck, followed by scavenging concentrated at the thoracic cavity. The observed pattern of scavenging by wolves of deer carcasses does match the dog and coyote scavenging of human remains as described in Haglund et al.'s (1989) study. The scavenging sequence observed in Haglund et al.'s (1989) study on scavenging patterns in forensic cases in the Pacific Northwest saw a pattern beginning with the removal of soft tissue from the face and neck of a body, and then proceeding to the thorax, in a type of head to toe pattern of scavenging. Haglund et al.'s (1989) study on coyotes and dogs identified a model of five stages of canid scavenging on human remains starting with no bone involvement, followed by scavenging to the thorax and upper limbs, then the lower limbs thus leaving only the vertebral column articulated until, finally, total disarticulation. While scavenging by foxes in this study on deer was found to be more dynamic and occurred in a different order to that of larger canid scavengers both of deer and forensic cases (Figure 4.28).

In environments where the red fox is not the largest canid scavenger their access to remains can be restricted by the presence of larger canids, such as dogs, coyotes and wolves, which gain access to a set of remains before smaller sized scavengers and show aggressive territoriality over remains (Christian 1970; Andrews and Evans 1983; Macdonald 1983; Haglund et al. 1989; Haglund and Reay 1993; Selva and Fortuna 2007). The presence of such larger sized canids has the potential to affect the scavenging behaviours of foxes and the areas on a carcass that are modified by foxes. As observed in this study, foxes avoided approaching, investigating and scavenging from deer when a dog was present at the deer deposit site or scavenging. Scavenging by larger canids may both expose areas of soft tissue that may otherwise be inaccessible by foxes (e.g. restrictive clothing) or scavenge and consume areas of a body usually scavenged and removed by foxes from the deposit site. If based on the North American studies of larger canid scavenging patterns of human remains, the most commonly recovered skeletal elements are vertebrae, skull, pelvic girdle, and femora when there is scavenging by larger canids (Haglund 1997a). Thus, damage by foxes in such environments would be restricted to these elements and would not be expected for other skeletal elements. However, this study has shown that in an environment where the fox is the largest and most common wild canid scavenger, fox scavenging has a different pattern of carcass utilisation involving a wider variety of skeletal elements because foxes have access to all skeletal elements. For instance, 60 % of the deposited deer in this study had all skeletal elements modified or removed by fox scavenging. Therefore, if the region-specific and scavenger-specific forensic studies from North America were used to identify scavengers within this study the presence of scavenging on the wide variety of skeletal elements would have been attributed to the presence of larger canids known to scavenge these skeletal elements such as domestic dogs.

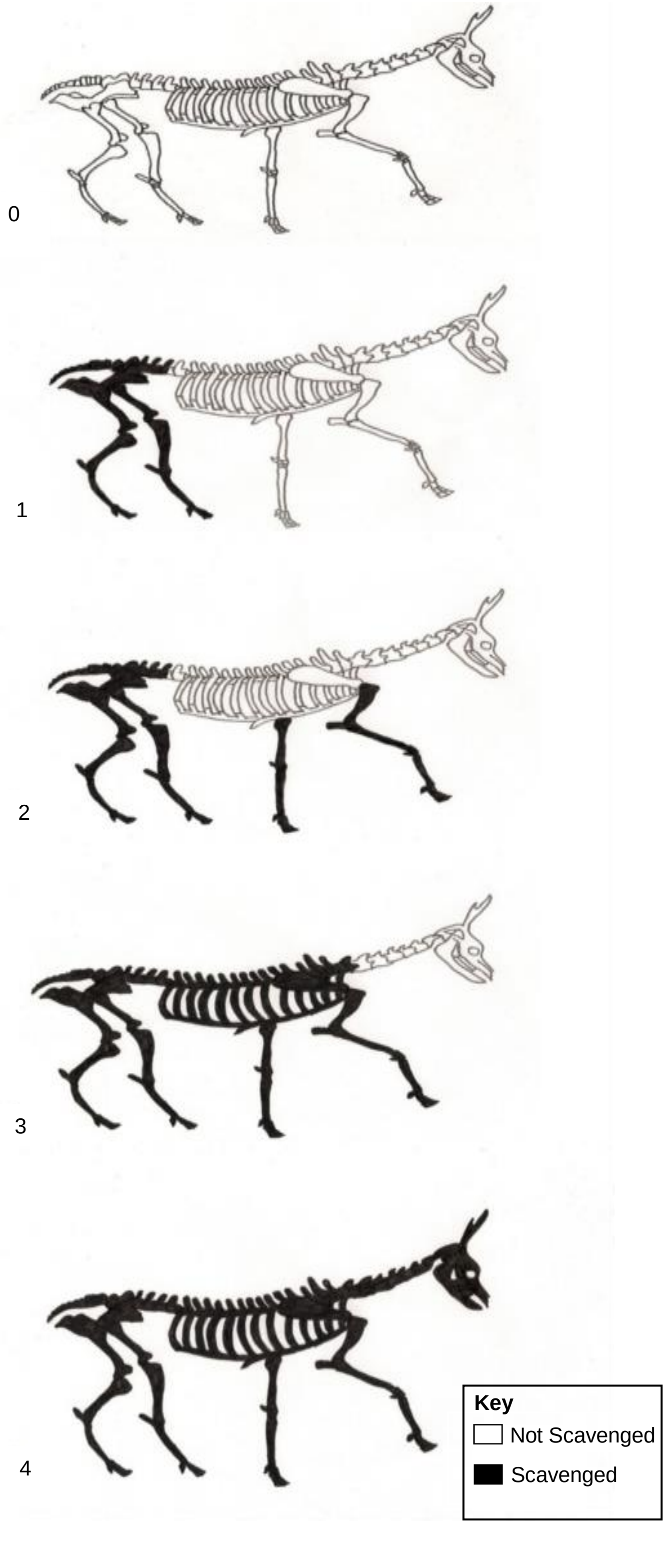

Figure 4.28. The five stages of red fox scavenging of deer: 0) investigative behaviours and multiple visits by foxes to a deer; 1) scavenging and/or removal at the hind limbs; 2) scavenging of the front limbs; 3) scavenging of the thoracic cavity; 4) scavenging of the cervical vertebrae and skull. It is important to note that foxes will re-scavenge and re-scavenge a set of remains thus exceeding just five stages.

4.5.3 Comparison of deer and human remains: red fox scavenging behaviour and pattern

Foxes were observed to more frequently scavenge a carcass either when it was fresh, at an early stage of decomposition with slight bloating but no maggot mass present, or when it was partially to fully skeletonised. Seasonal variations in temperatures can affect the rate of decomposition of a set of remains which, in turn, affects the frequency and type of scavenging by foxes, as well as which areas of a body are utilised. Foxes were observed to scavenge deer more frequently in colder temperatures (e.g. late fall to winter). Colder, freezing, temperatures can allow a carcass to remain fresher for a longer period of time and with limited insect activity which presents foxes with a more desirable food source to scavenge and cache or consume. The effects of freezing may limit a fox's ability to manipulate and remove a whole body from a deposit site, whereas warmer temperatures contributable to increased insect activity and decomposition rates delay and restrict fox scavenging until the departure of a maggot mass and the desiccation of soft tissue as observed in this study. If the pattern of decomposition of a set of remains is not uniform then a fox, unlike wolves (Willey and Snyder 1989), will only scavenge from the areas where insect activity is limited or a maggot mass is not present. Moreover, the decomposition or breaking down of joints will also affect the sequence in which different areas of a body are disarticulated and removed by a scavenger.

In general, the most persistent joints of a human body which would be more difficult for a fox to disarticulate prior to advanced decomposition include joints that support more weight, such as the knee joint or the lumbar spine (Duday 2009). In contrast, areas such as the cervical vertebrae and scapulae decompose at a faster rate and would thus be disarticulated at an earlier stage and with more ease than other persistent joints (Duday 2009). All persistent joints found in humans are not the same as those found in deer, such as those of the lumbar spine, because of the quadruped skeletal structure of deer (Boszczyk et al. 2001; Wang et al. 2010). However, the knee joints are also persistent weight-bearing joints in deer but with some morphological differences in comparison to humans (Athanasiou et al. 1991; Pasda 2002). Pasda's (2002) study on the scavenging of reindeer (Rangifer tarandus groenlandicus) also found that weight-bearing joints in reindeer decomposed at a slower rate than persistent joints. Interestingly, Pasda (2002) found that the front legs disarticulated at an earlier stage than hind legs. Moreover, Pasda (2002) found that the cervical and thoracic vertebrae of reindeer stayed articulated the longest.

Within this study, foxes were observed removing soft tissue primarily from the hind end or limbs of deer until it was possible for a fox to remove the deer from the deposit site. This pattern of scavenging of deer by foxes only differed for the one deer which was scavenged first by a dog that opened the thoracic cavity, thus providing foxes easier access to the soft tissue and organs of that area first. In contrast, the scavenging sequence observed in Haglund *et al*.'s (1989) study on scavenging patterns in forensic cases in the Pacific Northwest interpreted that scavenging by coyotes and dogs began with the removal of soft tissue from the face and neck of a body, and then proceeded to the thorax, in a type of head to toe pattern of scavenging. Additionally, Haglund et al.'s (1989) study on coyotes and dogs identified a model of five stages of canid scavenging on human remains starting with no bone involvement, followed by scavenging to the thorax and upper limbs, then the lower limbs thus leaving only the vertebral column articulated until, finally, total disarticulation. While scavenging by foxes in this study on deer was found to be more dynamic and occurred in a different order to that of larger canid scavengers both of deer and human remains (Figure 4.28).

The recovery of skeletal elements of deer scavenged by foxes are as follows in descending order of their recovery rates: ribs, innominates, cranium and vertebrae, scapula, hind and front limbs at the same rate as the mandible, phalanges, and sternum with lowest recovery rate (Table 4.7). Although the cranium and vertebrae had the same recovery rate, vertebrae were often recovered alongside scavenged ribs or limbs. Foxes were found to be capable of removing and fragmenting the majority of skulls, thus the cranium and mandible did not have the highest recovery rate. It is important to note that the morphology of a deer's skull differs from that of human and the presence of the elongated nasal bones of the deer allow it to be transported more easily than that of a human's skull (Figure 1.5). Despite the differences in skull morphology, the presence of soft tissue, mummification or delay in the disarticulation of the mandible from the cranium (Moraitis and Spiliopoulou 2010), trauma to the skull (e.g. dismemberment), and the presence of a downward slope (Ruffell and Murphy 2011) could allow a fox to remove a human skull. Nonetheless, foxes were able to fragment the entire cranium of deer within these experiments and were able to transport skulls a short distance. It is during the scavenging and removal of the skull that the cervical vertebrae can be damaged and transported from the deposit site, especially if these bones are still articulated.

Interestingly, despite foxes first scavenging from the hind end or hind legs of the deer, the front and hind limbs were recovered at the same rate. This is contradictory to Young *et al*.'s (2014) forensic cases in the U.K., in which foxes were interpreted as scavengers, and Haglund *et al*.'s (1989) cases in the Pacific Northwest, in which dogs and coyotes were interpreted, where lower extremities from human cases were recovered more frequently than upper extremities and scapulae. The recovery rates of scavenged human remains in Haglund (1988) suggest that the cranium and mandible should be the most recovered elements (80-100%) and then in descending order: vertebrae, pelvis and femur (60-90%), upper and lower extremities, the sternum and scapulae (40-59%) and finally, the hands and feet as the least recovered elements (20-39%). Comparison of the forensic cases in Young *et al*. (2014) to the deer remains in this study, both interpreted as involving fox scavenging, suggest that the most frequently scavenged and removed elements by foxes are the extremities of deer and human remains. However, foxes were more resilient in their total scavenging and modification of a deer carcass in these experiments than the human remains presented in Young *et al*. (2014), as well as those scavenged by larger canids in Haglund *et al*. (1989).

In the forensic cases presented in Young *et al*. (2014) and Haglund *et al*. (1989) the interpretation of scavengers was not based on bite mark analysis or species-typical scavenging behaviour information but was primarily based on the interpretations of canid or carnivore-typical bone damage and the general knowledge of carnivore inhabitants of those environments. The scavenging of upper or lower extremities by foxes in the forensic cases presented in Young *et al*. (2014) was likely influenced by the presence of footwear and clothing. For instance, Young *et al*. (2014) reported that lower limbs were recovered still clothed and with feet contained in socks and/or shoes, thus foxes may have been restricted from accessing and scavenging lower limbs. In contrast, Haglund *et al*. (1989) indicated that dogs and coyotes were able to damage and remove clothing whilst scavenging human remains. Similarly, Willey and Snyder's (1989) study on the scavenging of deer by captive wolves stated that deer hide was comparable to the presence of clothing on a body and that because wolves were capable of scavenging the hide they were therefore undeterred by the presence of clothing when scavenging human remains. Within this study, the presence of deer hide did not deter foxes from scavenging and disarticulating deer remains, thus based on Willey and Snyder (1989) foxes should be able to scavenge, disarticulate, and remove clothing and the clothed lower limbs on human remains. Therefore, the human remains scavenged by foxes in Young *et al*. (2014) would be expected to have a lower recovery rate of lower limbs or have more extensive scavenging of lower limbs and damage to clothing and footwear but this did not occur. Moreover, the acetabulofemoral joint, although an area where there is increased weight on a body, deteriorates at a faster rate than other persistent joints due to the positioning of the femoral head, thus implying that this area would be easily disarticulated by foxes (Duday 2009). However, based on the forensic cases presented in Young *et al*. (2014) the presence of footwear and clothing appeared to influence a fox's ability to scavenge human remains. Whereas, if the human remains in Young *et al*. (2014) were scavenged by dogs, like in Haglund *et al*. (1989), then damage to clothing would have been expected to be extensive. Additionally, the weight, muscle mass, condition, and position of a body have the potential to affect the scavenging, disarticulation, scattering and removal activities of foxes. Likewise, the method of deposition of a body (e.g. wrapped in a blanket, placed in a bin liner) will influence which areas are accessible to foxes for scavenging. The identification of scavenging and the areas of a body modified by scavengers, as well as those not scavenged, can contribute to interpretations of time of exposure, deposition sites and methods, trauma, and the condition of remains.

4.5.4 Comparison of deer and human remains: red fox scattering pattern

The scatter pattern of fox scavenging within this study led towards areas of high vegetation, raised trees or fallen tree branches, or setts and dens (Figure 4.27). The majority of scatter patterns were also in a linear pattern extending from the deposit site towards these areas. The scavenging patterns and average distance of recovery from deposit sites found in the forensic cases in Young *et al*. (2014) were similar to those found in these experiments with deer (c. 18 m bone; c. 10 m fur). The removal of scavenged deer remains by foxes towards areas of high vegetation or collections of overturned tree trunks and branches provided individual foxes cover from other foxes and scavengers that would have been attracted to the deposit site where the scent of the deer was strongest.

When red foxes and Eurasian badgers are considered as scavengers within a rural or peri-urban environment, this study found that the key areas to search for scattered remains are dense trees or collections of fallen trees and branches, setts and dens, and animal paths. Nevertheless, there are a variety of factors that can affect the dispersal of scavenged remains and should be considered. For instance, the condition of remains and how they were deposited can limit dispersal distances, such as heavy textiles or an outdoor shed; the rate of decomposition of a set of remains; competition at the deposit site such as inter- or intra-species aggression causing a scavenger to take an item farther from the site or a dominant scavenger obtaining the remains and taking them farther than the previous scavenger; the distance of the deposit site to setts, dens, or areas of concealment favoured by foxes; topography (e.g. downward slope enabling easier transportation); bone destruction caused by scavengers ingesting bones; and the availability of a scavenger's main food source affecting whether that scavenger needs to seek alternative food sources, will all affect dispersal. Moreover, the re-scavenging, re-scattering, and re-caching of already scavenged remains, both soft tissue and dry bone, by foxes not only extends recovery distances but also highlights the necessity to conduct a search at a site more than once. Thus it is not possible to assign a maximum recovery distance for all scavenged remains as scatter distances will be affected differently in each forensic case but it is possible to target search areas when the environment and scavenger species are known. At scenes of scavenging, assessing the environment, the climate during the deposition and exposure of remains, condition of remains at deposition, scavenger species present in the area, and those scavengers' species-typical scavenging behaviours are factors that can aid in the more efficient and effective search and recovery of scavenged and scattered remains.

Foxes often co-habit active and inactive badger setts which provide not only a den but also an additional place to hoard food (Alderton 1994; Macdonald et al. 1996, 2004; Pasda 2002). Paths to setts and dens should be searched for any remains and/or personal effects that have fallen or become disarticulated through the dragging process by foxes or badgers to the setts or dens. Sett entrances should not only be searched for evidence that remains have been taken down but also for skeletal elements that badgers have pushed out of the setts' tunnels. Badgers regularly clear out their setts and bring in new bedding material, which is often a visible trail of dried vegetation leading into entrances. The clearing process by badgers produces a large soil heap directly outside of the sett entrance which has the potential to contain scavenged skeletal elements (Figure 4.29). The identification of soil drag marks, produced by the removal of remains by scavengers, and animal tracks can also aid in the recovery of remains and associated materials (Figure 4.30).

Wild foxes in this study were not observed caching but cached scavenged deer remains were recovered. However, captive foxes were recorded caching more frequently and at a faster rate when food items were of a smaller weight and consisted of either their preferred food or an item that required prolonged mastication, such as long bones. Caching allows foxes to hide disarticulated skeletal elements and/or soft tissue to ensure that metabolic needs are met at times when the availability of main prey is low (Jackson et al. 2007; Caraeu et al. 2007). The observed caching in this study is in contrast to Caraeu et al.'s (2007) perishability hypothesis on artic fox caching suggested that food items that do not perish for extended periods of time will be cached more frequently than items that perish at a faster rate. Caraeu et al.'s (2007) work with arctic foxes also identified short-term caches as a tool for arctic foxes to temporarily hoard food whilst going after another food source. Although this was not observed with the captive and wild foxes in the U. K., the use of short-term caches could allow a fox to fully remove, scavenge and disarticulate a full carcass in a shorter span of time without exceeding its energy constraint and avoiding inter- or intra-species competition, rather than scavenging and consuming the carcass where it was deposited. Therefore, caches should also be searched as these may hide key skeletal elements for identifications and interpretations. Caches are more likely to be located through the use of a fingertip search method which allows closer inspection of the ground surface. Common locations, as was observed with captive foxes and the recovery of deer scavenged by wild foxes, for caches are at the base of trees, areas of thick vegetation, or at semi-permanent fixtures (e.g. fencing) within the scene.

Figure 4.29. Whilst clearing out their setts, badgers push out old bones and soil which can cause scavenged bones to be covered by a soil heap (A). An active badger sett with scattered deer fur in its entrance (B); active badger sett entrance (C).

Figure 4.30. Drag marks (outlined in black) in the soil surface indicate the direction in which Deer 2 had been dragged by a fox from its deposit site. Scattered fur and less obvious drag marks are outlined in white.

4.6 CONCLUSION

In a rural or peri-urban environment, red foxes are more likely than Eurasian badgers to scavenge a set of remains. Badgers do scavenge but are less likely to scavenge in an environment rich in their main trophic resources. Foxes, being a solitary scavenger, will first attempt to remove a set of remains away from a deposit site to a more secluded area at which to scavenge or cache without threat of another scavenger. This study found that an individual fox is capable of removing a whole deer weighing 24 kg (c. 1.5 m length) from a deposit site, which is similar to the average weight of an 8 – 10 years old child, but cannot remove a whole deer weighing 59 kg (c. 2 m length), similar to the average weight of an adult human female of 5’3” – 5’5” height. Scavenging by foxes, although observed during the entire study, was more frequent in colder seasons and during the fresh and early stages of a deer’s decomposition. The average length of exposure of deer until scavenging by foxes began was found to be 18 days. Foxes did not scavenge during advanced stages of decomposition or when insect activity was increased, unless other areas of the same deer were at an earlier stage of decomposition. The scavenging pattern of the red fox, in regards to deer remains, was found to differ to that of larger canids, such as the domestic dog, wolf, and coyote. Red fox-typical scavenging pattern is as follows: multiple visits and investigations with quick bites to remains; attempts to remove remains from the deposit site; and then the scavenging, disarticulation, caching and scatter of the extremities followed by the thoracic cavity including vertebrae and damage to the skull. Red fox scavenging does not end there but instead is characterised by the re-visiting, re-scavenging, and re-scattering of dry remains over an extended period of time. Within this study, scatter distances by foxes averaged 18 m for bone and 10 m for fur. Recovery distances of bone and fur were concentrated within a radius of 45 m but were found at a maximum distance of 103.54 m and led to areas of high or thick vegetation, dense tree cover or fallen trees, and setts co-habited by badgers and foxes. The scavenging patterns and recovery distances of deer remains were found to be similar to human remains scavenged by foxes. However, the presence of clothing and footwear on human remains appear to influence the areas on human remains that a fox can access to scavenge and disarticulate. The full extent of the effects of clothing on the scavenging behaviour and scattering pattern of foxes is an area of research that needs to be explored further in future scavenger species-typical and region-specific studies like this study.

Forensic cases involving scavenged, disarticulated and scattered human remains from surface depositions can occur in a multitude of different scenarios which may affect the areas of the body which can be scavenged, disarticulated, or transported by a scavenger. Prior to this research, forensic investigations and physical searches have been at a disadvantage by relying on region-specific studies of large sized scavenger species not found in this region and with different scavenging behaviour and scattering patterns than foxes and badgers. Direct observations, actualistic methods, and multidisciplinary approaches, like those used in this study, enable the use of species-typical, region- and environment-specific studies to better recreate and interpret the crime scene. The use of such studies not only aids in the reconstruction of the circumstances surrounding death and deposition but also assist in the more effective search and recovery of scattered human remains that are essential to interpretations and identifications.

Chapter 5

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

5.1 ABSTRACT

Scavenger-induced alteration to bone not only occurs whilst scavengers access soft tissue but also during the scattering and re-scavenging of skeletal remains. Bone modifications will vary based on scavenger species-typical scavenging behaviour, scavenger species' dentition, condition and deposition of remains, and environmental factors. Using bite mark dimensional data to assist in the correct identification of a scavenger can improve interpretations of trauma and enhance search and recovery methods. This study analysed 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.

5.2 INTRODUCTION

Mammalian scavengers of vertebrate remains can modify bone surfaces during the scavenging, disarticulation, and removal of a set of remains. Modifications to bone surfaces can occur both whilst scavengers access soft tissue and skeletal elements. Mammalian scavenger-induced alteration to bone can produce both fractures and bite marks on bone surfaces which can obscure and hinder interpretations associated with a set of remains, such as trauma (ante-, peri- or post-mortem) (Rothschild and Schneider 1997; Byard *et al*. 2002; Schulz *et al*. 2006). The types of modifications to bone surfaces produced by scavengers will vary due to bone morphology, scavenger species' dentition, scavenger species-typical scavenging behaviour, the condition and deposition of remains, and environmental factors (Haynes 1980; Johnson 1985; Haglund *et al*. 1988; Christiansen and Wroe 2007; Delaney-Rivera *et al*. 2009; Gidna *et al*. 2013). The analyses of bite marks can aid forensic scientists, investigators, police search officers, and other fields of study 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 behaviour and pattern. An accurate interpretation of a scavenger species' scavenging behaviour and pattern can indicate key reference points within and around a crime scene area to be searched.

In Chapter 3 and 4 the red fox and Eurasian badger were found to be 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. In Chapter 3 and 4 scavengers of six deer carcasses surface deposited within a typical Northwest European woodland environment were observed using infrared motion detection cameras which recorded the scavenging activities of wood mouse (*Apodemus sylvaticus*), grey squirrel (*Sciurus carolinensis*), buzzard (*Buteo buteo*), carrion crow (*Corvus corone*), red fox, Eurasian badger, and domestic dog (Chapter 3 – 4). This study has the advantage of both actualistic methods and direct observation of the taphonomic agents producing bone modifications which were analysed.

Rodent scavengers do produce gnaw marks on bone surfaces, commonly seen as parallel striations, oblong hexagonal marks termed windows, and uneven margins (Johnson 1985; Haglund 1992). Avian scavengers, dependent on beak morphology, are also capable of producing conical punctures on bone surfaces whilst pecking at soft tissue (Komar and Beattie 1998c). There are four main types of bite marks: pits, scores, punctures and furrows (Binford 1981; Haynes 1983a; Haglund *et al*. 1988; Milner and Smith 1989; Coard 2007). 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 domestic dog (Hillson 2005; Murmann *et al*. 2006), thus these three species are the focus of this study.

