

STUDIES IN TAPHONOMY: BONE AND SOFT TISSUE MODIFICATIONS BY POSTMORTEM SCAVENGERS

A Dissertation Presented for the
Doctor of Philosophy
Degree
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ABSTRACT

This study documented animal scavengers at the University of Tennessee's Anthropology Research Facility. Remotely-captured digital video and still photography equipment was stationed at the outdoor human decomposition facility intermittently from September 2003 through October 2009. The primary scavengers of corpses were identified as the northern raccoon (*Procyon lotor*), Virginia opossum (*Didelphis virginiana*), brown rat (*Rattus norvegicus*), and white-footed mouse (*Peromyscus leucopus*); and the primary scavenger of skeletal remains was the eastern gray squirrel (*Sciurus carolinensis*). Among these species, the raccoon was the dominant scavenger and is the focus of this report.

The captured imagery of raccoons documented four primary feeding behaviors at human remains: 1) scavenging soft tissue, 2) foraging in body cavities for late instar maggots en masse, 3) foraging for individual prepupae as they migrated away from the corpse, and 4) foraging for prepupae and puparia and other insects burrowed beneath ground litter and in the soil. As expected, these behaviors were largely sequential in appearance and their presence or absence depended on the conditions under which the corpse decayed, e.g., foraging for insect larvae did not occur at bodies placed in winter because few maggots were present.

Raccoons at the facility preferentially scavenged on the musculature of relatively fresh bodies. Their feeding sites often appeared atypical of a mammalian carnivore, because once they chewed a hole through the skin, they repeatedly placed a forepaw—even a forelimb—deep inside the wound and extracted tissue by way of the newly-formed hole. Although fresher bodies were more extensively scavenged, raccoons modified corpses throughout flesh decomposition—especially, by chewing the fingers and toes.

Bodies placed during winter were more intensively scavenged by raccoons in terms of total tissue removed and bone damage than those placed during fall or spring. Positional disturbances were noted at many bodies, but those placed in the spring incurred greater and more rapid skeletal disturbance and scatter due to warming temperatures and raccoons foraging within body cavities and the soil for maggots and pupae.

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INTRODUCTION

The present research took place at the University of Tennessee's Anthropology Research Facility. When this study began in September 2003, this outdoor human decomposition facility was unique in North America. This facility provided an unparalleled opportunity to observe small animals in their native habitat scavenging on human remains.

The 1.3-acre facility is located within the city limits of Knoxville, Tennessee; and on a bluff of the Tennessee River at mile marker 645.5 (Damann 2010; USACE 2013:Chart No. 87). The facility's approximate geographic location and elevation were obtained from www.terraser.com: the point coordinates are 35.94031, -83.93889; and the elevation is 283 m (900 ft) above mean sea level (amsl). Cardinal directions convey: the Tennessee River is north, Cherokee Bluff is east, Cherokee Trail is south, and the University of Tennessee Medical Center is west. The semi-wooded property lies just upslope of a string of UT Medical Center parking lots; and downslope of Cherokee Bluff—part of a heavily-wooded, steep section of South Knoxville (Figures 1-3).



Figure 1. An aerial view of the Anthropology Research Facility. Note the varying elevation of the south waterfront. Photograph taken in March 2001.



Figure 2. An aerial view of the Anthropology Research Facility. The lower arrow points to the location of several rock dens. The upper arrow points to the eastern fenceline. Image adapted from: <http://www.virtualearth.com>; courtesy of the U.S. Geological Survey Pictometry International.



Figure 3. A section of South Knoxville's Waterfront. The red target points to the facility. Image adapted from: <http://www.google.com/maps>; Imagery©2008 DigitalGlobe GeoEye MapData©2008 Tele Atlas.