Pits are indentations in the bone surface made by individual tooth cusps which do not penetrate the bone cortex (Haglund *et al*. 1988; Milner and Smith 1989; Pickering *et al*. 2004; Coard 2007). Punctures are often irregular shaped marks caused by a tooth penetrating cortical bone (Haglund *et al*. 1988; Milner and Smith 1989). The canine and carnassial teeth (fourth upper premolar, first lower molar), which are used in the shearing of soft tissue, can puncture bone (Haynes 1983a; Haglund *et al*. 1988; Hillson 2005). 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 (Haglund *et al*. 1988). 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 (Selvaggio 1994; Coard 2007).

Previous studies have used the dimensional data of bite marks to identify the general size of scavengers (small, medium, large) and occasionally taxa (Haynes 1983a; Andrews and Fernandez-Jalvo 1997; Dominguez-Rodrigo & Piqueras 2003; Pickering *et al*. 2004; Coard 2007; Delaney-Rivera *et al*. 2009; Andrés *et al*. 2012). 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 (Haynes 1983a; Andrews and Fernandez-Jalvo 1997; Domínguez-Rodrigo and Piqueras 2003; Pickering *et al*. 2004; Andrés *et al*. 2012; Coard 2007; Delaney-Rivera *et al*. 2009). The majority of archaeological, zooarchaeological, and forensic studies that have analysed 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 (Haynes 1980, 1983a; D'Andrea and Gotthardt 1984; Haglund *et al*. 1988; Milner and Smith 1989; Andrews and Fernandez-Jalvo 1997; Pickering 2001; Selvaggio and Wilder 2001; Dominguez-Rodrigo & Piqueras 2003; Pickering *et al*. 2004; Schulz *et al*. 2006; Coard 2007; Delaney-Rivera *et al*. 2009; Andrés *et al*. 2012). In contrast, research into the dimensional data of bite marks produced by foxes is limited and, even more so, that of badgers (Coard 2007; Delaney-Rivera *et al*. 2009; Andrés *et al*. 2012).

Although quantitative methods of analyses of bite marks have been used in a variety of fields of study, the majority of forensic studies on scavenger modification of skeletal remains tend to use qualitative methods to describe modifications (Haglund *et al*. 1988; Milner and Smith 1989) (Table 1.2). The focus of such forensic studies has not been towards identifying a scavenger species or the species-typical scavenging behaviour and patterns but has instead focused on the general characterisation of bone modification produced by a biological family of scavengers (e.g. Canidae) (Haglund *et al*. 1988; Milner and Smith 1989) (Table 1.2). This generalisation of bone modification and carcass utilisation of a single biological family assumes that all scavenger species within that family share the same scavenging behaviour and patterns regardless of different factors, such as environment, region, weather, topography, trophic resources, and intra- and inter-species interactions. Moreover, that regardless of such factors scavenger species within the same family will 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 behaviours and patterns, as well as be differently affected by various factors, which can affect the type of bite marks produced on bone surfaces (see Chapter 3-4) (Murmann *et al*. 2006; Gidna *et al*. 2013).

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

- Hypothesis 1) In Chapter 3 and 4, wild red foxes were observed as the most frequent mammalian scavengers of surface deposited deer (*Cervus nippon*; *Capreolus capreolus*). The scavenging behaviours of captive red foxes toward pig (*Sus scrofa*) bones were also observed for comparison in Chapter 4. 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 behaviour and patterns dependent on a variety of factors, such as trophic resources, environment, and region (Doncaster and Macdonald 1991; Roper *et al*. 2003; Gidna *et al*. 2013). Additionally, differences in scavenging behaviour can potentially exist between captive and wild scavengers of the same species (McPhee 2003; Vickery and Mason 2003; Gidna *et al*. 2013). Therefore, Hypothesis 1 predicts that the bite mark dimensions of captive and wild red fox will not be significantly different.;
- Hypothesis 2) The dentition of domestic dogs is also considered within this chapter because other than 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 (i.e. scores, pits, punctures) (Haglund *et al*. 1988; Corbet and Harris 1991; Alderton 1994; Dominguez-Rodrigo & Piqueras 2003; Sterry 2005; Wroe *et al*. 2005; Christiansen and Wroe 2007; Andrés *et al*. 2012; AKC 2013) (Figure 5.1). 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 behaviour and

patterns (Schmitz and Lavigne 1987; Corbet and Harris 1991; Hillson 2005; Sterry 2005; Wroe *et al*. 2005; Murmann *et al*. 2006; Chapter 4). 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 (Hillson 2005) that are capable of producing the same types of bite marks (i.e. score, pit, puncture). However, the tooth morphology of the Eurasian badger and these canids differs, such that the dentition of the badger includes generally broader tooth cusps and molars with a more scallop-shaped surface than those of canids (Baryshnikov *et al*. 2003; Hillson 2005). Moreover, the scavenging behaviour and patterns, jaw muscle strength, body size, and bite force of the Eurasian badger, red fox, and domestic dog are different (Schmitz and Lavigne 1987; Corbet and Harris 1991; Hillson 2005; Sterry 2005; Wroe *et al*. 2005; Chapter 4). 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 chapter 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.

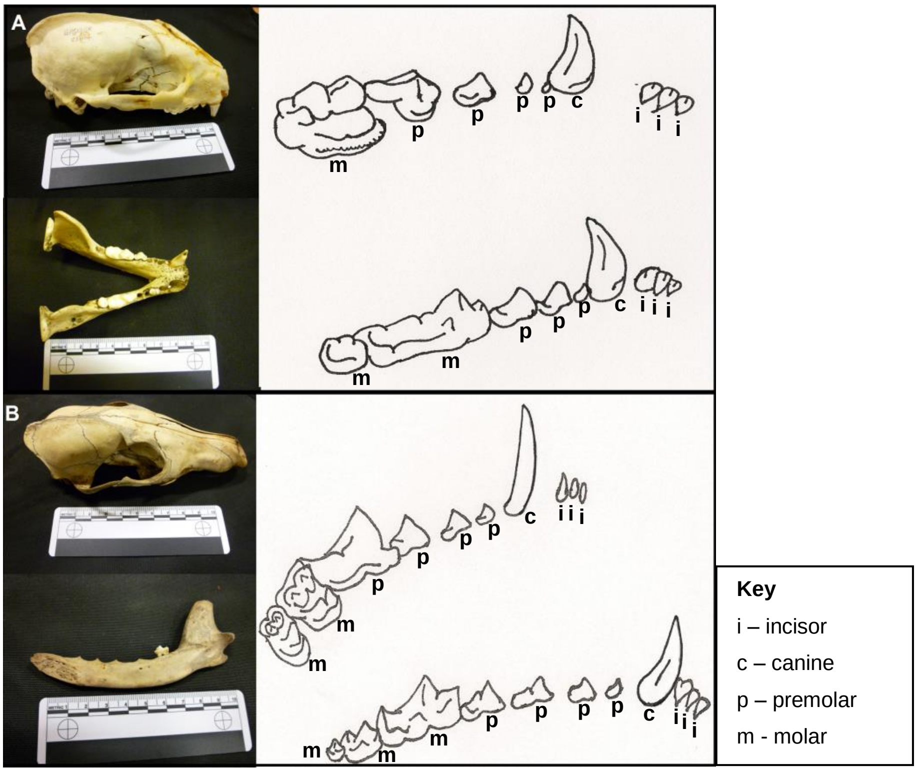

Figure 5.1. Crania and mandibles, as well as the left upper and lower dentitions for Eurasian badgers (A) and red foxes (B).

5.3 MATERIALS AND METHODS

A sample of scavenged deer bones were obtained from six deer carcasses surface deposited in a mixed temperate woodland in the U.K. The deer were observed being repeatedly scavenged by at least six wild foxes at different times over a total period of 210 days (Chapter 3-4). Wild Eurasian badgers were observed near the deer but did not scavenge any remains, whereas captive badgers were observed scavenging fresh and dry bones (Chapter 4). Deer 2 was the only deer scavenged by a domestic dog, which only lasted for a total time of one hour and 30 minutes (Chapter 4). Deer 1 was gralloched (no head, no hooves, and no internal organs) by the deer stalker but was still used in this study and its remaining skeleton was analysed. The sample size of marks obtained from scavenged deer included 376 pits, 57 punctures, and 59 scores.

Bite marks on bones were also obtained from feeding experiments conducted with captive foxes, captive badgers, and domestic dogs. Domestic dogs were divided between five small-sized dogs (Cairn Terrier 23 cm – 33 cm height, 4.5 kg – 3.6 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) and five Staffordshire Bull terriers (36 cm – 42 cm height;10 kg – 17 kg weight) (AKC 2013), which was the only breed of dog recorded scavenging from a deer (Chapter 4). Since foxes have a smaller body size (35 cm – 50 cm height; 5 kg – 10 kg weight) and bite force relative to Staffordshire bull terriers (Corbet and Harris 1991; Wroe *et al*. 2005; Christiansen and Wroe 2007), smaller-sized dogs were added to the study for further comparison to foxes. These additional four samples of bones allowed for the dimensional data of bite marks to be compared between captive and wild scavengers, as well as scavenger species. 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 (Figure 5.2) 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 fragment bones (Chapter 4). The sample of bones scavenged by a total of seven captive foxes consisted of marks was seven pits, 31 scores, and two punctures. A total of three captive 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 Staffordshire bull terriers produced a sample of seven pits, seven scores, and no punctures.

Figure 5.2. The dry roast ham bones given to captive scavengers and domestic dogs.

A sample of domestic cow (Bovidae) bones, recovered from a bog in a woodland environment in Sutton Park, Birmingham, U.K., scavenged by an unknown taphonomic agent was obtained for comparison to the ranges of marks found on the deer bones and bones scavenged by captive scavengers and domestic dog. The sample size included 55 pits, 31 punctures, and 30 scores. The sample of scavenged cow bones acted as a blind sample to assess the use of bite mark analysis in the identification of a scavenger species.

Bite marks were initially measured with use of the Alicona 3D InfiniteFocus imaging microscope (IFM) with the aim of measuring the length, breadth and depth of marks. The Alicona IFM allows for a three-dimensional cross-section image, its accompanying computer software produces an accurate profile analysis of both the optical image and three-dimensional image captured, thus allowing depth measurements. However, the Alicona IFM was unable to capture images of modern bones due to the reflective properties of bone surfaces. The Alicona IFM did work for the measurement of marks on cow bones but those bones were older than 12 months heavily stained from soil and decomposition, whereas, deer bones were a maximum 210 days old and had been subjected to maceration after their recovery for health and safety reasons (Figure 5.3). Various anti-reflective sprays were tested on macerated pig bones but the Alicona IFM was unable to capture any images.

Other options would have required a coating on the deer bones which would have damaged the bone surfaces in both colour and potentially texture. The Alicona IFM can be of great use in the analyses of archaeological bones but is not time- or cost-effective in a forensic context where forensic scientists and investigators are often constrained by time and budgets. Likewise, the requirement of anti-reflective sprays or coatings could damage the quality of bone surfaces, which may be disadvantageous if other forensic tests are required. Therefore, all bite marks within this study were instead identified by the naked eye and hand lens (2-6x) measured with a handheld digital calliper.

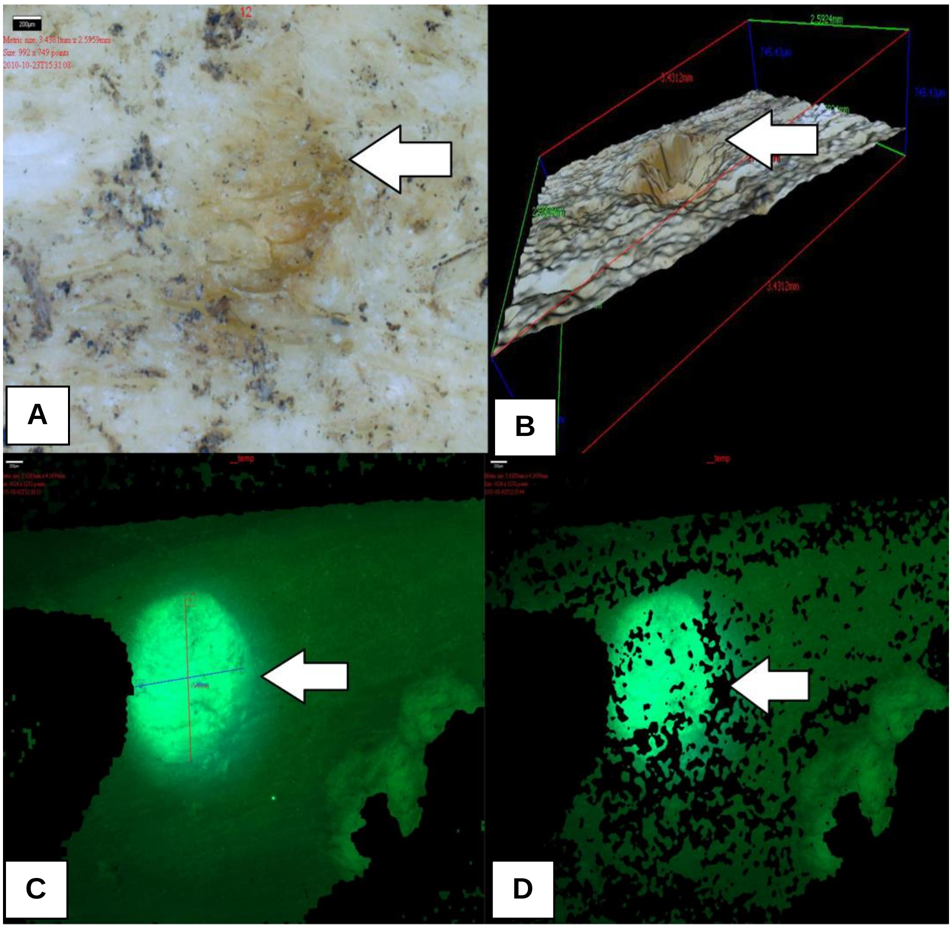

Figure 5.3. An optical image of a pit mark (see arrow) on a rib from the cow sample was captured using the Alicona IFM (A). The same pit mark from the cow sample in 3D format via the Alicona IFM (B). The picture shows the poor quality of optical images of modern and cleaned deer bones as captured by the Alicona IFM; the arrow points towards a pit on a deer rib (C). The 3D image of the same pit (see arrow) on the deer bone via the Alicona IFM (D).

The bite marks on deer and cow bones were not divided between epiphyseal and diaphyseal ends because bite marks were analysed on bones from the entire 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, cow and pig bones could be compared. The maximum length and maximum breadth of each mark were measured using the digital callipers. 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, score breadths, puncture lengths, and puncture breadths. This research also presents the analyses of pits, scores, and punctures for comparison with previous bite mark studies which focused on these mark types (Coard *et al*. 2007; Delaney-Rivera *et al*. 2009; Andrés *et al*. 2012). 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 (0.05/5= .01 level of significance regarding pits and scores; 0.05/2= .025 level of significance for punctures) were applied to the Mann-Whitney tests to avoid inflating the Type I error. All statistics were conducted with PASW Statistics version 18. In addition to the dimensional data obtained, each visually inspected bone was classified from 1-3, as adapted from Janjua and Rogers' (2008) levels of scavenging, to provide a general description of the changes to bone surfaces caused by scavengers (Table 5.1). This research also presents the analyses of pits, scores, and punctures for

Table 5.1. The levels of scavenging used to give a general description of the overall appearance of scavenged bones, as based on Janjua and Rogers (2008).

	Level of Scavenging
1	Mild Scavenging (bite marks on bone and both ends present on the bone)
2	Moderate Scavenging (bite marks on bone and one end of the bone chewed off)
3	Extensive Scavenging (bite marks on bone and/or both ends of bone removed)

5.4 RESULTS

See Appendix V for images of all scavenged bones from this study.

5.4.1 Deer

For the deer sample, 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 5.2). Innominates had the highest occurrence of marks (*n*= 148, 30.08%) (Table 5.2). Regarding long bones, marks were found in a higher quantity on lower limbs than front limbs (Table 5.2). Damage to long bones included not only marks but also fracturing and fragmentation at epiphyseal and diaphyseal ends (Figure 5.4). Marks were found on all areas of long bones, including furrowing on epiphyseal ends (Figure 5.5-5.6). Ribs were often fragmented and had more marks located at sternal ends (Figure 5.7). Innominates had a wider variety of marks and damage with punctures commonly at the ilium or acetabulum and pits along the iliac crest and ischial tuberosity (Figure 5.8). Marks and fragmentation on vertebrae were common at the spinous process, laminae, and transverse processes (Figure 5.9). The majority of marks and fragmentation on scapulae were observed at the medial border (Figure 5.10). Teeth were frequently recovered undamaged and still with mandibles which were not extensively scavenged apart from the coronoid process or condyle (Figure 5.11). All other scavenged bones were found to have marks at a wide variety of locations. Bite marks occurred most frequently on bones described as fitting the criteria of a level two of scavenging (47.09%) (Table 5.3-5.4).

Pits (*n*= 376, 76.42%) were the most commonly found type of bite mark on all deer bone surfaces (Table 5.4). 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 5.5-5.6). The mean length of pits was 1.46 mm and the mean breadth was 0.92 mm (Table 5.5-5.6). The mean length of punctures was 2.83 mm and the mean breadth was 1.94 mm (Table 5.5-5.6). The mean length of scores was 6.03 mm and the mean breadth was 0.96 mm (Table 5.5-5.6).

Figure 5.4. An extensively scavenged deer tibia with a longitudinal fracture.

Figure 5.5. A deer metatarsal with numerous pits on the shaft and ends of the bone (see arrows).

Figure 5.6. A deer femur with furrowing at the proximal end (see arrows).

Figure 5.7. Deer ribs with marks and fracturing at the sternal ends.

Figure 5.8. Punctures (see arrows) found at the acetabulum and pubis.

Figure 5.9. Five articulated deer lumbar vertebrae show scavenging damage at the spinous and transverse processes.

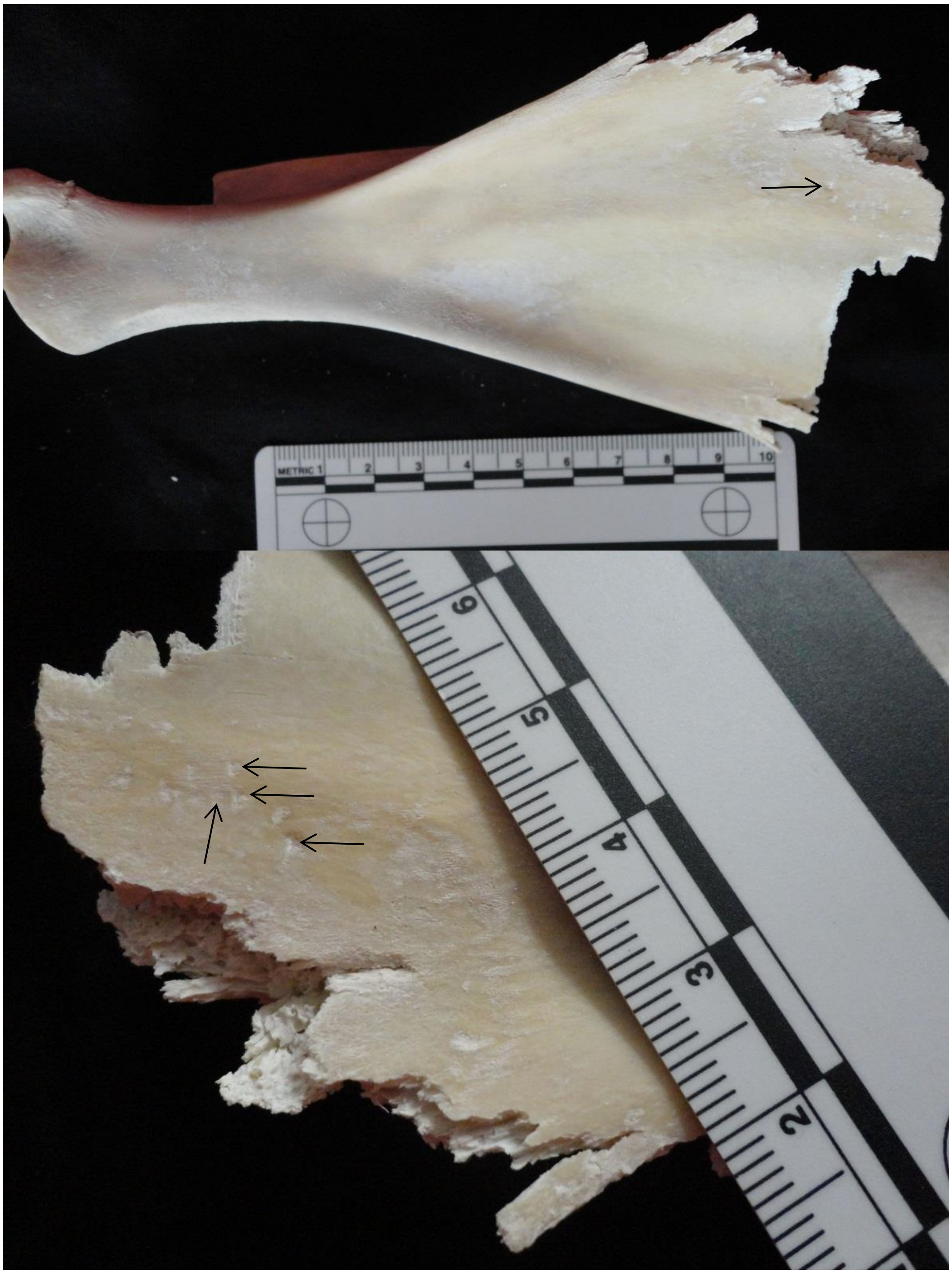

Figure 5.10. The deer scapula shows a concentration of scavenging damage along the medial border with pit marks (see arrows) and fracturing.

Figure 5.11. A deer mandible with all teeth still intact and scavenging limited to the coronoid process and condyle. Pits are visible on the coronoid process (see arrows).

Table 5.2. The number of bite marks found on each skeletal element of the deer sample of bones.

	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 Vertebrae	13	2.64
Thoracic Vertebrae	19	3.86
Lumbar Vertebrae	22	4.47
Innominates	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 5.3. The occurrence of all types of marks (pits, punctures, scores) within each level of scavenging per sample of bones.

Level of Scavenging	Deer Bones		Cow Bones		Captive Fox Scavenged Bones		Captive Badger Scavenged Bones		Staffordshire Dog Scavenged Bones		Small Dog Scavenged Bones		Total	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%
1	90	18.04	31	26.72	12	30.00	8	72.73	7	50.00	19	73.08	167	23.89
2	235	47.09	70	60.34	21	52.50	2	18.18	0	0	7	26.92	335	47.93
3	167	33.47	15	12.93	7	17.50	1	9.09	7	50.00	0	0	197	28.18
Total	492		116		40		11		14		26		699	

Table 5.4. The different types of marks on deer bones were associated with the level of scavenging, based on Janjua and Rogers (2008), assigned to the bone on which it was found.

	Levels of Scavenging							
	1		2		3		Total	
Mark Type	N	%	N	%	N	%	N	%
Pits	81	21.54	168	44.68	127	33.78	376	76.42
Scores	8	13.56	37	62.71	14	23.73	59	11.99
Punctures	1	1.75	30	52.63	26	45.61	57	11.59
Total	90		235		167		492	

Table 5.5. The dimensional data for the length of marks on deer and cow bones, and samples of dry bones chewed by captive foxes, captive badgers, small dogs and Staffordshire Bull Terrier breed 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
Pit on Deer Bones	376	1.46	0.72	1.39-1.53		0.72	0.58	5.01
Pit on Cow Bones	55	2.20	1.75	1.73-2.68		0.86	0.07	7.31
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
Score on Deer Bones	59	6.03	2.83	5.29-6.77		0.42	1.94	13.92
Score on Cow Bones	30	11.41	7.35	8.66-14.15	0.32		1.25	27.89
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
Puncture on Deer Bones	57	2.83	1.23	2.50-3.16		0.87	0.15	6.01
Puncture on Cow Bones	31	2.47	1.34	1.98-2.96	0.81		1.07	6.97
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 5.6. The dimensional data for the breadth of marks on deer and cow bones, and samples of dry bones chewed by captive foxes, captive badgers, small dogs and Staffordshire Bull Terrier breed 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
Pit on Deer Bones	376	0.92	0.34	0.89-0.96		0.72	0.29	2.65
Pit on Cow Bones	55	1.13	0.74	0.93-1.33		0.86	0.04	2.87
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
Score on Deer Bones	59	0.96	0.65	0.79-1.13		0.42	0.35	4.56
Score on Cow Bones	30	1.43	0.61	1.20-1.66	0.32		0.36	3.37
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
Puncture on Deer Bones	57	1.94	0.84	1.71-2.16		0.87	0.70	4.26
Puncture on Cow Bones	31	1.45	0.75	1.21-1.76	0.81		0.21	3.50
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							

5.4.2 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 5.12). Marks were found most frequently on bones categorised as the second level of scavenging (52.50%) (Table 5.3). Scores (77.50%) were the most frequent type of bite mark found on the bones scavenged by captive foxes (Table 5.7). Pits and scores were visible on both the shaft and ends of bones but punctures were limited to ends (Figure 5.13).

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 5.5-5.6). The mean length of pits was 2.05 mm and the mean breadth was 1.48 mm (Table 5.5-5.6). The mean length of scores was 8.53 mm and the mean breadth was 1.07 mm (Table 5.5-5.6).

Figure 5.12. Dry pig bones scavenged by captive foxes had multiple furrows (see arrows) on the ends of bones where foxes have accessed the marrow cavity.

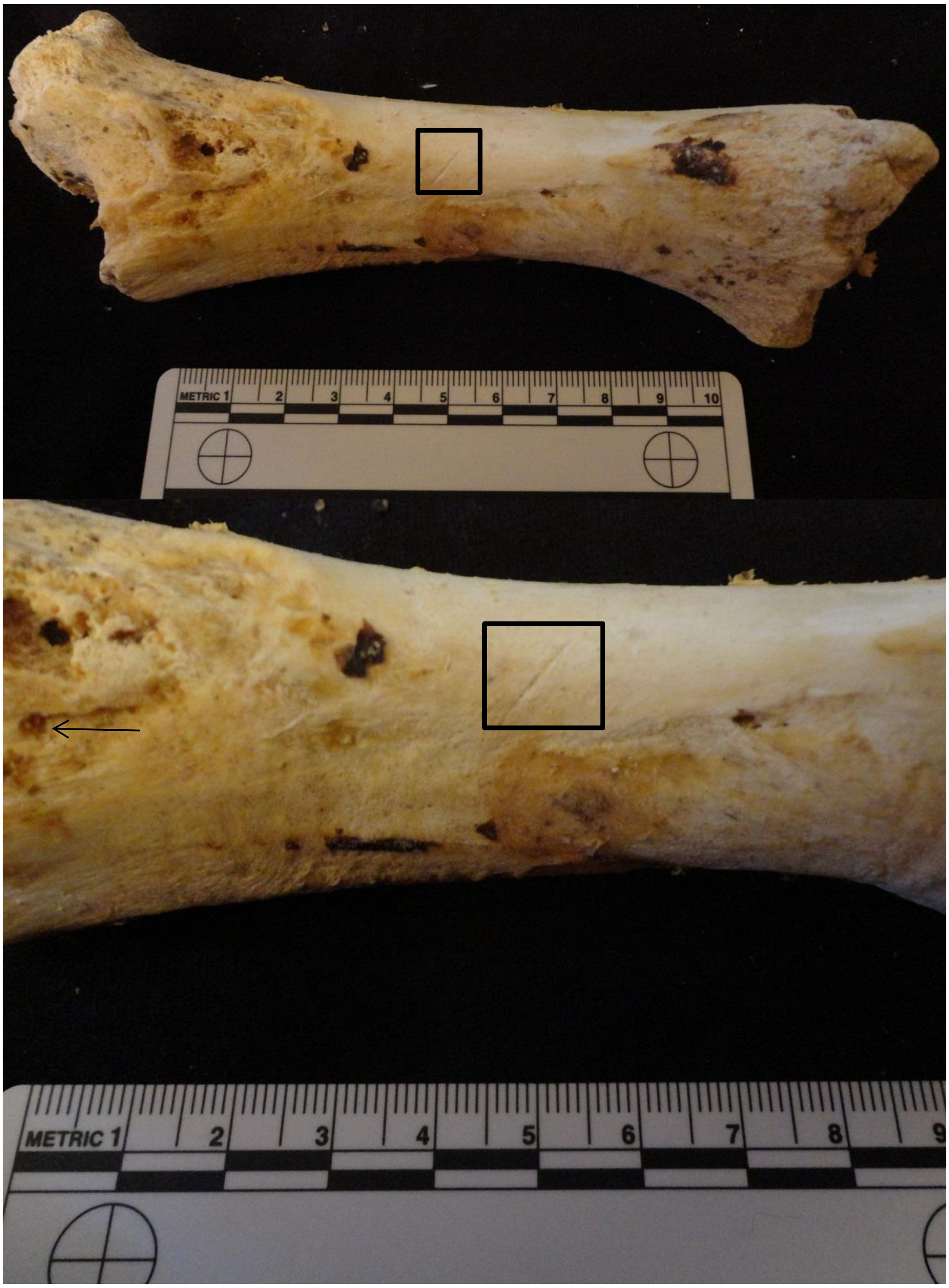

Figure 5.13. Dry bones scavenged by captive foxes were not fractured but did have punctures (see arrow) and score marks (see box).

Table 5.7. The different types of marks from the sample of bones scavenged by captive foxes were associated with a level of scavenging, based on Janjua and Rogers (2008), assigned to the bone on which it was found.

	Levels of Scavenging							
	1		2		3		Total	
Mark Type	N	%	N	%	N	%	N	%
Pits	1	14.29	3	42.86	3	42.86	7	17.50
Scores	11	35.48	16	51.61	4	12.90	31	77.50
Punctures	0	0	2	100.00	0	0	2	5.00
Total	12		21		7		40	

5.4.3 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 5.14). Most notably, heavily scavenged bones were coupled with extensive rodent gnaw marks on shafts (Figure 5.14). Overall, marks occurred most often on bones which were labelled as a level one of scavenging (72.73%) (Table 5.3, 5.8). The majority of marks on the bones were pits (81.82%) (Table 5.8). For pits, the relationship between the length and breadth was positive but not significant (r= .46, *p*= .11) (Table 5.5-5.6). The mean length of pits was 2.72 mm and the mean breadth was 2.00 mm (Table 5.5-5.6). 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 5.5-5.6). No punctures were found on the bones.

Table 5.8. The different types of marks from the sample of bones scavenged by captive badgers were associated with a level of scavenging, based on Janjua and Rogers (2008), assigned to the bone on which it was found.

	Levels of Scavenging							
	1		2		3		Total	
Mark Type	N	%	N	%	N	%	N	%
Pits	7	77.78	2	22.22	0	0	9	81.82
Scores	1	50.00	0	0	1	50.00	2	18.18
Punctures	0	0	0	0	0	0	0	0
Total	8		2		1		11	

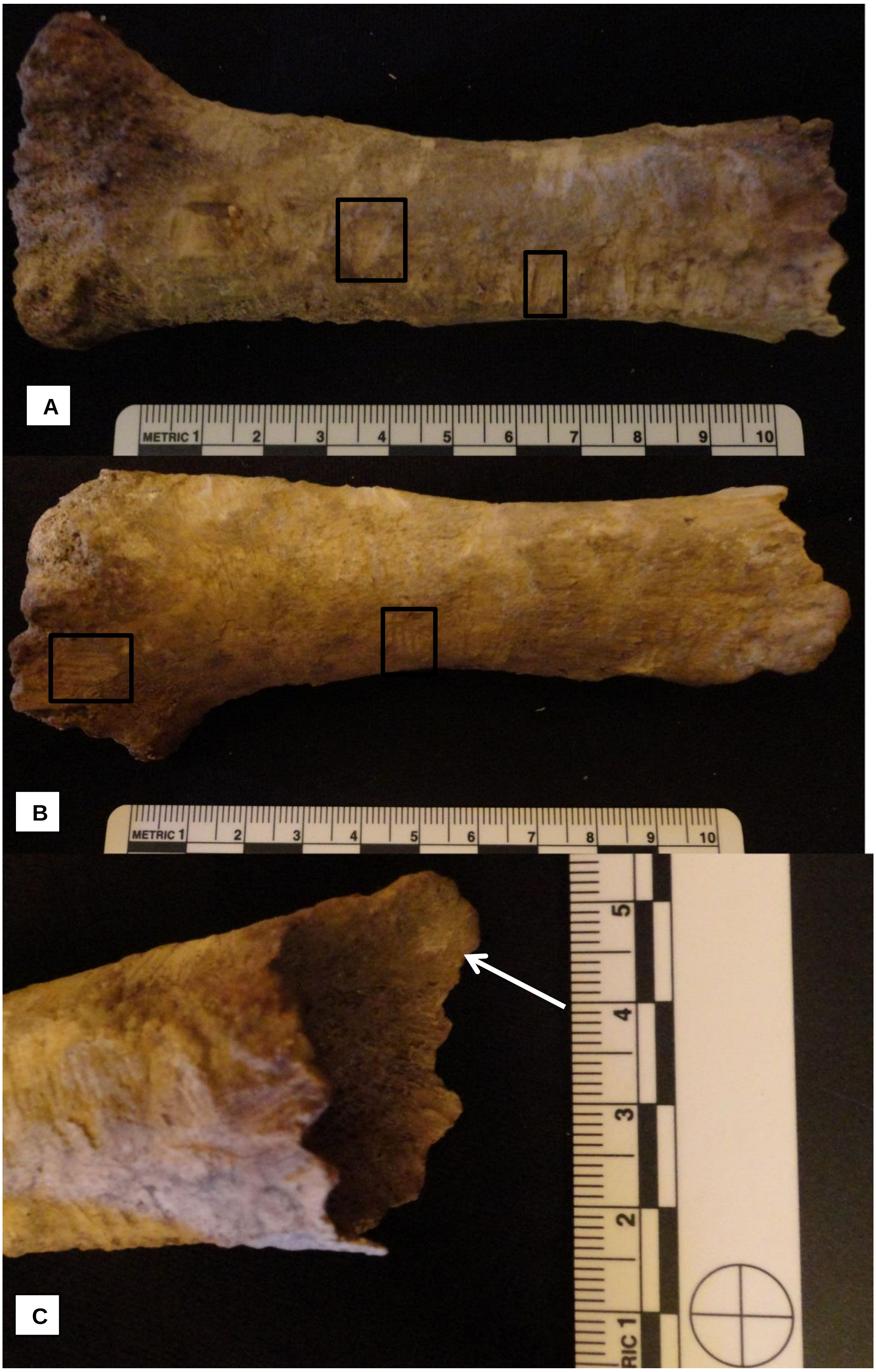

Figure 5.14. Dry pig bones scavenged by captive badgers had multiple rodent gnaw marks on shafts and ends (A,B). The ends of bones had heavy gnawing and signs of scooping (see arrow) where badgers accessed the marrow cavity (C).

5.4.4 Bones scavenged by small-sized domestic dogs

The bones scavenged by small-sized dogs varied between heavy fragmentation to just marks on bone surfaces (Figure 5.15). Bones were fractured along the shaft in the form of transverse and oblique fractures (Figure 5.15). Furrowing was present at the ends of bones but was not extensive. Marks were most frequently found on bones categorised as a level one of scavenging (73.08%) (Table 5.3). More specifically, scores were associated with bones at a level one of scavenging (83.33%) and pits with level one and two (50.00%) (Table 5.9). Scores were the most frequently occurring type of mark found on the bones (69.23%) (Table 5.9).The mean length of pits was 3.25 mm and the mean breadth was 1.88 mm (Table 5.5-5.6). 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 5.5-5.6). No punctures were observed for any of the bone scavenged by small-sized dogs.

Figure 5.15. Dry pig bones scavenged by small dogs varied between fracturing (A) and marks on both ends (B) and shafts (C).

Table 5.9. The different types of marks from the sample of bones scavenged by small-sized domestic dogs were associated with a level of scavenging, based on Janjua and Rogers (2008), assigned to the bone on which it was found.

	Levels of Scavenging							
	1		2		3		Total	
Mark Type	N	%	N	%	N	%	N	%
Pits	4	50.00	4	50.00	0	0	8	30.77
Scores	15	83.33	3	16.67	0	0	18	69.23
Punctures	0	0	0	0	0	0	0	0
Total	19		7		0		26	

5.4.5 Bones scavenged by large-sized domestic dogs: 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 5.16-5.18). In addition to transverse and oblique fractures, longitudinal fractures were present along shafts (Figure 5.18). The bones on which marks were located were equally categorised as level one and three (Table 5.3). However, pits were associated more often with bones labelled as three (71.43%) and scores with those at one (71.43%) (Table 5.10). Pits and scores were found in the same quantity on bones (n= 7) (Table 5.10). No punctures were found. Pits had a mean length of 2.95 mm and a mean breadth of 2.20 mm (Table 5.5-5.6). Scores had a mean length of 8.1 mm and a mean breadth of 1.50 mm (Table 5.5-5.6). 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).

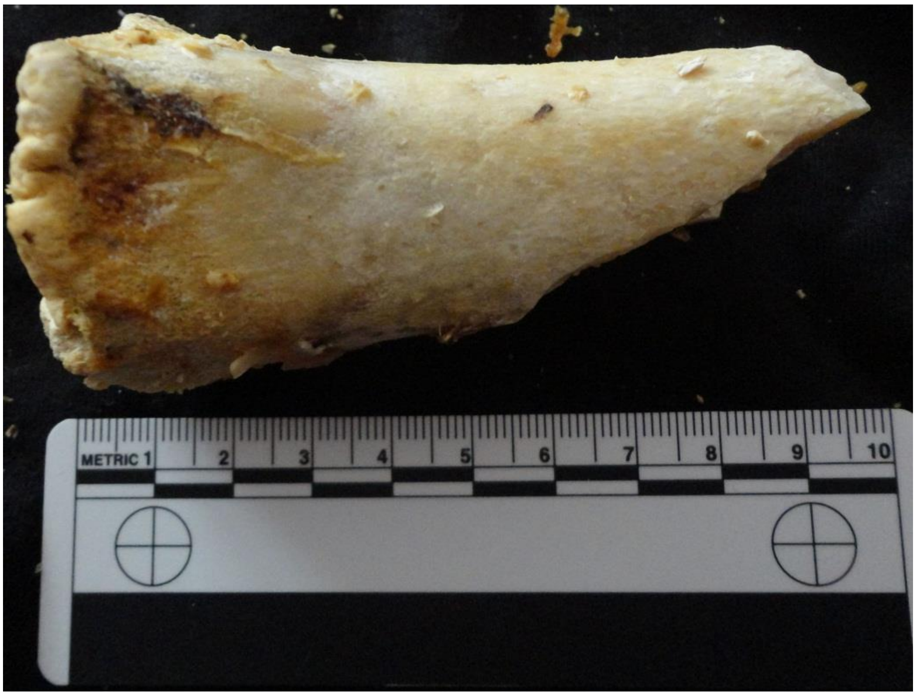

Figure 5.16. A dry pig bone fragmented by a Staffordshire bull terrier breed dog.

Figure 5.17. Staffordshire bull terrier breed dogs produced marks on bones such as scores on ends (see arrow).

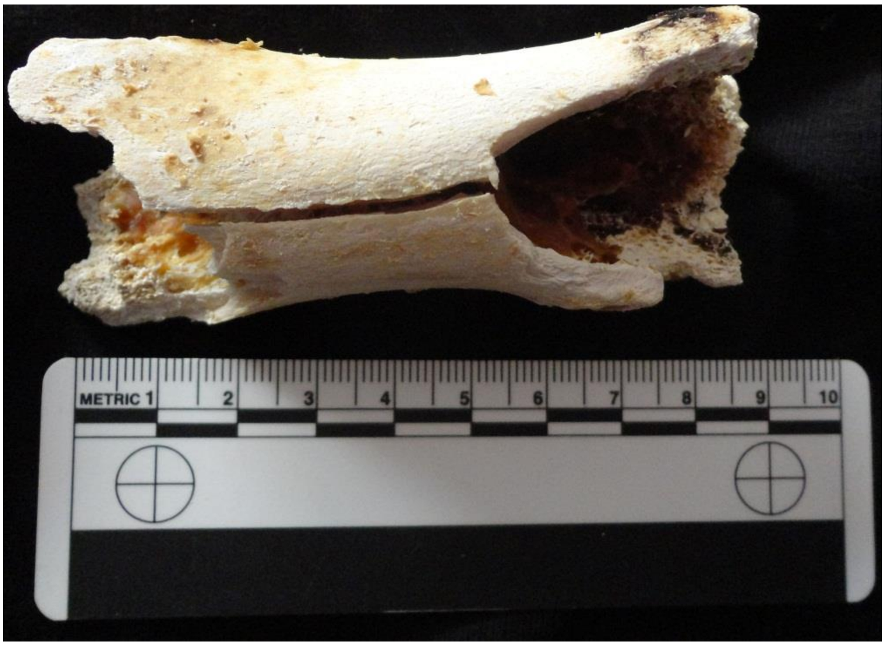

Figure 5.18. Staffordshire bull terrier breed dogs not only removed the ends of dry bones but also produced longitudinal fractures along shafts.

Table 5.10. The different types of marks from the sample of bones scavenged by Staffordshire bull terriers were associated with a level of scavenging, based on Janjua and Rogers (2008), assigned to the bone on which it was found.

	Levels of Scavenging							
	1		2		3		Total	
Mark Type	N	%	N	%	N	%	N	%
Pits	2	28.57	0	0	5	71.43	7	50.00
Scores	5	71.43	0	0	2	28.57	7	50.00
Punctures	0	0	0	0	0	0	0	0
Total	7				7		14	

5.4.6 Cow Bones

The skeletal elements of the cow sample which showed signs of scavenging were similar to that of the deer sample (Appendix V). Additionally, the areas on scapulae, ribs, and long bones where bite marks were most often located were similar to that of the deer bones. The cranium, mandible, and innominates were not available for analyses. The majority of bones with bite marks were found to be at a level two of scavenging (60.34%) (Table 5.3). Pits were the most frequent type of mark found on the cow bones (47.41%) (Table 5.11).

Pits had a mean length of 2.20 mm and mean breadth of 1.13 mm (Table 5.5-5.6). Punctures had a mean length of 2.47 mm and mean breadth of 1.49 mm (Table 5.5-5.6). Scores had a mean length of 11.41 mm and mean breadth of 1.43 mm (Table 5.5-5.6). The dimensions of the length and breadth of pits (r_s= .86, p<.001), punctures (r_s= .81, p<.001), and scores (r_s= .32, p= .04) all had positive and significant relationships (Table 5.5-5.6).

Table 5.11. The different types of marks from the sample of cow bones were associated with a level of scavenging, based on Janjua and Rogers (2008), assigned to the bone on which it was found.

	Levels of Scavenging							
	1		2		3		Total	
Mark Type	N	%	N	%	N	%	N	%
Pits	11	20.00	34	61.82	10	18.18	55	47.41
Scores	12	40.00	13	43.33	5	16.67	30	25.86
Punctures	8	25.81	23	74.19	0	0	31	26.72
Total	31		70		15		116	

5.4.7 Comparison of Samples of Scavenged Bones

5.4.7.1 Pit Dimensions

The range of the mean pit length of the bones scavenged by captive foxes, the deer bones, and the cow bones was < 2.5 mm and mean pit breadth was < 1.5 mm (Table 5.5-5.6). In contrast, the range of the mean pit length of bones scavenged by captive badgers, small-sized dogs, and Staffordshire dogs was > 2.5 mm and mean pit breadth was > 1.5 mm (Table 5.5-5.6). More specifically, the range of the mean pit length of small-sized dogs was > 3mm and mean pit breadth was < 2 mm.

Pit lengths from all samples were found to be significantly different, H (5) = 55.14, p<.001. The pit lengths found on the deer bones were significantly different to those on cow bones (U= 7589.00, r= -.15) and bones scavenged by captive badgers (U= 429.50, r= -.19), small-sized dogs (U= 219.50, r= -.1), and Staffordshire dogs (U= 186.00, r= -.20). The pit lengths produced by captive foxes (U= 628.50, r= -.12) were not significantly different to pit lengths on deer bones. Pit breadths were also significantly different for all samples (H (5) = 63.67, p<.001). The pit breadths on deer bones were significantly different to the bones scavenged by captive foxes (U= 430.00, r= -.15), captive badgers (U= 283.00, r= -.22), small-sized dogs (U= 133.50, r= -.22), and Staffordshire dogs (U = 61.00, r = -.22). However, pit breadths on deer and cow bones were not significantly different (U= 8352.00, r= -.11).

5.4.7.2 Score Dimensions

The range of all mean score lengths was > 3.5 mm, the majority of which were > 6 mm (Table 5.5). The range of mean score breadth of bones scavenged by captive foxes, captive badgers, the deer bones, and the cow bones was < 1.5 mm. The range of mean score breadth of bones scavenged by dogs was < 2 mm (Table 5.6). Score lengths and breadths from all samples proved to be significantly different (H (5) = 25.65, p<.001; H (5) = 35.70, p<.001). The score lengths on deer bones were significantly different to those on cow bones (U= 495.00, r= -.36) and 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= -.20) and Staffordshire dogs (U= 132.00, r= -.19). 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 cow bones (U= 384.50, r= -.43) and 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 Staffordshire dogs (U= 92.00, r= -.29).

5.4.7.3 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 and cow bones had a mean puncture length < 3 mm (Table 5.5). Similarly, the range of mean puncture breadth of bones scavenged by captive foxes was > 3mm. The range of mean puncture breadth for the deer bones and cow bones was < 2 mm (Table 5.6).

Puncture lengths from the bones scavenged by captive foxes, the deer bones, and the cow bones were found to be significantly different (H (2) = 7.31, p= .03). Puncture lengths on the deer bones were not significantly different to those on cow bones (U= 685.00, r= -.18) and bones scavenged by captive foxes (U= 7.00, r= -.27). The bones scavenged by captive foxes only had two punctures, thus the sample may not be a true comparison of puncture dimensions. Puncture breadths from the samples were also found to be significantly different (H (2) = 9.44, p= .009). Similar to puncture lengths, puncture breadths from deer bones were not significantly different to those on cow bones (U= 595.50, r= -.27) and bones scavenged by captive foxes (U= 18.50, r= -.21).

5.5 DISCUSSION

The extent of scavenging of bones in this study varied across three different levels of scavenging but was most prevalent at level two. The majority of scavenged bones thus had at least one damaged or removed epiphyseal end. 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 (Haynes 1980,1983a, 1983b;

D'Andrea and Gotthardt 1984; Johnson 1985; Haglund *et al*. 1988, 1989; Horwitz and Smith 1988; Milner and Smith 1989; Patel 1994; Pickering *et al*. 2004; Janjua and Rogers 2008; Andrés *et al*. 2012). 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 (Haynes 1980, 1982, 1983a, 1983b; Shipman 1981; D'Andrea and Gotthardt 1984; Johnson 1985; Haglund *et al*. 1988; Milner and Smith 1989). However, scavenging behaviour and patterns causing bone modifications differs 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 behaviours).

5.5.1 Hypothesis 1

The bite mark dimensions of captive and wild red foxes were predicted not to be significantly different for all types of bite marks. However, the differences between bite mark dimensions of wild and captive foxes were not uniform for all bite mark types. The only bite mark dimensions which were not significantly different were for punctures but the sample size of punctures produced by captive foxes was very low.

Ideally, the wild and captive scavengers used in this study would have been given the same species and condition of bones to scavenge but this was not possible for health and safety reasons as aforementioned. 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 (Nicholson 1992; Sauer 1998; Weiberg and Wescott 2008). In contrast, bone that has dried due to weathering (e.g. sun bleaching), burning, boiling, or roasting will lose its tensile strength and pliability through the depletion of collagen and fluids (Nicholson 1992; Sauer 1998; Weiberg and Wescott 2008). 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, Chapter 3 and 4 indicated that remains initially deposited as fresh can be further scavenged and modified when skeletonised, so it is important to also analyse bite marks produced on dry bones.

The pit lengths produced by wild foxes on deer bones and those produced by captive foxes on dry pig bones were not significantly different, whereas pit breadths 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 breadths produced by the captive and wild foxes is 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 moulding 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 behaviour 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 teeth and any dental problems because they are cared for by keepers.

The score lengths produced by these wild and captive foxes were significantly different but score breadths were not significantly different. Scores have the potential for the most variability in their dimensions because they are the result of a tooth sliding across the bone surface (Selvaggio 1994; Coard 2007). 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 the scavengers' environments, such that there is less competition for food within a captive 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 puncture lengths and breadths caused by the wild and captive foxes were not significantly different. The number of punctures present on the dry bones scavenged by captive foxes was much less than those on the deer bones scavenged by wild foxes. 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 behaviours between the captive and wild scavengers. In Chapter 4, the captive foxes were observed scavenging less frequently than the wild foxes because their diet consisted of regular feeding of more desirable foods by keepers. 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 (Henry 1977; Caraeu *et al*. 2007). 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 affect of the foxes being fed a regular diet by keepers.