The irregular-shaped property is surrounded by two fences—an 8 ft wooden privacy fence and a chain-link security fence topped with concertina wire. The two fences are separated by a variable distance of 1.0 to 5.0 ft, so one can walk most sections of the fencing. Free-ranging canids and coyotes are excluded from the property as long as the chain-link fencing is routinely inspected for problematic breaches. Because of the fencing, some of the smaller animals that forage inside the facility may decrease their overall risk of predation.

The woods along the east and north sides of the facility were inspected by foot for small mammal traces—primarily, raccoon. On the upslope, and to the east and southeast of the facility, multiple raccoon-sized denning sites were located: some showed clear use by raccoons. Several latrines or isolated scats were also found along the hillside. On the downslope and to the north and northwest of the facility, between one and three well beaten animal trails led to a wooded, relatively flat, and low-lying river bluff. A number of scat and smaller latrines were identified along these trails. On the east side of the bluff, were several large raccoon latrines with numerous, variably-aged scat accumulations—some even fresh. A number of well-used ground dens were located, opposite the river and spaced along the rock upslope and bluff floor. The dens were fashioned beneath-and-between the many rock outcroppings and crevices (Figure 4). The north side of the bluff overlooked the river; and there was a narrow trail that snaked down towards the water below. On the west side of the shaded bluff, a narrow animal trail appeared to continue westwards along the riverfront.

The Anthropology Research Facility is located in the Great [Appalachian] Valley of East Tennessee—known locally as the Tennessee Valley. This broad valley is oriented northeast to southwest and bordered by two mountain ranges: the Cumberland Mountains and Plateaus, which lie to the northwest and west, respectively; and the Great Smoky Mountains, which lie to the southeast. These mountain ranges buffer the valley from cold winter air that flows from the north; as well as hot summer winds, such as those experienced on the western plains (NOAA 2007). While the mountains shelter the valley from weather extremes, they also reduce the amount of wind that blows across the region, and stagnant air could form.

Knoxville's residents experience all four seasons. The climate is humid sub-tropical with short, mild winters and hot, humid summers (Ritter 2014). Thunderstorms and showers are



Figure 4. Probable raccoon dens. The den on the left is the same den pictured in the right photograph (left arrow). Persimmon seeds from a decomposed raccoon scat lay above the entrance. Photograph taken on 11 March 2009.

particularly common on summer afternoons, and bring the region relief from extreme heat. The valley experiences occasional periods of drought when dry air moves in from the Southwest (NOAA 2007).

Knoxville receives about 122.5 cm (48.2 in.) of annual precipitation, which is distributed roughly evenly throughout the year (Figure 5). Precipitation (rain and the liquid water equivalent of frozen precipitates) is greatest in the winter and spring; and least during the months of August, September, and October. About 25 cm (10 in.) of frozen precipitation (hail, snow, sleet, etc.) falls annually, but it typically melts within the first few days—rarely does it remain longer than a week. Knoxville’s normal annual temperature for years 1971-2000 is 14.7°C (58.4°F). The warmest month is July, with normal minimum and maximum temperatures of 20.3°C and 30.5°C (68.5°F and 86.9°F), respectively. The coldest month is typically January, with normal minimum and maximum temperatures of -1.7°C and 7.9°C (28.9°F and 46.3°F), respectively (NOAA 2007).

Knoxville is located in the Ridge and Valley physiographic province; further, the heterogenous Southern Limestone/Dolomite Valleys and Low Rolling Hills subdivision. About