5.5.2 Hypothesis 2

The bite mark dimensions of captive and wild red foxes were expected to be smaller than marks produced by domestic dogs that were of equal or larger body size to the fox. The mean length and breadth of pits and the mean score breadth produced by wild foxes on deer bones (1.46 mm, 0.92 mm; 0.96 mm) and captive foxes on dry pig bones (2.05 mm, 1.48 mm; 1.07 mm) were smaller than those of the larger-sized dogs (2.95 mm, 2.20 mm; 1.50 mm), specifically Staffordshire bull terriers, and smaller-sized dogs (3.25 mm, 1.88 mm; 1.91 mm). The mean score length of captive foxes (8.53 mm) was larger than that of large-sized dogs (8.10 mm), whereas the length on deer bones was smaller (6.03 mm). The score length has the most variability in its length because it is caused by a tooth sliding across the bone surface, thus it is not the most reliable type of bite mark in 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 is a result of their tooth cusp morphology, jaw size, and bite force (Hillson 2005; Wroe *et al*. 2005; Christiansen and Wroe 2007). The bite force of domestic dogs is generally greater than the red fox (Wroe *et al*. 2005; Christiansen and Wroe 2007) but foxes are capable of completely scavenging, disarticulating, and fragmenting a whole deer carcass (Chapter 4). 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 (Murmann *et al*. 2006).

Interestingly, the mean length and breadth of scores and the mean pit length of marks from the small-sized dogs (9.75 mm, 1.91 mm; 3.25 mm) were larger than the marks of the large-sized dogs (8.10 mm, 1.50 mm; 2.95 mm). The sample of bones scavenged by the large-sized dogs 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 large-sized dog scavenging, whereas the sample from the small-sized dogs consisted of more complete bones with more marks. In comparison to the larger dogs, the smaller dogs would have less bite force and smaller tooth morphology which would have affected their scavenging behaviour 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.

5.5.3 Hypothesis 3

The bite mark dimensions of captive Eurasian badgers were predicted to be greater than the dimensions created by wild and captive red foxes and large- and small-sized domestic dogs. The bite mark dimensions of badgers were only 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 (Lee and Mill 2004; Wroe *et al*. 2005). 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 large-sized dogs 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 (Lee and Mill 2004; Wroe *et al*. 2005; Hillson 2005).

The dimensions of scores produced by the badgers were also smaller than those of the captive and wild red foxes, and large- and small-sized 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.

5.5.4 Unknown Scavenger: cow bones

The scavenged cow bones were recovered as surface deposits in a similar woodland environment within the U.K. as the scavenged surface deposited deer bones in Chapter 4, thus both sets of remains had the potential to be exposed to similar scavenger species. Therefore, the dimensions of the bite marks found on the cow bones would be expected to not be significantly different to those created by wild foxes on deer bones. However, the cow bones were recovered within a bog-type area within the woodland, which may have influenced the scavenging behaviour and patterns of different scavenger species. In comparison to the deer remains, all skeletal remains of the cow were nearly whole despite scavenging efforts. The high recovery rate of the skeletal elements and the near complete elements of the cow remains suggests that the bone morphology and size may have limited the scavenger's scavenging abilities. Nevertheless, the general appearance of the scavenged cow bones, such as the location of the bite marks and the removal of some epiphyseal ends exposing the marrow cavity suggested canid scavenging.

The mean pit length, score length, and score breadth of the deer and cow bones were significantly different, whereas the mean pit breadth, puncture length, and puncture breadth were not significantly different. Furthermore, the mean pit length and breadth, and the mean score length and breadth found on cow bones (2.20 mm, 1.13 mm; 11.41 mm, 1.07 mm) were greater than those on the deer bones. The punctures on the deer bones (2.83 mm, 1.94 mm) had greater dimensions than the punctures on the cow bones (2.47 mm, 1.45 mm). Therefore, it is not possible to identify the species of the scavenger of the cow bones with full accuracy when relying only on the analysis of bite mark dimensions. The bite mark dimensions found on the cow bones, if produced by the same scavenger that scavenged the deer, were affected by the differences in the environment (e.g. bog), carcass size and bone morphology, which, in turn affected the scavenging behaviour and pattern of the scavenger. For example, the bog-type environment and carcass size may have limited which scavenger species could access and scavenge or remove the remains. Similarly, the scavengers' scavenging behaviour and modification of the cow bones could have been influenced by the proximity of the cow remains to scavengers' habitat or shelter (e.g. easy or difficult access), availability of trophic resources, intra- and inter-species aggression, seasonality, rate of decomposition of the cow (Gittleman and Harvey 1982; Lindström 1982; Doncaster and Macdonald 1991; Hiraldo et al. 1991; Cavallini 1996; Kauhala et al. 1998; Leckie et al. 1998; Revilla and Palomares 2001; Kjellander and Nordström 2003; Roper et al. 2003; Jarnemo 2004; Selva and Fortuna 2007). Thus, increasing or limiting the likelihood and available time for scavengers to produce bite marks.

5.5.5 Bite Mark Analysis: Identifying a Scavenger Species

Overall there was no consistent pattern in the comparisons of bite mark dimensions of each scavenger species. The type, dimension, location, and how bite marks are produced by scavengers will differ per scavenger species and their species-typical scavenging behaviour and patterns, which influence the following:

- 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.

Additionally, the types of bite marks and bite mark dimensions produced by scavenger species are influenced by the body size, dentition, jaw size, and bite force of the scavenger, as well as the carcass size, morphology of skeletal elements, and condition of remains. These results further emphasise the necessity to use bite mark analysis in conjunction with qualitative methods of analyses and knowledge of scavengers' species-typical scavenging behaviour and patterns in different environments with different factors in order to fully understand scavengers' effects on a set of remains. Nevertheless, it was possible to characterise scavenger species based on the ranges of the mean length and breadth of bite marks.

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 Staffordshire dogs 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 mean pit length and breadth of the cow bones, which had an unknown but suspected scavenger, was more similar to that of the bones scavenged by captive foxes than the deer bones scavenged by wild foxes. The range of mean length and breadth of pits found on the cow bones, 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 (2007), Delaney-Rivera *et al*. (2009), and Andrés *et al*. (2012).

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 (Wroe *et al*. 2005; Christiansen and Wroe 2007; Coard 2007; Delaney-Rivera *et al*. 2009;

Andrés *et al*. 2012; Gidna *et al*. 2013). 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, Staffordshire dogs, and captive badgers, as well as the lengths produced by foxes presented in Coard (2007), Delaney-Rivera *et al*. (2009), and Andrés *et al*. (2012). 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 Staffordshire dog samples (1.50 mm). No distinctions could be made between scavengers (e.g. individual scavenger or scavenger size) 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 (2007), Delaney-Rivera *et al*. (2009), and Andrés *et al*. (2012) were smaller than the range of score dimensions in this study.

The range of the mean length of punctures from the deer bones and the cow bones were both < 3 mm and the range of mean breadths were 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 skeletonised and/or dry bones (e.g. fire damage, weathering). Andrés *et al*. (2012) 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 (Chapter 4). 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.

5.6 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 scavenger species-typical scavenging behaviours and patterns, environment, region, topography, seasonality, scavenger size and dentition, carcass size, trophic resources, and the condition and deposition of remains (Chapter 4; Gidna *et al*. 2013; Delaney-Rivera *et al*. 2009). Using bite mark data juxtaposed with knowledge of species-typical scavenging behaviours 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 characterise 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 (Chapter 4).

Chapter 6

Applying knowledge of species-typical scavenging behaviour to the search and recovery of human remains

6.1 ABSTRACT

Forensic investigations involving suspected scavenging require a physical search of the scene and surrounding areas for human remains and deposit sites. Search and recovery methods used by police search officers are derived from different counter-terrorism methods such as winthropping, fingertip search, and systematic walking methods (e.g. grid, transecting lines). The goal of physical search methods in the search for human remains is to recover the highest percentage possible of a set of remains in order to make accurate identifications and interpretations. However, there is currently no standard procedure for the physical search of scavenged or scattered human remains. This study assessed how understanding scavenger species-typical scavenging behaviour and pattern could assist the search and recovery of scavenged skeletal remains. The recovery rate of police teams given scavenger species-typical scavenging information was greater than those without information. Understanding scavenging behaviour and patterns provide police search officers with key reference points and search radii pertinent to the more efficient and effective adaptation and organisation of physical search and recovery methods of scavenged remains.

6.2 INTRODUCTION

The scavenging, disarticulation, removal, and scattering of human remains by mammalian and avian scavengers can affect the search and recovery efforts of forensic professionals (Chapter 1, 2, 4; Haglund *et al*. 1989; Haglund and Reay 1993; Haglund 1997a; Listi *et al*. 2007). Crime scenes at which scavenging has occurred require a thorough physical search of the scene and surrounding area in an effort to recover skeletal remains for the purposes of identifying the deceased, the assessment of trauma, establishing manner of death, post-mortem interval (PMI), the interpretation of the deposition site, and any third party involvement (Haglund *et al*. 1989; Willey and Snyder 1989; Haglund and Reay 1993; Haglund 1997a; Byard *et al*. 2002).

Within forensic investigations, the standard procedure is for a forensic examination to be conducted prior to a physical search so that forensic evidence at a scene, such as blood, is not contaminated during a search (NCPE 2006). However, a physical search may occur before a forensic examination if the priority is to search for a location and not the victim or other evidence (NCPE 2006). A forensic examination is developed by the senior investigating officer (SIO) in conjunction with the crime scene manager (CSM) and crime scene coordinator (CSC), which is then carried out by scene of crime officers (SOCOs) who will record, photograph, recover and sample evidence (Hunter and Cox 2005; NCPE 2006). The search strategy of a physical search will also be developed by the SIO but with the aid of police search advisers (POLSAs) (NCPE 2005, 2006). PolSAs provide SIOs with pertinent information regarding the use of different search methods which will achieve the objectives of the search strategy in the most effective and efficient manner (NCPE 2005, 2006). Physical searches for forensic evidence or human remains can include non-specialist and specialist searchers (NCPE 2005, 2006). Non-specialist searchers are those not trained or licenced by the Association of Chief Police Officers (ACPO) or the National Centre for Policing Excellence (NCPE) and specialist searchers include those that are trained or licenced (NCPE 2005, 2006). Within the types of specialist searchers, PolSAs must renew their licencing and training with NCPE every three years, whilst other searchers must renew every year (NCPE). Specialist searchers operate a stand by status, such that depending on the risk level, time constraints, search parameters, objectives, and available resources per police force any number of searchers could be requested to perform a physical search (Tilley and Ford 1996; Hunter and Cox 2005; NCPE 2006). PolSAs, police search teams, and police search coordinators are trained by the NCPE in physical search methods for counter-terrorism (CT) and crime (e.g. drugs or homicide) (NCPE 2005, 2006). CT methods are used as the foundation for systematic searching in physical searches in counter-terrorism, crime, and homicide (NCPE 2005, 2006). Specialist searchers are trained to use systematic CT methods, like a fingertip search, to locate small materials when searching indoor locations (Brown *et al*. 2002; Blau 2004; NCPE 2005, 2006). For outdoor searches, CT methods are adapted for searching large areas in a systematic line or grid search (Komar 1999; Rooney *et al*. 2004; Hunter and Cox 2005; NCPE 2006). An additional CT search method available to officers is the Winthrop method. The National Search Adviser, C. Hope, states that "the Winthrop or reference point technique is a search tactic that can be considered by a search team in circumstances where they are deployed to search for items that a person would intend to have recovered, i.e. items [drugs, weapon] that are hidden but not lost" (personal communication, 09 May 2013). Although CT search methods are not based on the search of human remains, searchers are advised to apply these methods to the search and recovery of human remains (NCPE 2005, 2006).

Currently in the U.K., there are no standard search protocols regarding the search for scavenged or scattered human remains (NCPE 2005, 2006). SIOs and searchers involved in the design and implementation of physical searches are not knowledgeable in the scavenger species-typical scavenging behaviour and scatter patterns or scavenger-induced alteration to human remains, as evident by Chapter 2 and further emphasised by the National Search Adviser, C. Hope (personal communication, 09 May 2013). Nevertheless, Chapter 2 showed that scavenging within this region does occur and can affect physical searches. Chapter 2 has also shown that where SIOs and searchers have knowledge of scavenging in this region it is limited, subjective, undervalued, or based on potentially incorrect anecdotal evidence.

Prior to this study, the adaptation and application of CT methods, such as line, grid, and fingertip methods, to the physical search and recovery of scavenged human remains has not been assessed. Additionally, the Winthrop method has not been previously applied to physical searches involving scavenged human remains. The scavenger of interest in this chapter is the red fox (*Vulpes vulpes*) because it is the wild scavenger, within this region, which causes the most damage and modification to surface deposited human remains (Chapter 3 – 4). Foxes can modify and heavily fragment bone surfaces, as well as disarticulate, remove, and scatter skeletal remains (Chapter 4 – 5). This chapter aims to analyse whether or not providing police with information on the scavenging behaviour and pattern of foxes can enhance search and recovery efforts for scavenged remains.

6.3 MATERIALS AND METHODS

An experiment was conducted in two locations, Kent and Dorset, U. K., and on two separate days (27/02/2012; 12/06/2012). In total, four different 10 m x 10 m grid sites and 42 police officers (two constabularies) were used for this study. Within each site there was a mix of short, thick and high vegetation (e.g. grass, weeds, shrubs, bramble, ivy, and tussocks), small to large trees, and tree stumps (Figure 6.1). Inclusive of 0 m, flags of opposing colour were placed at every 0.5 m along the outline of the grid to assist searchers in walking in a grid search pattern (following transect lines) (Figure 6.1-6.2).

Figure 6.1. One of the grid sites in Dorset, U.K.

Figure 6.2. One of the grid sites in Kent, U.K.

Each grid contained a total of 24 bone fragments (Figure 6.3). Half of the fragments were c. 4 cm (large) and the other half were c. 2 cm (small) (Figure 6.3). Bones were fragmented to reflect the small size of bones scavenged by foxes. The bones were macerated prior to the experiment for health and safety reasons. Additionally, bones were lightly stained with coffee to lessen the bright appearance caused by maceration and to recreate the appearance of skeletal remains that have been exposed to decomposing soft tissue and fluids. Bones were placed in locations associated with red fox scavenging and scatter patterns (Chapter 4) (near trees, within thick vegetation) and locations not associated with fox scavenging, termed as random, within each grid. The arrangement of bones within each grid was as follows: two large bones buried near trees, two large bones buried within thick vegetation, two bones buried in random locations (Table 6.1). This was repeated for large bones deposited on the ground surface, buried small bones, and small bones deposited on the ground surface (Figure 6.4-6.7). There were many locations of thick vegetation and trees within each site, thus there were also fox and non-fox associated areas within each grid that did not have bones deposited. Plans were drawn showing the location of each bone and accompanying feature (e.g. tree) within each grid (Figure 6.4-6.7). When bones were deposited, the side of the bone which was not exposed had a number attached so that a searcher could record the number of the bone found. The numbering of bones also allowed for later analyses on the effects of size, location, and type of deposition in the recovery of the bones.

Figure 6.3. Small and large bone fragments.

Table 6.1. The locations of each numbered bone within each grid site for the experiments in Kent and Dorset, England, U.K.

	Kent								Dorset							
	Site 1				Site 2				Site 1				Site 2			
	4 cm		2 cm		4 cm		2 cm		4 cm		2 cm		4 cm		2 cm	
Feature	Buried	Surface	Buried	Surface	Buried	Surface	Buried	Surface	Buried	Surface	Buried	Surface	Buried	Surface	Buried	Surface
Tree	6	10	4	3	17	20	21	22	6	10	4	3	7	20	21	22
Tree	22	7	23	8	7	2	13	15	22	7	23	8	17	2	13	15
Thick Vegetation	15	1	16	9	10	6	24	9	15	1	16	9	10	6	24	9
Thick Vegetation	5	13	14	17	12	11	4	5	5	13	14	17	12	11	4	5
Random	19	20	11	24	23	8	1	18	19	20	11	24	23	8	1	18
Random	2	12	21	18	19	3	16	14	2	12	21	18	19	3	16	14

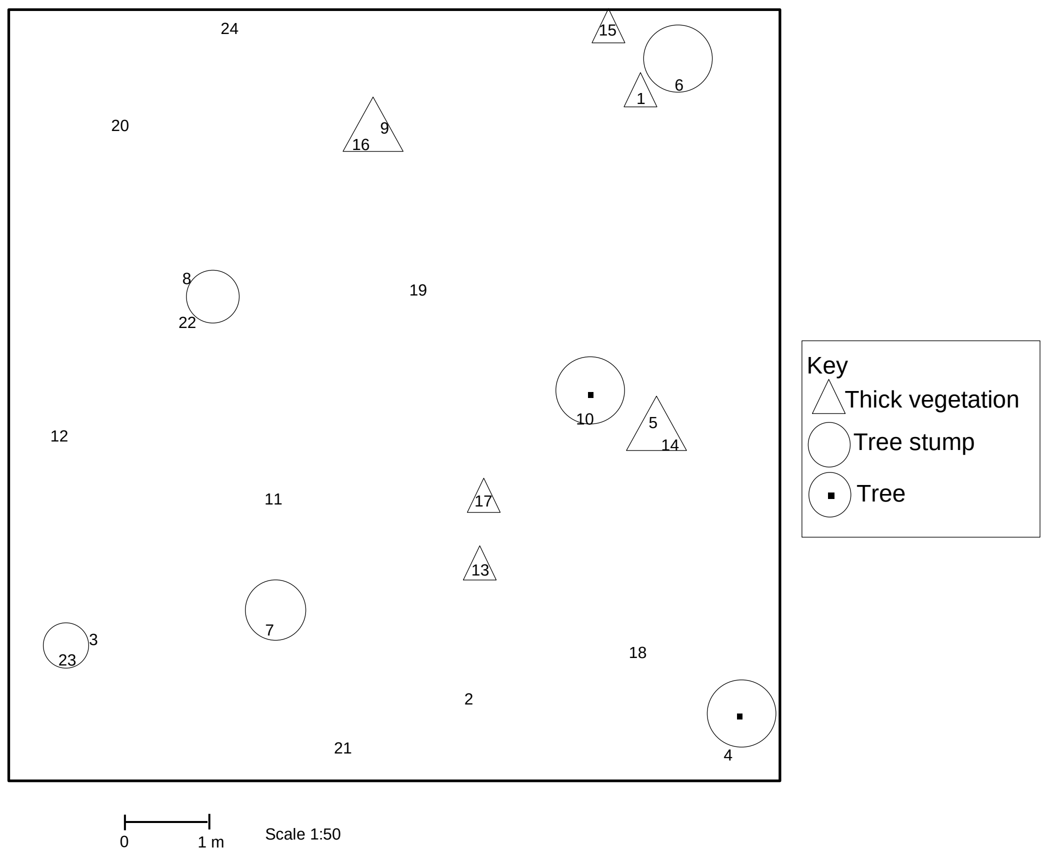

Figure 6.4. Plan drawing of the arrangement of bone fragments within Site 1 in Kent.

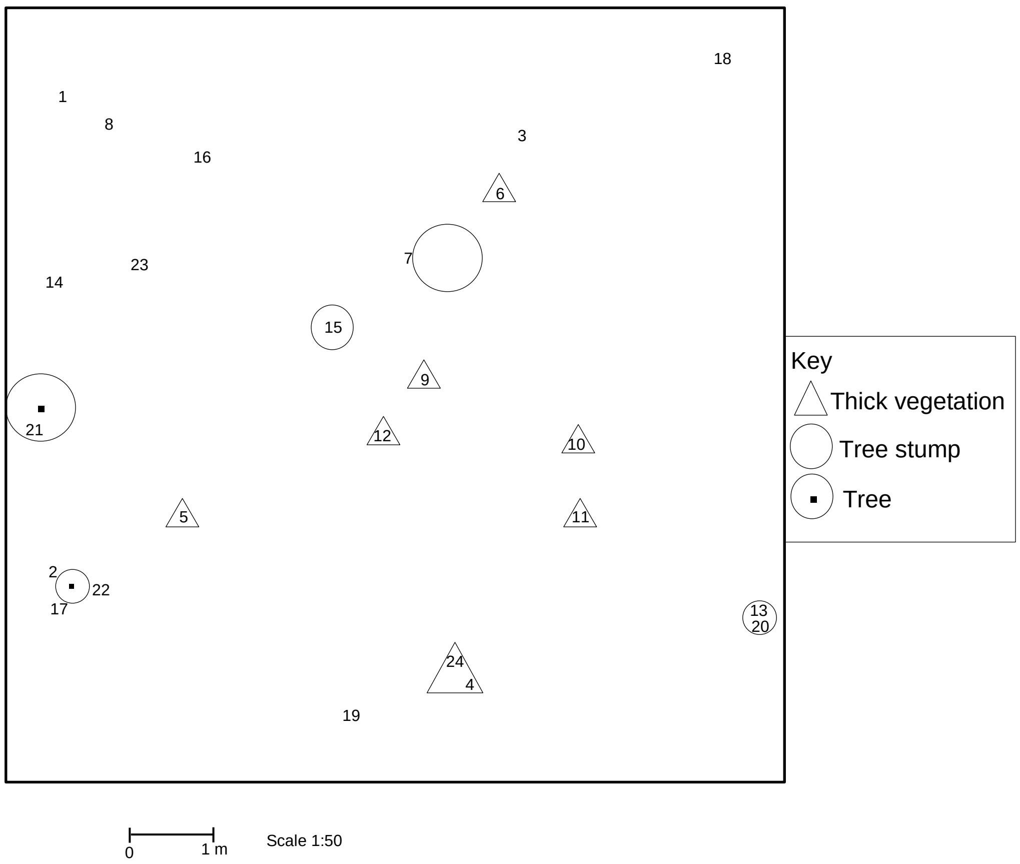

Figure 6.5. Plan drawing of the arrangement of bone fragments within Site 2 in Kent.

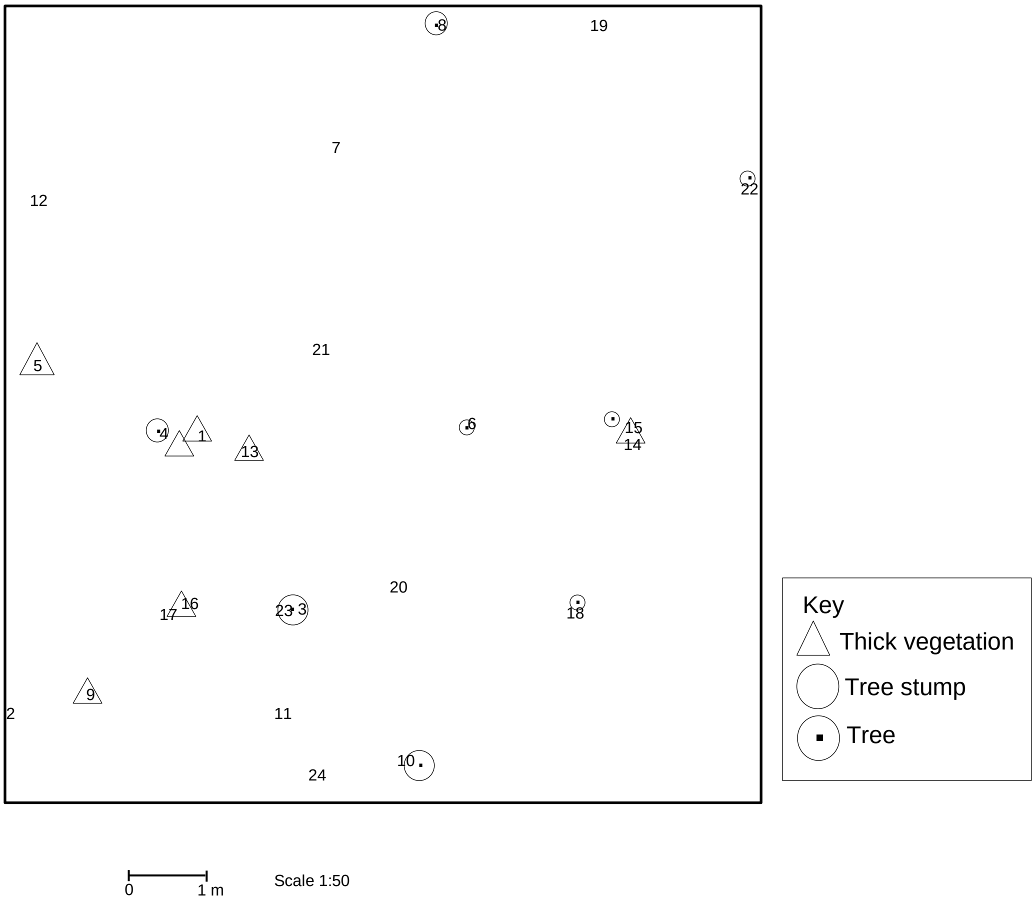

Figure 6.6. Plan drawing of the arrangement of bone fragments within Site 1 in Dorset.

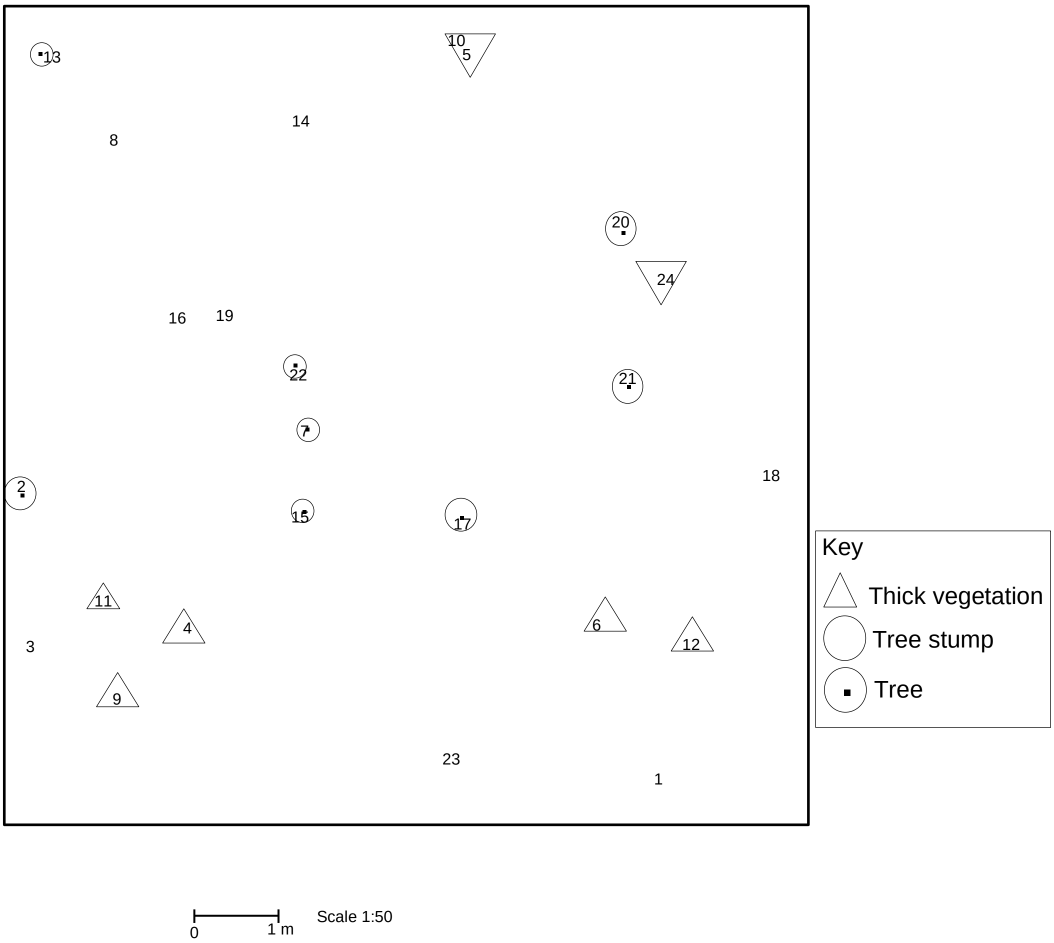

Figure 6.7. Plan drawing of the arrangement of bone fragments within Site 2 in Dorset.

The first experiment took place in Kent and consisted of eight teams of four officers searching two grids. The weather conditions on the day were partly cloudy with a maximum temperature of 10˚C and minimum temperature of 6˚C. Prior to searching, four teams were randomly chosen to be given information about fox scavenging behaviour and scatter patterns. The second experiment took place in

Dorset and consisted of three teams, one team had four officers and the other teams had three officers due to unforeseen issues. The weather conditions on the day were partly cloudy with a maximum temperature of 14.2˚C and minimum temperature of 10˚C. Two randomly chosen teams from the Dorset experiment were provided with information fox scavenging behaviour and scatter patterns. All teams were briefed separately prior to starting their search of a grid but all were told the same basic description of the crime scene scenario that teams were to search a scene where human remains were scavenged. The amount and appearance of bones in each grid site were not told to any search team. The teams given information on typical fox scavenging behaviour were provided with four key points: fox scatter patterns commonly lead towards areas of thick or high vegetation, the base of trees and tree stumps, and collections of fallen tree branches; and foxes will bury bones in caches (depths of c. 7 cm – 12 cm) with light covering of leaves or twigs. The other four teams were not provided with any information identifying the scavenger species or pertaining to fox scavenging behaviours and patterns.

Only one team was allowed to search a grid in a single session. A session lasted 35 minutes but teams were not given countdowns of their time so that there was a consistent effort of searching throughout the entire session. The length of a session had been chosen based on the available daylight and officers' work schedules. All teams were instructed on the use of a grid search method wherein two searchers from a single team started their search on one side of the grid and at parallel corners in a left to right direction (Figure 6.8). The other two searchers started their search in the opposite direction (Figure 6.8). Searchers were instructed to walk a total of five lines each and to keep a space of 1 m between each other. They were told to not to walk over the same line twice or back over areas once their designated five lines were completed. Whilst walking, searchers were allowed to look 0.5 m to their left and right for any bones. If it was necessary to clear away any vegetation, searchers were instructed to only use their hands to conduct a light clearing (no sticks or feet) of debris or leaf litter. Searchers were told to turn bones over when located, record the associated number, and then place the bone back down as it was found. Teams and searchers were at no point allowed to inform each other of the location or number of a bone. Although a grid search method was used to control how searchers walked through the sites, the manner in which an individual searched the soil surface was allowed to vary (e.g. fingertip search close to the ground surface or simple walking) (Figure 6.9-7.0). Searchers given information on fox scavenging were also allowed to adapt their search method (within the limits of a grid search method) as they saw fit to incorporate the scavenging information, such as only looking at typical fox scatter locations or searching the entire grid section.

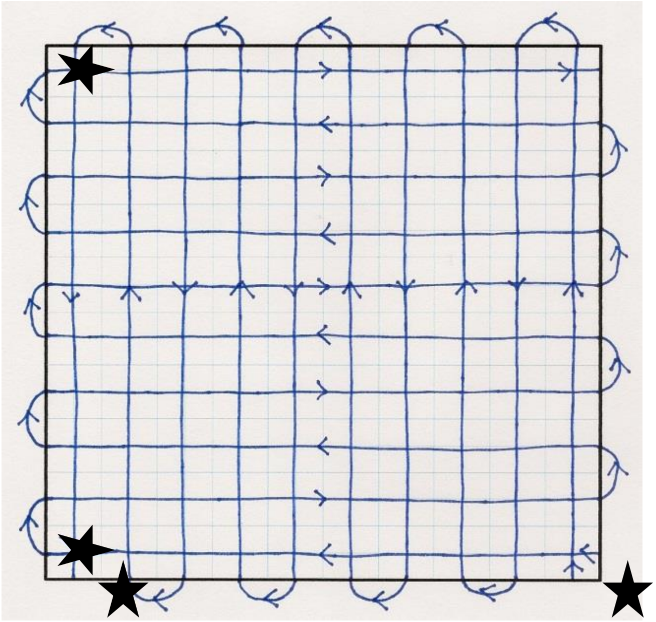

Figure 6.8. Searchers were instructed to follow a grid search method in each site. The starting position of each searcher is indicated by a star.

Figure 6.9. Searchers adapted their search techniques. This searcher can be seen clearing leaf litter.

Figure 6.10. A searcher can be seen using a fingertip search method.

After a team searched both grid sites, each for 35 minutes, searchers completed a short questionnaire asking their opinion on the search. The following questions were asked of those teams given information on fox scavenging prior to their search:

- Question 1 - Do you feel that your search method was improved with information on the species-typical scavenging behaviour of foxes (how they scavenge, modify and scatter remains; how and where they are likely to deposit remains)?
- Question 2 - Do you feel that your recovery rate of bone was improved with information on the species-typical scavenging behaviour of foxes (how they scavenge, modify and scatter remains; how and where they are likely to deposit remains)?

Whilst completing the questionnaire, the teams not given information on fox scavenging for their searches remained unaware of the provision of such information to other teams. The following questions were asked of those teams not given information on fox scavenging prior to their search:

- Question 1 - Do you feel that your search method could have improved with information on the species-typical scavenging behaviour of foxes (how they scavenge, modify and scatter remains; how and where they are likely to deposit remains)?

- Question 2 - Do you feel that your recovery rate of bone could have improved with information on the species-typical scavenging behaviour of foxes (how they scavenge, modify and scatter remains; how and where they are likely to deposit remains)?

At the end of both grids being searched and the completion of the questionnaire by a team, a debriefing was held to discuss the experiment and the opinions of the searchers. All teams were informed in the debriefing of the scavenging information provided prior to some teams' searches and the location of bones.

The outcome of searches by teams given information on fox scavenging behaviour versus those not given information was statistically analysed using a chi-square test. The effects on teams' recovery rates by the provision of scavenging information, the size of bone fragments, the location of bones within a grid, and whether bones were buried or surface deposited were analysed using logistic regression. All statistical analyses were conducted using PASW Statistics version 18. The results of the questionnaire were charted to show searchers' overall opinions towards the addition of species-typical information, as well as to show any differences of opinion between searchers given and not given scavenging information.

6.4 RESULTS

The total number of bones recovered from both days of the experiment by teams given information on fox scavenging behaviour and scatter pattern information was 87 and those without information was 42 (Figure 6.11). The maximum number of bones recovered from two grids by a team with information was 32 and by a team without information was 27 out of a possible 48. The minimum number of bones recovered from two grids by any team was 2 out of a possible 48. On both days of the experiment, it was evident that after each team searched there was the potential for bones to be displaced by each searcher within their search area, as well as the possibility that the disturbance to the ground surface during a prior search could mislead or even correctly lead the next searcher.

At the experiment in Kent, teams with information found a total of 30 bones and those without information found 15 (Figure 6.11). Teams at the Dorset experiment which were provided with information found a total of 57 bones and those without information found 27 (Figure 6.11). It is important to note that there was only one team not given information and two teams with information during the Dorset searches because of limited number of searchers. The overall recovery rate of bones by officers was significantly affected by whether or not they were provided with information on fox scavenging behaviour and scatter patterns ($x^2(1)= 11.45$, $p=.001$) (Figure 6.11). This represents the fact that the odds of the officers finding bones within this study was 2.05 times higher if they were provided with the information on fox scavenging than if not provided with the information. Further analysis showed that the size of the bones ($p= .44$) and whether the bones were located on the soil surface or buried ($p= .61$) did not have significant effects on whether or not a bone was found. However, the location of the bones (e.g. tree, thick vegetation) ($p= .003$) and the provision or lack of information on fox scavenging and scattering ($p= .001$) did have significant effects on whether or not a bone was found ($R^2 = .04$, $x^2(4) = 21.67$, $p< .001$).

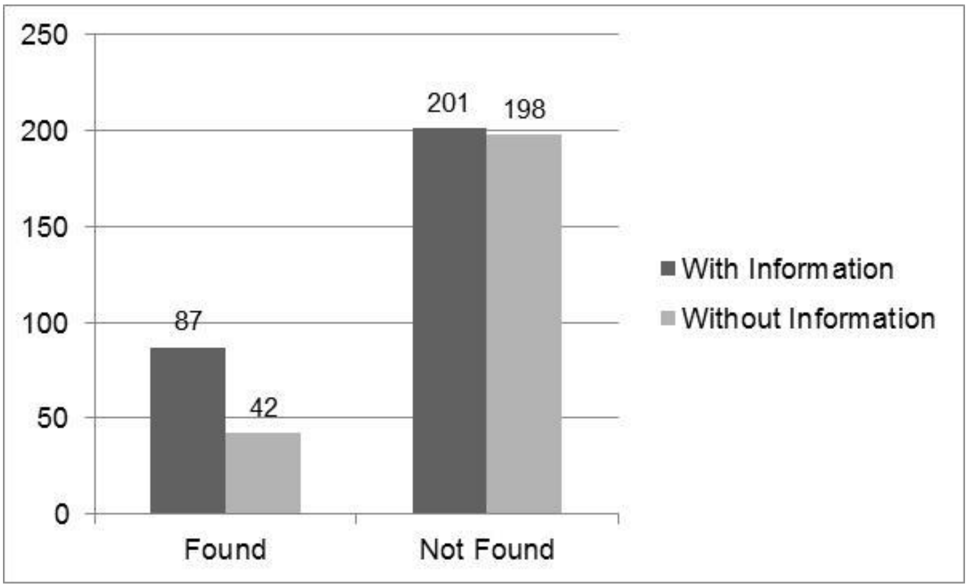

Figure 6.11. Total counts of bones found and not found by teams given and not given information on fox scavenging behaviour and scatter pattern.

6.4.1 Questionnaire

Searchers' overall opinion as to whether they felt that search methods were/could have been improved with information on the scavenging behaviour and pattern of foxes (Q1) was similar for strongly agree (42.86%) and agree (46.94%) (Figure 6.12). Regarding whether they felt that their recovery rate of bone was/could have been improved with scavenging information (Q2), opinions were also nearly equal for strongly agree (42.86%) and agree (38.78%) (Figure 6.12). More specifically, searchers who were not given any information on fox scavenging behaviour were mostly positive in their feedback with 59.09% strongly agreeing with both Question 1 and 2 and no disagreeing or strongly disagreeing (Figure 6.13-6.14). Interestingly, searchers who were provided with scavenging information had more varied opinions. The majority of opinions of those given information agreed with Question 1 (51.85%) and 2 (44.44%) (Figure 6.13-6.14). Nonetheless, those with information were also unsure (14.81%; 18.52%) and disagreed (3.70%; 7.41%) with Question 1 and 2 (Figure 6.13-6.14).

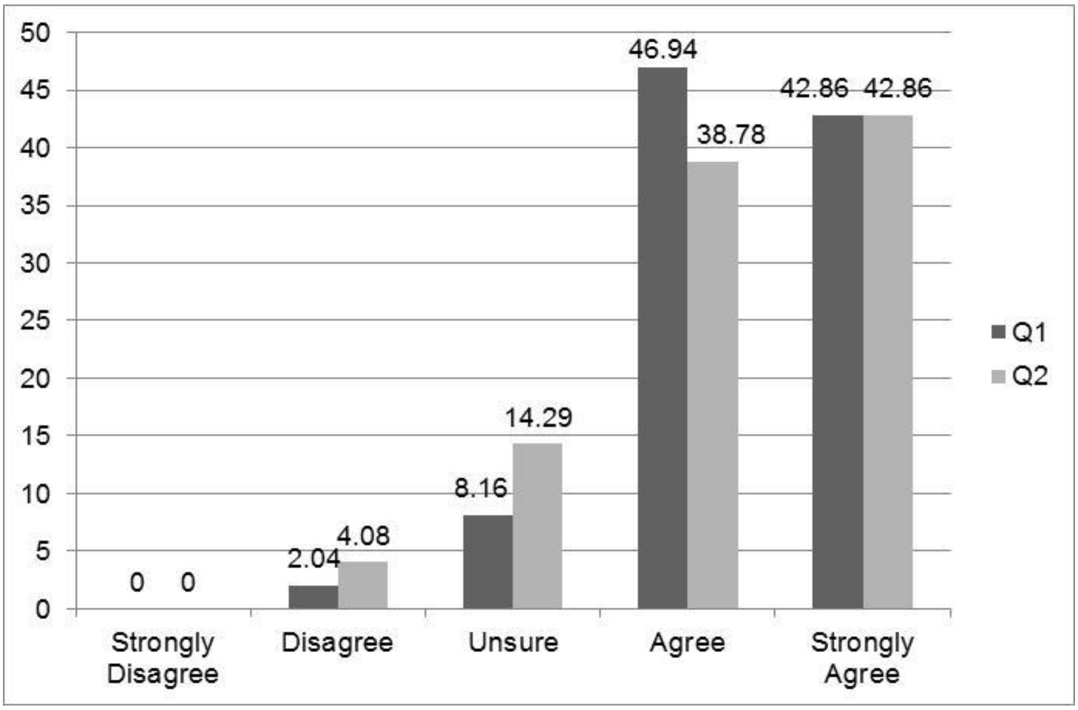

Figure 6.12. Overall responses to question 1 and 2 from searchers given and not given scavenging information.

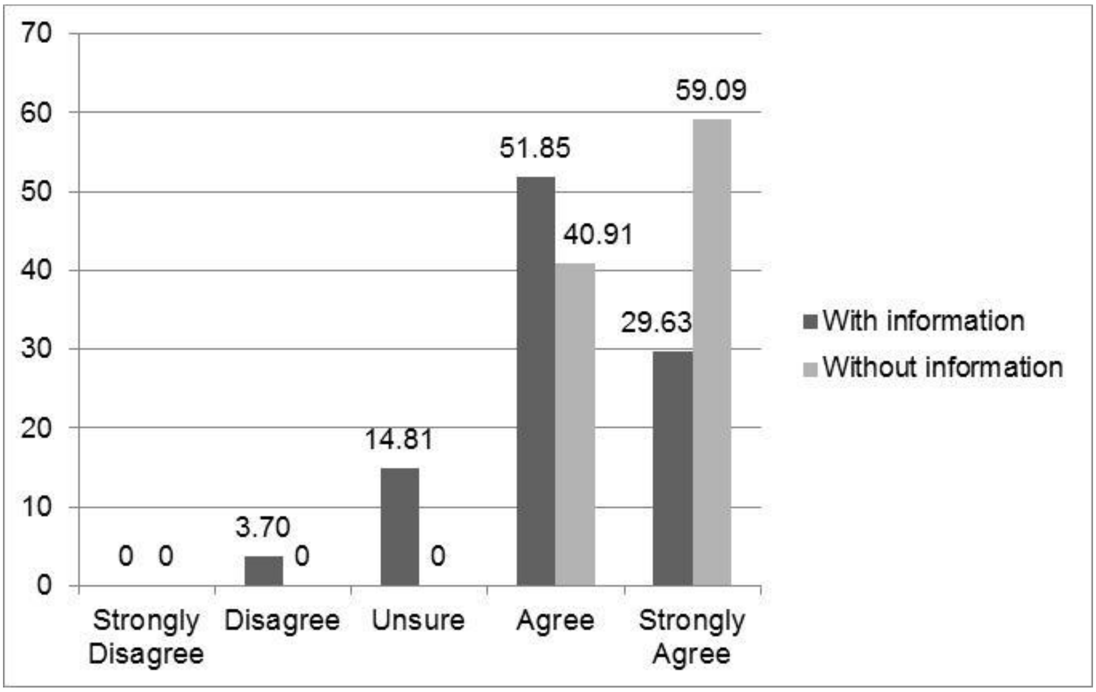

Figure 6.13. Responses to question 1 (Do you feel that your search method was/could have improved with information on the species-typical scavenging behaviour of foxes?) by searchers who were given and not given scavenging information.

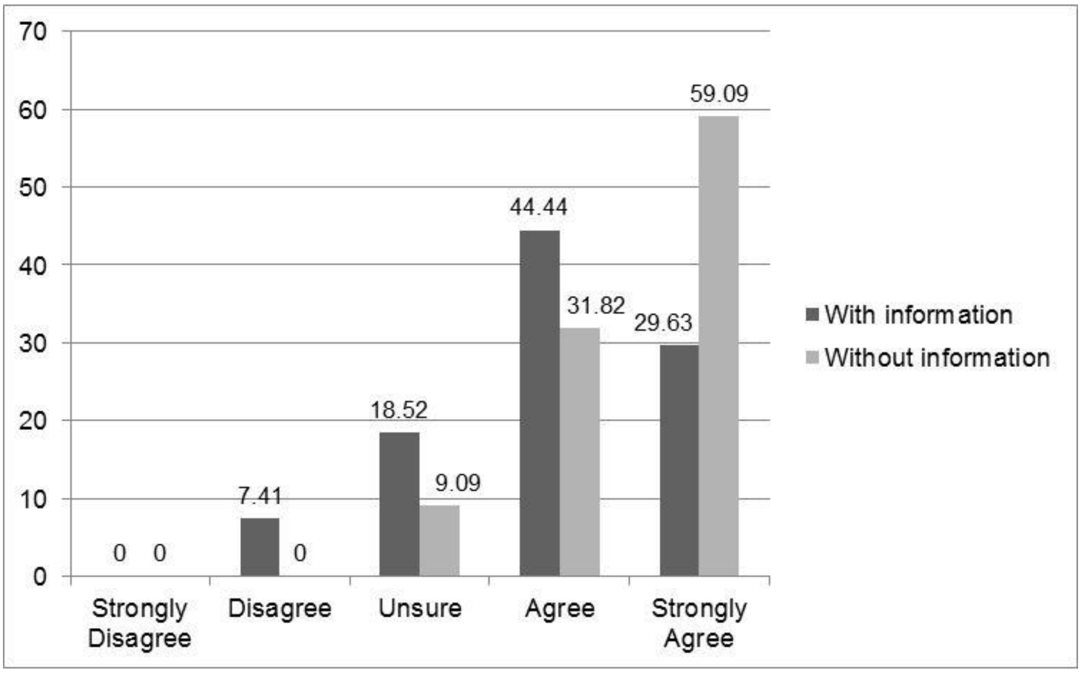

Figure 6.14. Responses to question 2 (Do you feel that your recovery rate of bone was/could have improved with information on the species-typical scavenging behaviour of foxes?) by searchers who were given and not given scavenging information.

6.5 DISCUSSION

This study has shown that the provision of information on species-typical scavenging behaviour and patterns to PoLSAs and police search team members does improve the recovery of scavenged bones and can lead to improvements in search methods. In this study, there was the potential bias towards searchers recovering bones located specifically at reference points associated with foxes. However, no team recovered 100% of the bones in any grid, searchers were observed adapting the grid search method differently to incorporate the reference points, and bones were not deposited at every reference point within each grid. In order to overcome a potential bias, the results from this study should be compared to scenes in which searchers are able to search for remains scattered by wild scavengers so that the effects of the provision of reference points can be further understood.

The officers used within this study were all trained specialist searchers including police search team members and PolSAs with a minimum of five years of experience as a non-search officer followed by one to 15 years of experience as a search officer. All participants had been trained in current standard search procedures and CT search methods for counter-terrorism, crime scene, and homicides, which they had previous experiences applying to indoor and outdoor searches, as well as to physical searches for human remains. Standard procedures for homicide investigations call for SIOs, with the assistance of CSMs and CSCs, to construct and implement a forensic strategy and forensic examination before a search strategy and physical search with specialist searchers (NCPE 2005, 2006). Presently in the U.K., there is no standard search protocol or training for the search of scavenged or scattered human remains (NCPE 2005, 2006). The training of specialist searchers in the application of CT search methods to the search for human remains is restricted to the locating of homicide burials and not surface deposits (NCPE 2006). However, scavenging in this region can occur for both buried and surface deposited human remains (Chapter 2; Andrews 1995; Coard 2007). Scavenging and scattering of human remains by foxes can cause significant damage and modification to bones, such as fragmenting and transporting bones over wide distances, which can hinder search and recovery efforts (Chapter 4 – 5; Listi *et al*. 2007). Scavenger-induced modifications and scattering of human remains can occur at both crime scenes and scenes not related to criminal activity. SIOs and specialist searchers should treat all scenes of scavenged human remains as crime scenes until criminal activity has been identified or eliminated because it is not within their expertise or role to analyse and interpret skeletal remains but is instead that of forensic anthropologists, forensic archaeologists, and pathologists (Patel 1994; Byard *et al*. 2002; Hunter and Cox 2005; NCPE 2006; Schulz *et al*. 2006). Moreover, a physical search by specialist searchers for scavenged remains may also reveal further forensic evidence that require forensic examination and re-assessment of the objectives and search methods of the physical search (NCPE 2006). Nonetheless, SIOs, PoLSAs, and other specialist searchers need to be knowledgeable in the effects of scavenging on human remains and how it will affect search strategies and methods.

Despite the capability of foxes to scavenge and scatter human remains (Chapter 4), they are rarely the focus of forensic and archaeological literature (Chapter 1; Andrews and Cook 1985; Andrews 1995; Morton and Lord 2006; Wilson *et al*. 2007); and, as a consequence, their species-typical scavenging behaviour and patterns are not well known to police search officers (Chapter 2). During the briefings and debriefings with participants of this study it was evident that their knowledge of scavenging was limited and restricted to anecdotal evidence. This gap in scavenger knowledge leaves investigators and police search officers at a disadvantage when faced with a crime scene involving suspected scavenging. Thus, PolSAs are limited in advising SIOs and informing search team members on the design and execution of a search strategy and methods for locating scavenged and/or scattered human remains. For instance, what to search for (e.g. whole or fragmented bones), where to concentrate search efforts, and what search methods to choose. Similarly, SIOs, PoLSAs, and other specialist searchers are unaware of what resources and expert advice is available to aid in the search of scavenged remains.

The gap in scavenger knowledge was further highlighted in this study by searchers stating during the debriefing and questionnaire that they expected scavenged and fragmented bones to retain characteristics of undamaged whole bones. The misconception by searchers that bones would be whole and easily recognisable may have given those searchers' whom were provided with scavenging information a higher expectation of their recovery rate. Likewise, those given information had not searched prior to the provision of information so were not able to compare searching without information. Searchers' lack of knowledge regarding the appearance of scavenged bone can affect the recovery rate of scavenged bones, such that scattered and fragmented bones are overlooked or disregarded. Within this study, searchers were found to adapt CT search methods in the following ways: using either a fast or slow fingertip search, removing leaf litter with their hands, or simply walking through a grid. Additionally, searchers given scavenging information and reference points varied between individuals choosing or not choosing to prioritise the points. Searchers' recovery rates, adaptations of the CT search method, and the length of time required to complete a search within each grid gave insight into future adaptations to search methods that can be used for more efficient and effective search and recovery of scavenged and scattered human remains.

6.5.1 Further Suggestions

Within the U.K., current standard search procedures and training of physical search methods to investigators and police search officers need to be updated to include the effects of scavenger species-typical scavenging behaviour and scattering patterns on buried and surface deposited human remains. SIOs, scientific support managers (SSM), PolSAs, and other specialist searchers must be made aware of the value of scavenging information to the search and recovery of scavenged human remains and of what expert advice in scavenging is available. In addition to the dissemination of accurate scavenging information to forensic professionals through seminars and lectures, search experiments in different environments and scenarios, such as those within this study, need to be used to expose specialist searchers to the various effects that different scavenger species have on human remains. Knowledge and hands-on experiences with scavenged and scattered human remains and animal proxies based on accurate scavenging information will allow searchers and PoLSAs to problem solve and adapt search methods more efficiently.

The following search methods are the most appropriate methods to be used in the search for scavenged and scattered human remains, depending on the environment and topography: systematic line and grid searching, fingertip searching, and winthropping (Komar 1999; Brown *et al*. 2002; Blau 2004; Rooney *et al*. 2004; Oesterhelweg *et al*. 2008). Line and grid search methods allow for small and large indoor and outdoor locations to be systematically searched by specialist searchers during a physical search (Hunter and Cox 2005; NCPE 2006). During a systematic physical search, fingertip searching allows for a detailed search of scavenged and scattered skeletal elements. The Winthrop method concentrates search efforts at those reference points or locations at which a scavenger species is most likely to transport scavenged and scattered remains.

When creating the search strategy for the physical search of scavenged and scattered human remains, SIOs and PoLSAs should consider the following: the environment, topography, and weather to which remains have been exposed; and the suspected time of exposure, state of decomposition, condition and deposition of remains, in order to make an assessment of the potential scavenger species and subsequent species-typical scavenging behaviour and scattering patterns affecting the human remains and physical search. In the employment of the search strategy and physical search, SIOs, along with PoLSAs and SSMs, should obtain resources and expert advice on scavenger species-typical scavenging behaviour and scatter patterns in order to delineate the search parameter and adapt search methods with a higher level of confidence.

Cadaver dogs are also widely used by police forces in the search of human remains but the effectiveness of a dog is dependent on a variety of factors such as the experience of the handler and dog, weather conditions, and wind direction

(Komar 1999; Lasseter *et al*. 2003; Rooney *et al*. 2004). A dog is not simply thrown into a scene and let to roam with no direction from a handler but is instead used to search targeted and/or tested areas based on the collation of various information (Komar 1999; Lasseter *et al*. 2003; Rooney *et al*. 2004; Oesterhelweg *et al*. 2008). Knowledge of scavenger species-typical scattering patterns and reference points will allow cadaver dog handlers to identify a search radius and use the Winthrop method to search reference points with the dog, so that the chances of recovering scavenged and scattered bones are maximised. However, without the knowledge, training, and expert advice on scavenger species-typical scavenging behaviour and scattering patterns police cadaver dog handlers, investigators, and police search officers are unable to fully adapt and apply search methods to the physical search and recovery of scavenged and scattered remains.

6.6 CONCLUSION

Providing police specialist searchers with information on scavenger species-typical scavenging behaviour and pattern enhances their chances of recovering scavenged skeletal remains. This study has shown searchers are 2.05 times more likely to recover scavenged bones when red fox scavenging behaviour and scatter pattern are known. Knowledge of the effects of foxes scavenging on human remains assists in the adaptation and improvement of search methods used at crime scenes involving fox-scavenged remains. Crime scene scenarios do vary thus studies which take into account different species-typical scavenging behaviour and scattering patterns, region-specific scavenging patterns, and varying conditions of human remains have the potential to greatly improve the recovery rate of scavenged and scattered remains.

Chapter 7

General discussion

7.1 INTRODUCTION

The scavenging of human remains by mammalian and avian scavengers found in Northwestern Europe has been a widely overlooked area of research. There has been a large number of scavenging studies produced in other regions such as North America and Africa which have focused on large canid and felid scavengers which are not found in Northwestern Europe (Appendix I, Table A1-1; Haynes 1982, 1983a, 1983b; Hill and Behrensmeyer 1984; Haglund *et al*. 1988, 1989; Milner and Smith 1989; Willey and Snyder 1989; Marean and Spencer 1991; Selvaggio 1994; Blumenschine *et al*. 1996; Selvaggio and Wilder 2001; Pickering *et al*. 2004; Domínguez-Rodrigo and Barba 2006). As a consequence, these scavenging models have been used in previous studies in Northwestern Europe and other regions as multi-regional and general models to aid in identifications and interpretations of scavenged animal and human remains (Moraitis and Spiliopoulou 2010; Ruffell and Murphy 2011) (Table 1.1; Appendix I, Table A1-1). Using region-specific and species-typical models as general models can lead to incorrect identifications and interpretations in environments and regions where large canids and felids are not present. Moreover, forensic scientists, investigators, and police search officers have tended to rely on anecdotal information regarding scavenging in Northwestern Europe because prior to this study there has not been in-depth multidisciplinary studies that have presented the species-typical scavenging behaviour and patterns of scavenger species in this region. The aim of this thesis was to aid forensic investigations in the physical search, recovery and interpretation of scavenged remains. The objectives were as follows: 1) to identify mammalian and avian scavenger species within Northwestern Europe, especially in Britain; 2) to identify and characterise the species-typical scavenging behaviour and pattern of the red fox (*Vulpes vulpes*) and Eurasian badger (*Meles meles*); 3) to determine the forensic impact and application of species-typical scavenging studies.

This chapter consolidates the methodologies and main conclusions derived from previous chapters. The forensic impact and applications of the thesis are summarised. Finally, suggestions for future research and applications are presented.

7.2 SUMMARY OF RESEARCH METHODOLOGIES

The purpose of this study was to fill the knowledge and methodology gaps in the identification, interpretation and characterisation of the species-typical scavenging behaviour and patterns of mammalian and avian scavengers found in Northwestern Europe, with an emphasis on red foxes and Eurasian badgers, so as to aid forensic investigations and physical searches of scenes. The approach to this research was multifaceted incorporating a multidisciplinary review and meta-analysis of previous studies (Chapter 1), review of U.K. police search officers' scavenging experiences (Chapter 2), field experiments with surface deposited deer and observations of wild scavengers (Chapter 3 – 4), observations and comparisons of captive and wild scavengers (Chapter 4 – 5), analyses of the dimensional data of bite marks (Chapter 5), and application of results to scene search and recovery methods used by police search officers (Chapter 6).

Review of previous studies in the fields of taphonomy, zooarchaeology, paleobiology, paleoecology, taphonomy, archaeology, forensic archaeology, forensic entomology, forensic anthropology, pathology, and forensic entomology highlighted the gap in the literature of fox scavenging behaviour and patterns (Chapter 1; Andrews and Cook 1985; Andrews 1995; Morton and Lord 2006; Wilson *et al*. 2007). Badgers and their scavenging behaviour and patterns were even rarer within the literature (Chapter 1; Andrews and Cook 1985; Andrews 1995). Likewise, data on the dimensions of bite marks produced by foxes and, even more so, badgers was limited despite both scavengers' abilities to produce bite marks whilst scavenging soft tissue and skeletal remains (Chapter 1 – 2; 4-5). Foxes and badgers were found to be well documented within ecological and behavioural ecology studies but with a focus on their social structures, home range sizes and diets (Kruuk and Parish 1981, 1985; Kauhala *et al*. 1998; Doncaster and Macdonald 1990; Doncaster *et al*. 1990; Harris and White 1992; Da Silva *et al*. 1993; Cavallini 1996; Macdonald *et* al. 1996, 2004; Revilla and Palomares 2001, 2002; Roper *et al*. 2003; Jarnemo and Liberg 2005). There was also a clear gap in the application of ecological and behavioural ecology studies of foxes and badgers to forensic studies, investigations, and searches.

In addition to the lack of literature and data on scavenger species within Northwestern Europe (Chapter 1), there was no previous assessment of police search officers' experiences and knowledge of scavenging or of how investigations and searches within the U.K. are affected by scavengers (Chapter 2). Moreover, there is currently no police search protocol for physical searches involving scavenged and scattered human remains (NCPE 2005, 2006). The analysis of the questionnaire completed by police search officers in the U.K. showed the following:

- Police search officers and police cadaver dog handlers did have experiences with the physical search for scavenged human remains;
- Scavengers within the U.K. scavenged, disarticulated, scattered, and removed both surface and buried deposited human remains;
- Search and recovery efforts by police cadaver dog handlers and police specialist searchers were hindered by scavengers' scavenging activities;
- The use of cadaver dogs in a search did not guarantee that all of the scavenged remains were recovered;
- The identification and interpretation of a scavenger species was very subjective or not undertaken;
- There was no application of scavenger species-typical scavenging behaviours and patterns by police cadaver dog handlers and police specialist searchers, which was due to a lack of knowledge or incorrect anecdotal evidence (Chapter 2).

In order to answer forensic scientists, investigators, and police search officers' questions; fill the gaps in the literature, data, and knowledge of the scavenger species to be found in this region; and improve the search, recovery, and interpretation of scavenged human remains, actualistic methods and direct observations were employed to understand the species-typical scavenging behaviours and patterns of avian scavengers (Chapter 3), rodent scavengers (Chapter 3), red fox (Chapter 4-5), and Eurasian badger (Chapter 4 – 5). The field experiments within this study provided recreations of potential crime scene scenarios involving scavenged human remains. Surface deposited baits and whole deer accompanied by infrared motion detection cameras allowed for direct observation and recording of scavenging activities by different scavengers at and near deposit sites (Chapter 3 – 4). Deer were deposited in winter through to summer and showed a variety of scavenger species within a British woodland environment, of which foxes were the most frequently observed scavenger (Chapter 3 – 4). The most frequently observed avian and rodent scavengers were carrion crow (*Corvus corone*) and grey squirrel (*Sciurus carolinensis*) (Chapter 3). Observations of avian and rodent scavengers showed the effects that different scavenger species and their species-typical scavenging behaviours had on different scavenger species, either through direct inter-species interactions or modifications of remains, which impacted how other scavenger species scavenged, disarticulated, and removed remains (Chapter 3). Moreover, avian-induced soft tissue modifications and rodent-induced soft tissue and bone modifications were characterised (Chapter 3).

An outline of red fox and Eurasian badger scavenging behaviours was created using actualistic methods and direct observations of captive and wild scavengers (Chapter 4 – 5). The scavenging behaviours displayed by captive and wild scavengers were found to be similar and comparable (Chapter 4). However, wild badgers were not observed scavenging deer remains. In contrast, the scavenging behaviour and pattern of wild foxes produced a variety of effects which included bite marks on bone surfaces, fracturing and fragmenting of bones, removal of soft tissue and skeletal elements, and the scattering of bones. The link method, similar to the Winthrop method used by police specialist searchers, was executed for the search and recovery of scavenged and scattered remains. The search and recovery of skeletal elements within this study aided in the analyses of bite marks on bones, recovery rates and distances of scattered bones, fox scatter patterns, and the identification of reference points to aid search methods.

In addition to the direct observation of wild and captive scavengers, actualistic methods and statistical analyses were applied in the comparison of captive and wild scavengers' bite mark dimensional data. The dimensional data of bite marks found on recovered bones were compared to the data of bite marks from captive foxes, captive badgers, and domestic dogs to assess the use of bite mark analysis in the identification of a scavenger species and to assist in the characterisation and identification of the range of dimensions for bite marks produced by foxes and badgers (Chapter 5). Wild foxes produced bite marks during different stages of decomposition when soft tissue was present and absent, whereas wild badgers were not observed to scavenge deer and thus did not create any bite marks (Chapter 4 – 5). However, wild badgers were observed investigating the deer and captive badgers were found to scavenge fresh and dry soft tissue and bone, hence their bite marks were included in analyses. As a result of scavenging skeletal remains, captive foxes and badgers produced bite marks on bone surfaces, which were analysed and compared (Chapter 4 - 5). Additionally, bite marks on bones were obtained from domestic dogs because as canids foxes and dogs have the same dentition and, depending on the breed, can have similar body sizes. The advantage of observing captive scavengers as they scavenged provided a reference of bite mark dimensional data for comparison to bite marks found on bones produced by wild scavengers from field experiments.

Bite mark analysis cannot be solely relied on to identify a scavenger species, thus further emphasising the importance of knowledge of scavengers' species-typical scavenging behaviours and patterns and the various factors that affect scavengers' utilisation and modification of remains (Chapter 5). Bite mark dimensions can add to interpretations and characterisations of scavenger species and the search of associated reference points. Nevertheless, dimensional data should be used in conjunction with accurate information on scavengers' species-typical scavenging behaviours and patterns in order to aid and improve the search, recovery, and interpretation of scavenged and scattered human remains. The results gained from the police search officer questionnaire, captive studies, and field experiments were applied to search experiments to test whether providing police specialist searchers with information and reference points pertaining to species-typical scavenging behaviour and patterns will improve outdoor recovery rates of scavenged and scattered bones (Chapter 6). Fragmented bones resembling those scavenged by foxes were scattered within four outdoor grid sites at reference points associated with red fox scavenging behaviour and at random locations not associated with foxes. Teams of specialist searchers, consisting of licenced police search advisers (PoLSAs) and police search officers, were divided between teams given and not given information on fox scavenging behaviour and scattering pattern. A grid search method was used by all searchers but they were allowed to adapt their search techniques whilst following a grid method. The recovery rates of teams given species-typical scavenging information and reference points associated with scavenging were higher than those not provided with information or points (Chapter 6). Additionally, it was evident that there were differences in how searchers applied the scavenging information due to the lack of a standard search protocol for the search of scavenged and scattered human remains; the basis of physical search methods stemming from indoor counter-terrorism (CT) methods rather than methods for outdoor human remains; and police search officers' limited knowledge of osteology (Chapter 6). These search experiments allowed for the assessment of police search officers' current standards of search methods for human remains and how best to apply information on scavenger species-typical scavenging behaviours and patterns to search methods, such that search methods can be adapted for the optimal recovery of human remains.

7.3 FORENSIC IMPACT AND APPLICATION OF RESEARCH

The results of this thesis have been applied to crime scenes within Northwestern Europe which have involved the search, recovery and analyses of human remains. Reports and advice, based on this research, have been requested for different cases in Northwestern Europe involving varying scenarios. The types of cases this research has been applied to include the following:

- Scavenging of charred human remains in order to decipher between criminal and animal scavenging activity;
- Identification of scavenger species most likely to scavenge charred soft tissue;
- Provision of reference points within and around the crime scene to be searched by police specialist searchers and cadaver dogs for clandestine graves disturbed by scavengers in woodland and farm environments;
- Provision of reference points to be searched within and around the crime scene by police specialist searchers and cadaver dogs for scavenged and scattered surface deposited remains in woodland, farm, and peri-urban environments;
- Delineation of physical search boundaries in which scavenged human remains will be recovered;
- Analysis of scavenger-induced bone alteration (e.g. bite marks and fracturing) with the aim of determining criminal or animal activity and to identify further reference points to be searched within and around the crime scene;
- Identification and interpretation of when scavenging of skeletal remains occurred;
- Identification and interpretation of scavenger species-typical scavenging behaviour over different seasons and extended period of times in order to adapt search and recovery methods;
- And identification and interpretation of scavenger species most likely to scavenge different types of textiles.

This research has succeeded in not only filling the gap in the literature but also in providing forensic scientists, investigators, and police search officers with new knowledge and methodologies regarding scavenging that can be effectively applied to forensic investigations and physical searches of scenes. Police non-specialist and specialist searchers aim to recover as many skeletal elements as possible for both identifications and interpretations pertaining to the individual but also in consideration of the individual's relatives. When conducting a physical search at a scene, PoLSAs whom are aiding and advising the senior investigating officer (SIO) and supervising police search officers in the implementation of a search strategy are keen to know what percentage and types of skeletal elements they should expect to recover, as well as the condition of bones in order to adapt search methods. In order to successfully plan and adapt search and recovery methods, police specialist searchers, including the SIO, PoLSAs, and police search coordinators (PolSCs), must consider the following factors which will differ in each scene scenario: environment, topography, scavenger species, species-typical scavenging behaviour and patterns, seasons, weather, condition and deposition of a set of remains, and possible length of exposure of the set of remains. The consideration of these factors coupled with scavenger species-typical reference points and recovery radii enable more efficient and effective search and recovery of scavenged human remains which will lead to more accurate identifications and interpretations.

This study found that the most common wild scavengers in a woodland environment in Northwestern Europe included wood mouse (*Apodemus sylvaticus*), grey squirrel, carrion crow, buzzard (*buteo buteo*), Eurasian badger, and red fox. All of these scavengers can cause soft tissue damage and modifications to bone surfaces of human remains (Haglund *et al*. 1988, 1989; Haglund 1992; Byard *et al*. 2002; Asamura *et al*. 2004; Morton and Lord 2006; Klippel and Synstelien 2007). However, foxes and badgers are capable of causing more significant modification to soft tissue and skeletal elements, as well as transport bone over wider distances, due to scavenging behaviour, dentition, jaw strength, body size, and bite force (Hillson 2005; Wroe *et al*. 2005; Christiansen and Wroe 2007). In comparison to badgers, foxes were more active as scavengers within this type of environment and scavenged more frequently (Chapter 4). Badgers scavenged both fresh and dry soft tissue and bone but these activities were heavily dependent upon seasonality and the abundance of trophic resources (Chapter 3 – 5). Therefore, foxes are the largest and most common wild scavenger of surface deposited human remains in a peri-urban and rural environment within the U.K.

The species-typical scavenging behaviour and pattern of red foxes were found to differ from that of larger canids, which have previously been the focus of many scavenging studies (Chapter 1; Haynes 1980, 1982, 1983a, 1983b; Haglund *et al*. 1988, 1989; Milner and Smith 1989; Willey and Snyder 1989; Rothschild and Schneider 1997; Komar 1998; Potmesil 2005; Vanlaerhoven and Hughes 2008). Unlike larger canids, foxes did not do the following: hunt in packs; scavenge and consume at the deposit site; start scavenging from the head or neck; or concentrate scavenging from the thoracic cavity first (Chapter 4). Foxes were recorded making multiple visits to a set of remains to investigate and eventually approach the upper or lower extremities where a fox would then make a quick bite and release. The bite was investigative but did cause soft tissue damage. The fox would then attempt to remove the remains from the deposit site to a location where the fox had a better chance of scavenging, disarticulating and consuming the remains without the threat of other scavengers. The order in which foxes modify a body, based on the comparison of the scavenging of deer and human remains (Chapter 4), has been characterised as follows:

1. Lower extremities;
2. Upper extremities;
3. Thoracic cavity (inclusive of vertebrae, ribs, sternum, scapulae, and clavicle);
4. Partial to complete disarticulation of all remaining skeletal elements.

In comparison to human remains scavenged by larger canids, like wolves (*Canis lupus*) or coyotes (*Canis latrans*), the presence of footwear and clothing appears to affect the ability of foxes to scavenge a body, in particular the presence of some form of trousers and footwear restrict scavenging and cause foxes to redirect or concentrate scavenging to the upper extremities of human remains (Chapter 4). Scavenging by foxes can be expected year round but will be more frequent during colder seasons when trophic resources are low within their environment thus causing them to seek alternative food sources (Chapter 4; Lindström 1982; Leckie *et al*. 1998; Kauhala *et al*. 1998; Kjellander and Nordström 2003; Jarnemo 2004). Foxes preferred to scavenge a set of remains whilst fresh or during early stages of decomposition prior to any insect activity. Increased insect activities deterred scavenging by foxes. After the departure of insect activity such as maggot masses, scavenging by foxes recommenced and continued whilst remains were dry and partially or completely skeletonised (Chapter 4).

Scavenging by foxes caused not only soft tissue damage but also bite marks on bone surfaces and the fracturing of bones (Chapter 5). Modification to bones by foxes can damage and obscure skeletal elements key for the identification of the individual and interpretation of trauma (Byard *et al*. 2002; Schulz *et al*. 2006). The range of the mean pit length and breadth of fox bite marks was found in this study to be distinguishable from domestic dogs and badgers (Chapter 5). The range of the mean pit length of foxes was < 2.5 mm and mean pit breadth was < 1.5 mm, whereas pits made by dogs and badgers were larger (Chapter 5). Knowledge of the characteristics and dimensional data of fox bite marks aids in the correct decipherment between scavenger-induced trauma and that associated with the individual's death or criminal activity (Byard *et al*. 2002; Schulz *et al*. 2006). For example, the absence of the skull from a set of remains juxtaposed with the presence of fox bite marks on other skeletal elements like cervical vertebrae, no other trauma, and the absence of a slope at the deposit site can indicate that the skull was removed by foxes. In contrast, the absence of bite marks and any other species-typical scavenging characteristics on any skeletal elements but the absence of the skull may suggest criminal activity. Additionally, such species-typical knowledge of bite marks and damage helps in the accurate identification of different scavenger species which, in turn, assists in interpretations of the condition of a body, method of deposition, and deposit sites. Different conditions and deposit sites will prohibit or allow different scavenger species. For instance, scavenging associated with an outdoor scavenger would not be expected to be found on a body deposited in a secured indoor location. Similarly, a body deposited in a heavy restrictive textile may restrict small scavengers from removing the textile or body, as well as possibly limiting scavenging to only a small exposed area.

Foxes also scattered and removed skeletal elements from human remains whilst scavenging and disarticulating (Chapter 4). Scattering and removal of bones by foxes impacted police search officers' ability to recover bones key to the identification of the individual and the interpretation of trauma (Chapter 2, 4). Foxes primarily scattered scavenged bones in a linear pattern which lead from the deposit site to species-typical locations or reference points. The species-typical reference points of foxes have been identified as caches, badger setts and sett entrances, fox den or earth, thick or high vegetation (e.g. tussocks; bramble), the base of trees and fallen trees, and collections of fallen branches (Chapter 4 – 5). There are a variety of factors which can affect the distances to which foxes will transport bones such as bone morphology, inter-species aggression, topography, scavenger size and physique, condition of the remains (e.g. restrictive textiles; burial; dismembered) and the deposit site's proximity to setts, dens, trees, and thick or high vegetation (Chapter 4; Gittleman and Harvey 1982; Rothschild and Schneider 1997; McNab 2000; Byard *et al*. 2002; DeVault *et al*. 2004; Wroe *et al*. 2005; O'Brien *et al*. 2007; Gidna *et al*. 2013). Thus, it is not feasible to state the maximum distance that human remains scavenged and scattered by foxes can be recovered. However, this study did find the majority of scavenged deer remains to be located within a 45 m radius inclusive of the deposit site (Chapter 4). For forensic investigations and physical searches this information is vital to making informed decisions and adaptations to search and recovery methods at scenes.

7.4 FUTURE RESEARCH

Criminal and non-criminal scene scenarios do vary and the effects that each scenario can have on scavenging will inevitably vary as well, thus this study also acts as a basis from which future scavenging studies can be compared. It will be beneficial to many fields of studies, forensic scientists, investigators, and police search officers for the methodologies used in the field experiments within this study to be repeated with different conditions of remains (e.g. clothed; buried; post-mortem interval) deposited in different environments (e.g. open land, farm, urban) and regions, so that any changes in scavengers' species-typical scavenging behaviour and patterns can be identified and interpreted. Likewise, extending the research to incorporate field experiments in other regions where foxes are not the largest scavengers will allow for the effects that such scavengers have on fox's species-typical scavenging to be measured and interpreted.

During this study it was evident that police search officers have experiences of cases of human remains being scavenged in Northwestern Europe (Chapter 2) but that this is underrepresented in the literature (Chapter 1). Police specialist searchers had different levels of experience and knowledge of human osteology and scavenging, which affected how and what search methods were adapted at a scene (Chapter 2; 6). The grid search experiments in this study should be extended to further police specialist searchers from different regions to highlight where searchers' knowledge of osteology and scavenging can be improved and adapted for more effective and efficient physical searches of scavenged remains. This research and its results have already been disseminated to a portion of police, police specialist searchers, and non-specialist searchers within this region but will be continued to be distributed. However, there is no current search protocol for scavenged and scattered human remains, nor is scavenging included in the licencing and training of police search officers. In order to improve the adaptation and implementation of search methods to the recovery of scavenged and scattered human remains, search protocols and the licencing and training of police search officers need to be updated to include scavenging.

7.5 CONCLUSIONS

This research has provided new knowledge on the scavenging behaviour and patterns of the main scavengers of surface deposited remains in a peri-urban or rural environment within the U.K., and, to a wider extent, Northwestern Europe, which include the wood mouse, grey squirrel, carrion crow, buzzard, Eurasian badger, and red fox. The effects of scavengers' species-typical scavenging behaviour and patterns on soft tissue and skeletal remains have been identified and interpreted using a multidisciplinary approach with both quantitative and qualitative methods. Factors which proved to have a significant impact on how and when different animals scavenged deer and human remains included carcass size and condition, post-mortem interval, stage of decomposition, insect activity, and seasonality. These factors must be taken into consideration when conducting a forensic investigation and physical search of a scene involving scavenging.

Out of the aforementioned scavengers found in this region, the red fox is the scavenger which is capable of causing the most damage and modification to human remains through its species-typical scavenging behaviour and pattern. The species-typical scavenging behaviour and pattern of the red fox has been outlined and characterised successfully within this study. The study has identified previously unknown differences between the scavenging behaviour and pattern of foxes and the more commonly studied larger canids found in other regions and in different environments, as well as differences in their effects on skeletal elements. The use of bite mark analysis without consideration of scavengers' species-typical scavenging behaviours and patterns and the factors affecting them was found not to be successful in the identification of a scavenger species.

The application to forensic investigations and physical searches of the new knowledge and methodologies of this study pertaining to scavengers' species-typical scavenging behaviour, modification to skeletal remains, and scatter pattern of skeletal elements was effective in improving investigations and search methods. This research has illustrated the necessity for species-typical and region- and environment- specific scavenging studies in order to assist in more accurate interpretations and identifications associated with not just forensic investigations and physical searches but also a multitude of fields (e.g. taphonomy, archaeology, ecology).

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APPENDIX I

Table A1-1. Scavenging literature from the fields of taphonomy, zooarchaeology, archaeology, forensic archaeology, forensic anthropology, paleoecology, and forensic pathology: highlighting scavenger species and the regions of focus.

Author(s)	Year of Publication	Region of Interest	Animal Scavenger(s)
Lyon, P.	1970	South America	Dog (*Canis familiaris*)
Sutcliffe, A.J.	1970	East Africa	Spotted hyena (*Crocuta crocuta*)
Hill, A.	1979	East Africa	Hyena, jackal (*Canis mesomelas*), vulture (*Gyps africanus*)
Behrensmeyer, A. & Dechant Boaz, D.E.	1980	East Africa	Hyena
Haynes, G.	1980	North America	Bear (*Ursus americanus*) , wolverine (*Gulo gulo*), coyote (*Canis latrans*), fox (*Vulpes*), lynx (*Lynx canadensis*), fisher (*Martes pemmanti*), bobcat (*Lynx rufus*), weasel (*Mustela*)
Binford, L.	1981	North America	Wolf (*Canis lupus*)
Brain, C.K.	1981	Africa	Hyaenidae; Leopard (Panthera pardus); South African porcupine (Hystrix africaeaustralis)
Haynes, G.	1982	North America	Wolf

Table A1-1 (continued). Scavenging literature from the fields of taphonomy, zooarchaeology, archaeology, forensic archaeology, forensic anthropology, paleoecology, and forensic pathology: highlighting scavenger species and the regions of focus.

Author(s)	Year of Publication	Region of Interest	Animal Scavenger(s)
Andrews, P. & Evans, E.M.N.	1983	Britain	Mongoose (Herpestidae), genet (*Genetta*), red fox (*Vulpes vulpes*), coyote, weasel, marten (*Martes*), polecat (*Mustela putorius*)
Haynes, G.	1983a	North America	Large cats, canids, bear (*Ursus arctos*, *Ursus americanus*), hyena, wolf
Haynes, G.	1983b	North America	Wolf, bear
D'Andrea, A.C. & Gotthardt, R.M.	1984	North America	Wolf
Hill, A. & Behrensmeyer, A.K.	1984	East Africa	Lion (*Panthera leo*), hyena, jackal, vulture
Andrews, P. & Cook, J.	1985	Britain	Red fox, badger (*Meles meles*), domestic dog
Blumenschine, R.J.	1988	East Africa	Hyena, mongoose, jackal
Haglund, W.D. et al.	1988	North America	Coyote, domestic dog, rodents

Table A1-1 (continued). Scavenging literature from the fields of taphonomy, zooarchaeology, archaeology, forensic archaeology, forensic anthropology, paleoecology, and forensic pathology: highlighting scavenger species and the regions of focus.

Author(s)	**Year of Publication**	**Region of Interest**	**Animal Scavenger(s)**
Horwitz, L.K. & Smith, P.	1988	Israel	Striped hyena (*Hyena hyena*)
Haglund, W.D. *et al*.	1989	North America	Coyote, domestic dog
Milner, G.R. & Smith, V.G.	1989	North America	Wolf, dog
Werdelin, L.	1989	North America	*Canis Osteoborus;* modern hyena
Willey, P. & Snyder, L.M.	1989	North America	Timber Wolf
Andrews, P.	1990	Britain	Shrew (Soricidae)
Mann, R.W. *et al*.	1990	North America	'Carnivores', rodents
Cruz-Uribe, K.	1991	Israel	Hyena
Marean, C.W. & Spencer, L.M.	1991	East Africa	Hyena

Table A1-1 (continued). Scavenging literature from the fields of taphonomy, zooarchaeology, archaeology, forensic archaeology, forensic anthropology, paleoecology, and forensic pathology: highlighting scavenger species and the regions of focus.

Author(s)	**Year of Publication**	**Region of Interest**	**Animal Scavenger(s)**
Stiner, M.	1991	Mediterranean Europe	Hyena, wolf
Haglund, W.D.	1992	North America	Rodents
Marean, C.W. *et al*.	1992	East Africa	Hyena
Owsley, D. *et al*.	1992	North America	'Scavengers'
Chase, P.G. *et al*.	1994	France	Hyena, wolf
Patel, F.	1994	Indoor	Rodents
Selvaggio, M.	1994	East Africa	Cheetah (*Acinonyx jubatus*), leopard, lion, jackal, spotted hyena
Andrews, P.	1995	Britain	Red fox, badger, domestic dog, rodents

Table A1-1 (continued). Scavenging literature from the fields of taphonomy, zooarchaeology, archaeology, forensic archaeology, forensic anthropology, paleoecology, and forensic pathology: highlighting scavenger species and the regions of focus.

Author(s)	Year of Publication	Region of Interest	Animal Scavenger(s)
Ropohl, D. *et al*.	1995	Indoor	Golden hamster (*Mesocricetus auratus*)
Blumenschine, R.J. *et al*.	1996	East Africa & North America	Spotted hyena, lion
Andrews, P. & Fernandez-Jalvo, Y.	1997	Spain	Lion, red fox, bear (*Ursus spelaeus*)
Rothschild, M.A. & Schneider, V.	1997	Indoor	Domestic dog
Komar, D.	1998	North America	Coyote, wolf, black bear, red fox, porcupine (*Erethizon dorsatum*)
Travaini, A. *et al.*	1998	South America	Avian
Domínguez-Rodrigo, M.	1999	East Africa	Lion
Tsokos, M. & Schulz, F.	1999	Indoor	Rodents, domestic dog

Table A1-1 (continued). Scavenging literature from the fields of taphonomy, zooarchaeology, archaeology, forensic archaeology, forensic anthropology, paleoecology, and forensic pathology: highlighting scavenger species and the regions of focus.

Author(s)	**Year of Publication**	**Region of Interest**	**Animal Scavenger(s)**
Pickering, T.R.	2001	southern Africa	Leopard, spotted hyena
Selvaggio, M.M. & Wilder, J.	2001	East Africa	Cheetah, leopard, lion, jackal, hyena
Pasda, K.	2002	Greenland	Polar fox (*Vulpes lagopus*), raven (*Corvus corax*), white-tailed eagle (*Haliaeetus albicilla*)
Komar, D.	2003	North America	'Carnivores', rodents, avian, domestic cat (*Felis catus*)
Asamura, H. *et al*.	2004	Asia	Crow (*Corvus macrorhynchos*; *Corvus corone*)
DeVault, T.L. *et al*.	2004	North America	Raccoon (*Procyn letor*), Virginia opossum (*Didelphis virginiana*), feral pig (*Sus scrofa*)
Pickering, T. & Carlson, K.J.	2004	southern Africa	Leopard
Pickering, T.R. *et al*.	2004	southern Africa	Leopard

Table A1-1 (continued). Scavenging literature from the fields of taphonomy, zooarchaeology, archaeology, forensic archaeology, forensic anthropology, paleoecology, and forensic pathology: highlighting scavenger species and the regions of focus.

Author(s)	Year of Publication	Region of Interest	Animal Scavenger(s)
Potmesil, M.	2005	North America	Coyote, rodents
Brown, O.J.F. et al.	2006	Australia	Feral pig, red fox, Australian raven, wedge-tailed eagle (Aquila audax), lace monitor (Varanus varius)
Domínguez-Rodrigo, M. & Barba, R.	2006	East Africa	Leopard, hyena, cheetah, lion
Morton, R.J. & Lord, W.D.	2006	North America	Red fox, turkey vulture (*Catharses aura*), crow (*Corvus brachyrhynchos*), opossum, raccoon, striped skunk (*Mephitis mephitis*)
Schulz, I. et al.	2006	Indoor	Domestic dog, domestic cats
Smith, M.J.	2006	Britain	Wolf, dog, rodents
Coard, R.	2007	Britain	Felids, red fox

Table A1-1 (continued). Scavenging literature from the fields of taphonomy, zooarchaeology, archaeology, forensic archaeology, forensic anthropology, paleoecology, and forensic pathology: highlighting scavenger species and the regions of focus.

Author(s)	**Year of Publication**	**Region of Interest**	**Animal Scavenger(s)**
Klippel, W. & Synstelien, J.	2007	North America	Grey squirrel (*Sciurus carolinensis*), brown rat (*Rattus norvegicus*)
Lord, T.C. *et al*.	2007	Britain	Wolf
O'Brien, R.C. *et al*.	2007	Australia	Avian, rodents
Steadman, D.W. & Worne, H.	2007	Indoor	Domestic dog
Wilson, A. *et al*.	2007	Britain	Red fox
Janjua, M.A. & Rogers, T.L.	2008	North America	Rodents, 'carnivore scavengers'
Vanlaerhoven, S.L. & Hughes, C.	2008	North America	Coyote, dog, rodents, avian
Kjorlien ,Y.P. *et al*.	2009	North America	Crow, magpie (*Pica pica*), coyote
Reeves, N.	2009	North America	American black vulture (*Coragyps atratus*) and turkey vulture

Table A1-1 (continued). Scavenging literature from the fields of taphonomy, zooarchaeology, archaeology, forensic archaeology, forensic anthropology, paleoecology, and forensic pathology: highlighting scavenger species and the regions of focus.

Author(s)	**Year of Publication**	**Region of Interest**	**Animal Scavenger(s)**
Moraitis, K. & Spiliopoulou, C.	2010	Greece	'Carnivores'
Cáceres, I. *et al*.	2011	Spain	Fallow deer *(Dama dama*), red deer (*Cervus elaphus*), red fox, black vulture (*Aegypius monachus*), griffon vulture (*Gyps fulvus*)
Domínguez-Solera, S. & Domínguez-Rodrigo, M.	2011	Spain	Griffon vulture
Spradley, M. *et al*.	2011	North America	Vultures

APPENDIX II

A2-1 PUBLICATIONS

- Young, A., Stillman, R., Smith, M.J., and Korstjens, A., 2014. An experimental study of vertebrate scavenging behavior in a Northwest European woodland context. *Journal of Forensic Sciences*, In Press.

- Young, A., Márquez-Grant, N., Stillman, R., Smith, M.J., and Korstjens, A., 2014. An investigation of red fox (Vulpes vulpes) and Eurasian badger (Meles meles) scavenging, scattering and removal of deer remains: forensic implications and applications. *Journal of Forensic Sciences*, In Press.

A2-2 BOOK CONTRIBUTION

- Young, A., 2013*.* Advances in Scavenging Research. *In*: Cooper, J., and Cooper, M., eds. *Wildlife Forensic Investigation: Principles and Practice*. CRC Press, 403-404.

"Techniques used within the field of wildlife forensics usually focus on identifying the animal as the victim and the human as the perpetrator; however, comparable techniques can readily be applied when these roles reverse. Animal attacks occur not only on living humans but also on deceased individuals. The effects of scavenging on human remains are of great interest to a variety of fields of study such as zooarchaeology, palaeoecology, behavioural ecology, archaeology, wildlife forensics, forensic archaeology, and forensic anthropology.

The ways in which various animal scavenger species manipulate a human body greatly differ due to species' size, environment, behaviour, and the condition of the human remains. It is important that all of these factors are considered in an investigation.

In order to understand how mammalian scavenger species modify human remains, it is essential to employ a multidisciplinary approach to the investigation. A widely used method within forensic studies for understanding the decomposition and scavenging of the human body is to use animal carcases as human proxies. In North America, the species most frequently employed as a human proxy is the domestic pig on account of its comparative body size, fat content, and lack of dense hair (France et al., 1992; Kjorlien et al., 2009; Morton and Lord, 2006; VanLaerhoven and Hughes, 2008; Wilson et al., 2007). However, deer have also been used in various scavenging studies and are currently the taxon of choice in Britain due to regulations by DEFRA relating to the deposition of carcases of domestic livestock out of doors that might encourage the spread of infectious organisms (Haynes, 1982; Willey and Snyder, 1989). Unfortunately, scavenging studies within North-Western Europe are limited and, as a result, many investigations rely on data from North America, where there has been a large amount of research on scavenging using pig, deer, and human carcases. The majority of the North American studies focus on large canid scavenger species such as domestic dogs, coyotes, and wolves, which is appropriate for that region where these species are the most common wild canid scavengers (Haglund et al., 1989). Nevertheless, those North American models of scavenging by large canids are now being applied to a wide range of contexts encompassing different regions, environments, and scavenger species (Moraitis and Spiliopoulou, 2010; Ruffell and Murphy, 2011). In particular, using North American models of scavenging by large canids cannot be used satisfactorily to explain scavenging within Britain where the largest wild canid scavenger is the red fox. This animal is smaller than North American carnivores (e.g. wolves, coyotes) and it displays different scavenging behaviour and patterns. Likewise, the canid model cannot be applied to Britain's second most common wild scavenger, the Eurasian badger, the dental morphology and scavenging behaviour of which differ greatly from those of canids.

Forensic investigations would greatly benefit from species-typical and region-specific scavenging studies that assist in the correct identification and interpretation of a scavenger species and in more efficient search and recovery of key skeletal elements for victim and trauma identification."

APPENDIX III

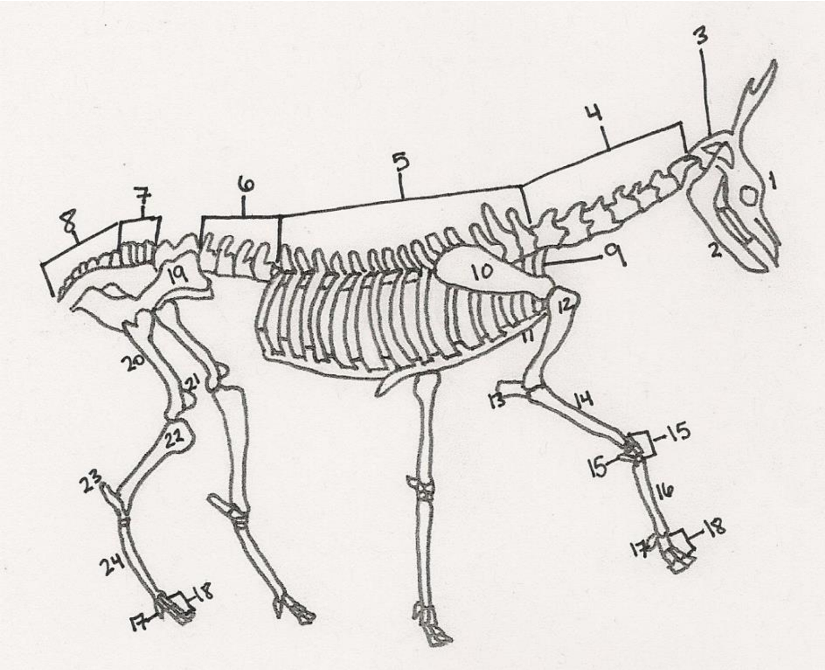

Figure A3-1. Skeletal system of deer.

1. Cranium
2. Mandible
3. Poll
4. Cervical vertebrae
5. Thoracic vertebrae
6. Lumbar vertebrae
7. Sacrum
8. Coccyx
9. Ribs
10. Scapula
11. Sternum
12. Humerus
13. Ulna
14. Radius
15. Carpals
16. Metacarpal
17. Sesamoid
18. Phalanges
19. Pelvis
20. Femur

21. Patella
22. Tibia
23. Calcaneus
24. Metatarsal

Figure A3-2. Surface deposit of Bait1A.

Figure A3-3. Surface deposit of Bait 2A.

Figure A3-4. Surface deposit of Bait 3A.

Figure A3-5. Surface deposit of Bait4A.

Figure A3-6. Surface deposit of Bait 5A.

Figure A3-7. Surface deposit of Bait 6A.

Figure A3-8. Surface deposit of Bait 1B.

Figure A3-9. Surface deposit of Bait 2B.

Figure A3-10. Surface deposit of Bait 3B.

Figure A3-11. Surface deposit of Bait 4B.

Figure A3-12. Surface deposit of Bait 5B.

Figure A3-13. Surface deposit of Bait 6B.

Figure A3-14. Surface deposit of Deer 1.

Figure A3-15. Surface deposit of Deer 2.

Figure A3-16. Surface deposit of Deer 3.

Figure A3-17. Surface deposit of Deer 4.

Figure A3-18. Surface deposit of Deer 5.

Figure A3-19. SPYPOINT IR-7 infrared motion detection cameras were secured to trees overlooking deposit sites.

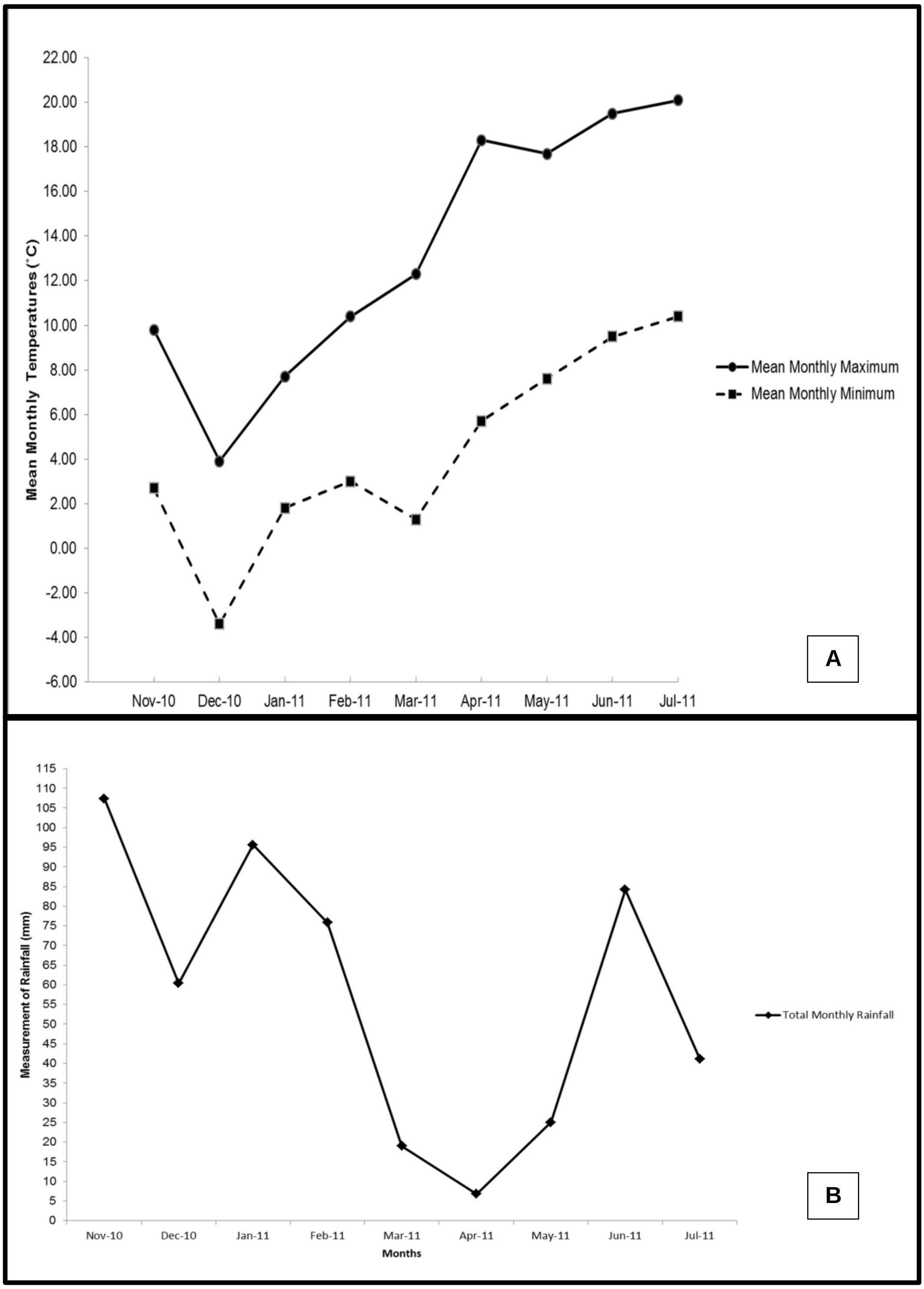

Figure A3-20. The mean maximum and minimum temperature per month of the experiment (A) and the total rainfall per month of the experiment (B).

Table A3-1. The locations affected on Deer 1 by red fox scavenging and investigative behaviours.

	Scavenging		Approaching		Sniff or Lick		Bite No Pick Up		Investigative Bite & Pick Up		Total	
Locations	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**
Head/Neck	0	0	0	0	0	0	0	0	0	0	0	0
Front Limbs	0.35	1	0	0	0	0	0	0	0	0	0.26	1
Dorsal	0.71	2	2.33	1	4.00	2	0	0	0	0	1.32	5
Thoracic Cavity	86.57	245	39.53	17	38.00	19	100.00	2	0	0	74.47	283
Genitals	0	0	0	0	0	0	0	0	0	0	0	0
Abdominal Cavity	0	0	0	0	0	0	0	0	0	0	0	0
Hind End	1.41	4	13.95	6	6.00	3	0	0	50.00	1	3.68	14
Hind Legs	2.12	6	2.33	1	4.00	2	0	0	50.00	1	2.63	10
Gunshot Wound (GSW)	0	0	0	0	0	0	0	0	0	0	0	0
Skull*	0	0	0	0	0	0	0	0	0	0	0	0
Cervical vertebrae*	0	0	0	0	0	0	0	0	0	0	0	0
Front Limbs*	0	0	0	0	0	0	0	0	0	0	0	0
Thoracic Vertebrae*	0	0	0	0	0	0	0	0	0	0	0	0
Ribs*	3.18	9	20.93	9	18.00	9	0	0	0	0	7.11	27
Lumbar Vertebrae*	0	0	0	0	0	0	0	0	0	0	0	0
Innominates*	0	0	0	0	0	0	0	0	0	0	0	0
Hind Limbs*	5.30	15	20.93	9	22.00	11	0	0	0	0	9.21	35
All over†	0.35	1	0	0	4.00	2	0	0	0	0	0.79	3
All over*†	0	0	0	0	4.00	2	0	0	0	0	0.53	2
Soil Scattered Decomposition matter	0	0	0	0	0	0	0	0	0	0	0	0
Decomposition Stomach Contents	0	0	0	0	0	0	0	0	0	0	0	0
Total		283		43		50		2		2		380

* Skeletonised remains

†The animal displayed the behaviour over all areas of the deer in a recorded event

Table A3-2. The locations affected on Deer 2 by red fox scavenging and investigative behaviours.

	Scavenging		Approaching		Sniff or Lick		Bite No Pick Up		Investigative Bite & Pick Up		Total	
Locations	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**
Head/Neck	0	0	0	0	25.00	1	0	0	0	0	6.67	1
Front Limbs	0	0	0	0	0	0	0	0	0	0	0	0
Dorsal	0	0	0	0	0	0	0	0	0	0	0	0
Thoracic Cavity	12.50	1	0	0	0	0	0	0	0	0	6.67	1
Genitals	25.00	2	0	0	0	0	0	0	0	0	13.33	2
Abdominal Cavity	0	0	0	0	0	0	0	0	0	0	0	0
Hind End	12.50	1	0	0	75.00	3	0	0	0	0	26.67	4
Hind Legs	50.00	4	0	0	0	0	0	0	100.00	3	46.67	7
Gunshot Wound (GSW)	0	0	0	0	0	0	0	0	0	0	0	0
Skull*	0	0	0	0	0	0	0	0	0	0	0	0
Cervical vertebrae*	0	0	0	0	0	0	0	0	0	0	0	0
Front Limbs*	0	0	0	0	0	0	0	0	0	0	0	0
Thoracic Vertebrae*	0	0	0	0	0	0	0	0	0	0	0	0
Ribs*	0	0	0	0	0	0	0	0	0	0	0	0
Lumbar Vertebrae*	0	0	0	0	0	0	0	0	0	0	0	0
Innominates*	0	0	0	0	0	0	0	0	0	0	0	0
Hind Limbs*	0	0	0	0	0	0	0	0	0	0	0	0
All over†	0	0	0	0	0	0	0	0	0	0	0	0
All over*†	0	0	0	0	0	0	0	0	0	0	0	0
Soil Scattered Decomposition matter	0	0	0	0	0	0	0	0	0	0	0	0
Decomposition Stomach Contents	0	0	0	0	0	0	0	0	0	0	0	0
Total		8		0		4		0		3		15

* Skeletonised remains

†The animal displayed the behaviour over all areas of the deer in a recorded event

Table A3-3. The locations affected on Deer 3 by red fox scavenging and investigative behaviours.

	Scavenging		Approaching		Sniff or Lick		Bite No Pick Up		Investigative Bite & Pick Up		Total	
Locations	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**
Head/Neck	0	0	0	0	0	0	0	0	0	0	0	0
Front Limbs	0	0	0	0	0	0	0	0	0	0	0	0
Dorsal	6.67	1	0	0	33.33	1	0	0	0	0	10.00	2
Thoracic Cavity	0	0	0	0	0	0	0	0	0	0	0	0
Genitals	0	0	0	0	0	0	0	0	0	0	0	0
Abdominal Cavity	0	0	0	0	0	0	0	0	0	0	0	0
Hind End	0	0	100.00	1	33.33	1	0	0	0	0	10.00	2
Hind Legs	86.67	13	0	0	33.33	1	100.00	1	0	0	75.00	15
Gunshot Wound (GSW)	6.67	1	0	0	0	0	0	0	0	0	5.00	1
Skull*	0	0	0	0	0	0	0	0	0	0	0	0
Cervical vertebrae*	0	0	0	0	0	0	0	0	0	0	0	0
Front Limbs*	0	0	0	0	0	0	0	0	0	0	0	0
Thoracic Vertebrae*	0	0	0	0	0	0	0	0	0	0	0	0
Ribs*	0	0	0	0	0	0	0	0	0	0	0	0
Lumbar Vertebrae*	0	0	0	0	0	0	0	0	0	0	0	0
Innominates*	0	0	0	0	0	0	0	0	0	0	0	0
Hind Limbs*	0	0	0	0	0	0	0	0	0	0	0	0
All over†	0	0	0	0	0	0	0	0	0	0	0	0
All over*†	0	0	0	0	0	0	0	0	0	0	0	0
Soil Scattered Decomposition matter	0	0	0	0	0	0	0	0	0	0	0	0
Decomposition Stomach Contents	0	0	0	0	0	0	0	0	0	0	0	0
Total		15		1		3		1		0		20

* Skeletonised remains

†The animal displayed the behaviour over all areas of the deer in a recorded event

Table A3-4. The locations affected on Deer 4 by red fox scavenging and investigative behaviours.

	Scavenging		Approaching		Sniff or Lick		Bite No Pick Up		Investigative Bite & Pick Up		Total	
Locations	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**
Head/Neck	0	0	0	0	0	0	0	0	0	0	0	0
Front Limbs	0	0	0	0	0	0	0	0	0	0	0	0
Dorsal	0	0	0	0	0	0	0	0	0	0	0	0
Thoracic Cavity	0	0	0	0	0	0	0	0	0	0	0	0
Genitals	0	0	0	0	0	0	0	0	0	0	0	0
Abdominal Cavity	6.67	1	50.00	1	0	0	0	0	0	0	8.00	2
Hind End	73.33	11	50.00	1	40.00	2	33.33	1	0.00	0	60.00	15
Hind Legs	20.00	3	0	0	40.00	2	66.67	2	0.00	0	28.00	7
Gunshot Wound (GSW)	0	0	0	0	0	0	0	0	0	0	0	0
Skull*	0	0	0	0	0	0	0	0	0	0	0	0
Cervical vertebrae*	0	0	0	0	0	0	0	0	0	0	0	0
Front Limbs*	0	0	0	0	0	0	0	0	0	0	0	0
Thoracic Vertebrae*	0	0	0	0	0	0	0	0	0	0	0	0
Ribs*	0	0	0	0	20.00	1	0	0	0	0	4.00	1
Lumbar Vertebrae*	0	0	0	0	0	0	0	0	0	0	0	0
Innominates*	0	0	0	0	0	0	0	0	0	0	0	0
Hind Limbs*	0	0	0	0	0	0	0	0	0	0	0	0
All over†	0	0	0	0	0	0	0	0	0	0	0	0
All over*†	0	0	0	0	0	0	0	0	0	0	0	0
Soil Scattered Decomposition matter	0	0	0	0	0	0	0	0	0	0	0	0
Decomposition Stomach Contents	0	0	0	0	0	0	0	0	0	0	0	0
Total		15		2		5		3		0		25

* Skeletonised remains

†The animal displayed the behaviour over all areas of the deer in a recorded event

Table A3-5. The locations affected on Deer 5 by red fox scavenging and investigative behaviours.

	Scavenging		Approaching		Sniff or Lick		Bite No Pick Up		Investigative Bite & Pick Up		Total	
Locations	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**
Head/Neck	0	0	0	0	0	0	0	0	0	0	0	0
Front Limbs	0	0	0	0	0	0	0	0	0	0	0	0
Dorsal	0	0	0	0	0	0	0	0	0	0	0	0
Thoracic Cavity	0	0	0	0	0	0	0	0	0	0	0	0
Genitals	0	0	0	0	0	0	0	0	0	0	0	0
Abdominal Cavity	11.11	1	0	0	66.67	2	0	0	0	0	25.00	3
Hind End	0	0	0	0	33.33	1	0	0	0	0	8.33	1
Hind Legs	11.11	1	0	0	0	0	0	0	0	0	8.33	1
Gunshot Wound (GSW)	0	0	0	0	0	0	0	0	0	0	0	0
Skull*	22.22	2	0	0	0	0	0	0	0	0	16.67	2
Cervical vertebrae*	22.22	2	0	0	0	0	0	0	0	0	16.67	2
Front Limbs*	0	0	0	0	0	0	0	0	0	0	0	0
Thoracic Vertebrae*	0	0	0	0	0	0	0	0	0	0	0	0
Ribs*	0	0	0	0	0	0	0	0	0	0	0	0
Lumbar Vertebrae*	0	0	0	0	0	0	0	0	0	0	0	0
Innominates*	0	0	0	0	0	0	0	0	0	0	0	0
Hind Limbs*	0	0	0	0	0	0	0	0	0	0	0	0
All over†	0	0	0	0	0	0	0	0	0	0	0	0
All over*†	0	0	0	0	0	0	0	0	0	0	0	0
Soil Scattered Decomposition matter	11.11	1	0	0	0	0	0	0	0	0	8.33	1
Decomposition Stomach Contents	22.22	2	0	0	0	0	0	0	0	0	16.67	2
Total		9		0		3		0		0		12

* Skeletonised remains

†The animal displayed the behaviour over all areas of the deer in a recorded event

APPENDIX IV

A4-1 INFRARED CAMERA DETECTIONS OF SCAVENGING BEHAVIOURS

A4-1.1 Baits (*Cervus nippon*; *Capreolus capreolus*)

Red foxes (*Vulpes vulpes*) were recorded at or near the baits a total of 33 times, of which foxes were observed scavenging in 42.42% of those recordings. All recordings of scavenging by foxes occurred after sunset. All baits were scavenged and removed from their deposit sites within seven days of exposure. A site search (80 m x 80 m) did not result in the recovery of any bones but did reveal areas where baits had been dragged (e.g. scattered deer fur from baits), depressed vegetation, and evidence of animal activity (e.g. scat, setts, dens).

A4-1.2 Deer 1

Overall, foxes were recorded present at or near Deer 1 a total of 335 times and were observed scavenging (e.g. removing soft tissue and/or bone) the deer 79.70% of the time. Foxes scavenged both after sunset and during daylight hours but were observed scavenging more often after sunset (96.63%) (Table 4.4). Scavenging was observed at different stages of decomposition but was more frequent whilst the carcass was still in a fresh stage of decomposition (Table 4.6). Foxes were also observed scavenging and removing soft tissue from the carcass in both dry and wet (e.g. snow) conditions.

Although the experiment site was restricted from public access off-lead domestic dogs were observed entering the site. Off-lead domestic dogs (*Canis familiaris*) were recorded 101 times at or near Deer 1, of these recordings scavenging occurred 44.60% of the time. Of those recordings, only a Staffordshire Bull Terrier was recorded scavenging from the deer on the 10th day of exposure. The presence of this canid scavenger had an effect on not only on Deer 1 but also the scavenging behaviours of the foxes in the site. The other dogs were only observed investigating (e.g. sniff or lick), urine marking or trampling the deer in both a fresh and skeletonised stage of decomposition at the head/neck. In comparison to the observed wild foxes, there were neither non-penetrative bites to the carcass nor displays of cautious behaviours nor any attempts by dogs to drag or remove the carcass, soft tissue or skeletal elements from the deposit site for further scavenging. No foxes were observed near the deer or deposit site throughout the whole time that the dog was present at the deer and did not appear at the site until five hours after the dog's departure.

Prior to making bites to the deer, individual foxes displayed cautious and investigative behaviours at all stages of the deer's decomposition. The removal of soft tissue and bones from Deer 1 by foxes was primarily concentrated on the thoracic cavity, previously opened and widened by the aforementioned scavenging dog. Throughout the total length of exposure of the deer (210 days), scavenging by foxes was also observed at the front limbs, hind end, hind legs, and dorsal side of the deer, as well as the skeletonised ribs and hind legs. Foxes were also recorded trying to pull and move the carcass from its deposit site, as well as removing smaller amounts of soft tissue or organs from the carcass at the deposit site. The final recording of a fox present and scavenging from the deer was on the 106th day of exposure, by that time the deer was skeletonised (Table 4.5).

A4-1.3 Deer 2

Throughout the entire time that Deer 2 was deposited, only one badger was observed before sunrise, walking into a sett entrance about 12 m southwest of the deposit site. Foxes were recorded at or near Deer 2 a total of 14 times, of these recordings 50.00% showed individual foxes scavenging from the deer. Scavenging was only observed at night and occurred only during the early decomposition stage for this deer. Foxes scavenged from the thoracic cavity, genital region, hind end and hind legs of Deer 2. Prior to scavenging, the hind end was the most commonly investigated area of the carcass by foxes prior to making any bites (Appendix III, Tables A3-1 to A3-5). The first fox observed at or near the deer was on the 16th day of exposure, the fox approached the hind end of the deer but made no attempt to sniff or bite the carcass. Scavenging of the deer did not occur until the 27th day of exposure, at which a single fox, twice, made a non-penetrative bite to the right hind leg of the deer and then quickly dropped the leg and stepped back from the carcass a short distance. There were no recordings of any further fox activity until the 31st day of exposure when the same behaviour, as seen on the 27th day, was displayed and followed by attempts by a single fox to remove the deer from its deposit site.

A4-1.4 Deer 3

Foxes were recorded as present at or near Deer 3 and its deposit site on 20 occasions, of those events foxes were observed scavenging 75.00% of the time. Similar to Deer 2, scavenging was only observed at night and occurred only during the early decomposition stage for this deer. Scavenging by individual foxes was primarily focused on the hind legs of the deer but was also seen at the site of trauma (gunshot wound) (Appendix III, Table A3-1 to A3-5). Overall, foxes concentrated their investigation of the deer at the hind end and hind legs. When approaching the deer, foxes were only observed to first approach and make non-penetrative bites to the hind end of the deer.

The first fox recorded at or near Deer 3 was on the 7th day of exposure. A single fox was recorded walking near the hind end of the deer at a distance, sniffing the air and ground with its nose in the direction of the hind end. The fox then walked away from the deer and out of view. Four minutes after this event, an individual fox made approximately five quick bites to the hind end of the deer. During these actions, the fox bit the hind end and jumped back from the deer each time. The fox then sat at a short distance from the hind end whilst looking towards the head of the deer and behind the fox itself. Approximately two minutes after these actions, a single fox was recorded dragging the deer from the deposit site a short distance for only one minute, followed by the same fox removing fur and soft tissue from the right hind leg of the deer. A single fox was recorded dragging the deer away from the deposit site by the deer's right hind leg (Figure 4.9). The stop and go action by a single fox to drag the deer from its deposit site lasted for a total of five minutes. Following the immediate removal of the deer from its deposit site, the fox also walked directly to the ground surface previously underneath the deer and consumed any fallen remains. The final recording of a fox at the deposit site for Deer 3 was on the 32nd day; however, the deer had already been removed and scavenged on the 7th day by foxes (Table 4.5).

A4-1.5 Deer 4

Individual foxes were observed a total of 26 times, of these recordings foxes were seen scavenging 57.69% of the time. Scavenging by foxes was only observed during the advanced decomposition stage of Deer 4 after the departure of the large maggot mass within the thoracic and abdominal cavities of the deer. Scavenging occurred primarily at night (6.67%) but was also observed during the day (93.33%) (Table 4.4). Scavenging was focused at the hind end and hind legs of Deer 4, as were the areas that foxes approached and investigated of the carcass prior to scavenging (Appendix III, Table A3-1 to A3-5). On the 17th day of exposure, the first fox was recorded near the deer and its deposit site. There were no recordings of further fox activity until the 20th day when a single fox slowly approached the hind legs of the deer and made a small bite to the right hind leg (no removal of fur or soft tissue) then slightly jumped back from the deer. The fox left the deer then returned and made additional small bites to the left hind leg and hind end of the deer. The single fox then pulled at the hind end of the deer until the lower half of the deer separated from the top half thus exposing the abdominal cavity and stomach contents of the carcass. The fox did not scavenge from the soft tissue within the abdominal cavity which was at a more advanced stage of decomposition than the hind end and hind legs of the deer. Instead, the fox scavenged and removed soft tissue from the hind end and hind legs of the deer. Following scavenging by this fox, the lower half of the deer remained near the deposit site (<1m). An additional single fox was not observed again until the 39th day. The single fox was observed during the day biting and picking up the right hind leg of the deer and removing the articulated lower half of the deer from the deposit site. The front half of the carcass (e.g. head to entire exposed ribcage) remained at the deposit site until the final day of exposure. The 57th day was the last day at which a fox was sighted at Deer 4. The fox was recorded sniffing the desiccated remains (e.g. intact ribcage) of the deer but did not make any attempts to remove or scavenge any remains.

A4-1.6 Deer 5

Foxes were recorded scavenging 57.14% in seven recordings of individual foxes at Deer 5. Scavenging was observed both during the day (25.00%) and at night (75.00%) (Table 4.4). Similar to Deer 4, foxes mostly scavenged during the advanced decomposition stage after the departure of the large maggot mass in the thoracic and abdominal cavities (Table 4.6). However, individual foxes were also observed to scavenge the deposit site after the deer had been previously scavenged, scattered and become skeletonised. Foxes scavenged from more areas of Deer 5 than was observed for Deer 4 (Appendix III, Tables A3-1 to A3-5). Scavenging was observed at the abdominal cavity, hind legs, skull, cervical vertebrae, and decomposed soft tissue from the abdominal cavity, as well as scattered decomposition matter on the soil surface.

The first fox recorded at Deer 5, on the 14th day of exposure, was observed only sniffing the hind end of the deer. Further fox activity was not detected until the 33rd day, upon which a fox was observed sniffing the abdominal region of the deer then walking away. The fox was not successful in dragging the deer from the site but made two additional bites to the leg and removed a small amount of fur and soft tissue. On the 34th day, a single fox approached the deer’s thoracic cavity whilst sniffing and removing scattered remains on the soil surface. The fox then proceeded to sniff towards the hind end of the deer and leave the site. The cameras failed to detect any further fox scavenging activity of Deer 5 until the 87th day, by which time the deer had been scavenged and scattered by a fox undetected by the camera between the 43rd day and the 56th day but was evident by the presence of fox paw prints, faeces containing deer fur, bite marks on bones, and fox fur at the deposit site. The fox recorded on the 87th day was observed scavenging from a collection of decomposed soft tissue, vertebrae and ribs deposited where the thoracic and abdominal cavities had been situated at the site. The final fox was recorded on the 88th day and was observed scavenging decomposed soft tissue and scattered bone within the deposit site (Table 4.5).

A4-3 INSECT ACTIVITY

Although insect activity was not quantified, it was observed and recorded during this study at each site visit. Insect activity had different effects on each scavenger species’ scavenging behaviours and patterns. Likewise, insect activity was affected by the scavenging of remains. The insect activity observed at each deer is comparable to forensic cases including and not including scavenging, thus it is of interest to describe the activity (Benecke 1998; Campobasso *et al*. 2001; Kulshrestha and Satpathy 2001; Pohjoismäki *et al*. 2010).

A4-3.1 Deer 1

No insect activity was observed at Deer 1 until the deer was exposed for 65 days and had already been scavenged by a dog, foxes, buzzards (*Buteo buteo*) and wood mice (*Apodemus sylvaticus*). On the 65th day, Deer 1 was almost completely skeletonised with fur and skin only present on the top of the cranium and hooves, including metatarsals and phalanges. The observed insect activity included blowflies, Calliphoridae, on the bone surface where cartilage was present (e.g. articular surfaces). Maggots were found between the articular surface of the ribs and thoracic vertebrae on the 87th day. Insect activity was not observed again until the 176th day and included the presence of carrion beetles including one *Nicrophorus orbicollis* and two *Oiceoptoma thoracicum* on the surface of a femur with dried cartilage (Figure A4-1). No additional insect activity was observed following the 176th day.

Figure A4-1. Carrion beetles on the skeletonised remains (distal end of femur) of Deer 1.

A4-3.2 Deer 2

On the 8th day of Deer 2's exposure, blowflies were observed near the head of the deer. Seven days later and there appeared to be an increase in blowflies on the fur of the deer. After an additional six days, there was still an increased presence of blowflies but also the presence of cheese skipper flies (*Piophila casei* Linné) observed near the bloated stomach of the deer (Figure A4-2). Insect activity was observed to decrease on the 30th day of exposure but blowflies were still present. No insect activity was observed during the additional 14 days that Deer 2 was within the site.

Figure A4-2. A cheese skipper fly on the abdominal cavity of Deer 2 prior to advanded stage of decomposition.

A4-3.3 Deer 3

There was no observed insect activity at Deer 3.

A4-3.4 Deer 4

There was a large presence of blowflies during the deposit of Deer 4. A large presence of blowflies was still present on the 8th day of the deer's exposure and included blowflies near the gunshot wound entry site in the soft tissue of the thorax. After seven days, the same level of insect activity was observed. On the 20th day of exposure, following a fox pulling at the hind end of the deer and thus exposing the abdominal cavity, a large maggot mass was exposed amongst the stretched contents of the deer's stomach. Blowflies were also present at the hind end and abdominal cavity and smaller maggot mass was present in the mouth of the deer. The maggot mass no longer existed on the 28th day but blowflies were present. Again on the 35th day blowflies were still present at the deer. No insect activity was present between the 43rd day and the 82nd day. On the 83rd day, Silphidae larvae were found on the desiccated head, in particular in the right ear, and a carrion beetle was found on the scavenged and scattered hind leg of Deer 4 (Figure A4-3). A wood ant (*Formica*) colony was also discovered underneath the thoracic cavity on the 90th day of Deer 4's exposure. No further insect activity was observed during its remaining 13 days within the site.

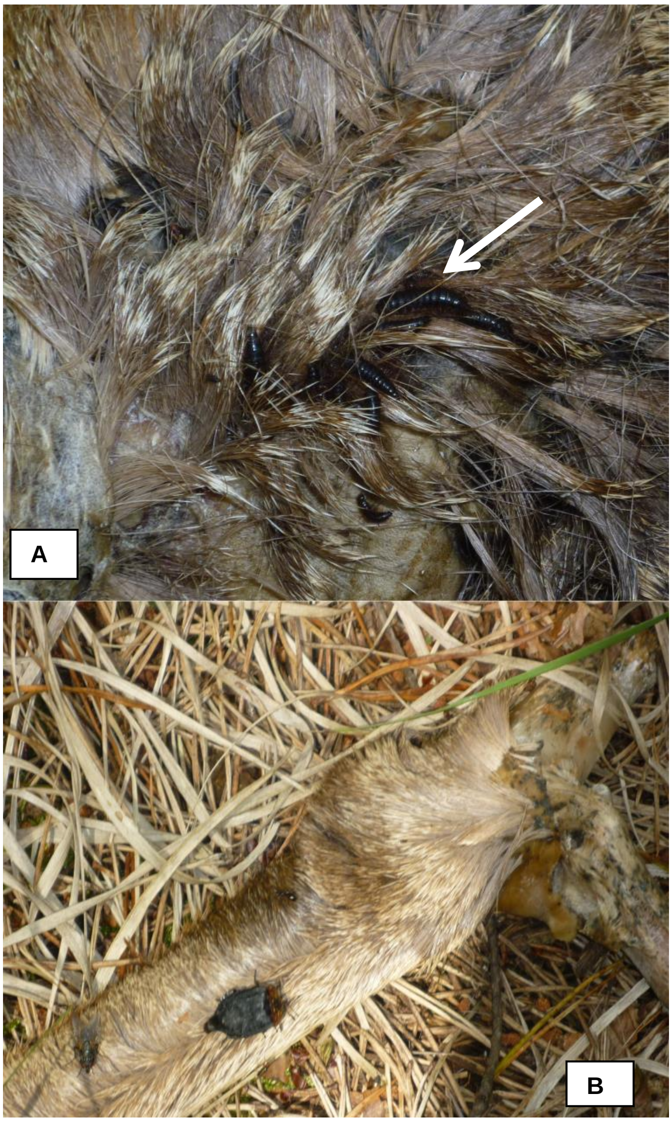

Figure A4-3. Silphidae larvae were found within the fur of the desiccated ear of Deer 4 (A). Carrion beetles were observed on the hind leg, disarticulated at the proximal end of the femur, of Deer 4 (B).

A4-3.5 Deer 5

As with Deer 4, there blowflies were abundant during the deposit of Deer 5. On the 8th day of exposure, there appeared to be more blowflies at Deer 5 than at Deer 4. Blowflies were seen entering and exiting the thorax via the gunshot wound entry site (Figure A4-4). The increased blowfly activity continued at the site of the gunshot wound until the 28th day, at which a large maggot mass was visible at the gunshot wound. Maggots were observed exiting from the gunshot wound (Figure A4-5). Smaller maggot masses were present in the mouth of the deer and at the hind legs where carrion crows had scavenged and exposed soft tissue (Figure A4-6). The large Calliphoridae maggot mass was no longer visible on the 35th day but a large Silphidae larvae mass was present on the dorsal side of Deer 5 (Figure A4-7). Blowflies and cheese skipper flies were still present in the air and at the deer. After eight days, the Silphidae larvae mass were still present on the dorsal side. The entire deer was desiccated, scavenged and scattered by the 56th day, at which no larvae were present and all insect activity appeared to decrease. There were no additional observations of insect activity during the final 47 days that the scavenged bones of Deer 5 remained within the site.

Figure A4-4. Many blowflies seen entering and exiting the thoracic cavity of Deer 5 via the gunshot wound. The skin surrounding the wound was absent of fur due to carrion crow activity.

Figure A4-5. Maggot mass visible at the gunshot wound site of Deer 5. Maggots seen exiting through the wound.

Figure A4-6. A small maggot mass was present within the hind legs where carrion crows had previously scavenged.

Figure A4-7. As Deer 5 became dessicated and the large maggot mass was no longer present or visible within the thoracic cavity, Silphidae larvae were found at an exposed area of soft tissue on the dorsal side of the deer.