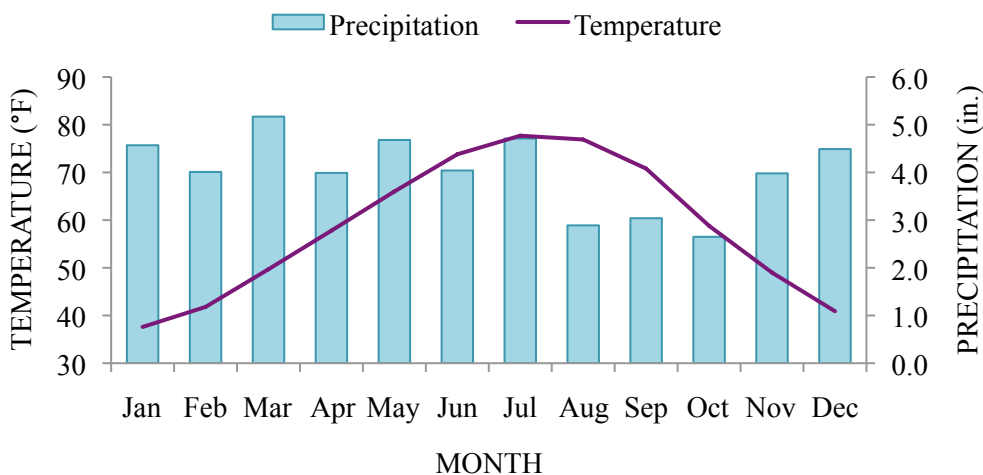


Figure 5. Normal monthly temperature and precipitation for Knoxville, years 1971-2000. Data published by the National Oceanic and Atmospheric Administration (NOAA 2007:3).

50% of this province is forested: ridges are often heavily so. Valleys are typically covered with cropland and pasture, residences—both urban and rural, and industry; with interspersed patches of thick forest (Griffith, et al. 1998). The vegetation of the Knoxville area is predominately mixed deciduous oak-hickory hardwoods (Griffith, et al. 1998). The Anthropology Research Facility's overstory is mostly comprised of secondary growth deciduous trees, like white oak (*Quercus alba*), silver maple (*Acer saccharinum*), and black walnut (*Juglans nigra*), among others. Numerous woody vines, briars, and weeds all common to East Tennessee are present, like honeysuckle (*Lonicera* spp.), poison ivy (*Rhus radicans*), and bitter nightshade (*Solanum dulcamara*). Wildflowers include the Indian strawberry (*Duchesnea indica*) and upright carrion flower (*Smilax ecirrata*)—a plant so named because it emits a decay odor which attracts blowflies, the main pollinators.

The facility lacks open water, but it is located by both flowing and still water sources. The largest body of water is the Tennessee River, which begins about 4.5 mi upstream of downtown Knoxville at the confluence of the Holston and French Broad Rivers. The Tennessee Valley Authority (TVA) controls the river's water level and flow through a series of locks and dams. At Knoxville, the Tennessee River is known as the Fort Loudoun Reservoir (or Lake), which extends 45 mi downriver to the Fort Loudoun Dam (TVA 2013).

The TVA generates the valley's hydroelectric power from the lengthy river and provides regional flood control; but the Tennessee River also serves as a mainstream navigable waterway and draws public recreationists. For these reasons, annual water drawdowns for the Fort Loudoun Reservoir are only about six feet; and the river's stage generally reads between 807 ft and 813 ft above mean sea level (amsl)—low pool and full pool, respectively (TVA 2013). As a controlled river system, valley precipitation shortages and excesses are monitored and largely offset; which makes riverine foods highly predictable for aquatic foragers, like the northern raccoon.

The Tennessee River is rich in aquatic resources. Benthic communities are dominated by midge larvae, aquatic worms, mayflies, mussels, and sometimes caddisflies and snails. About 50-90 freshwater fish species are present, like bass, crappie, sunfish, sauger, and catfish (TVA 1995). Crayfish are available year round. Minimally, raccoons forage along Knoxville's south

shoreline at low pool on shallow shoals up- and down-river from the facility; in search of clams and small minnows and shiners (e.g., ECATS 2008; TVA 2008). But the river channel by the facility drops quickly to 13 ft (Atlantic Mapping Inc. 2003). A photograph of the facility and riverfront taken in March 2001 (Figure 1) shows an isolated, narrow strip of shoreline. To determine the March pool stage, and other monthly stages, unofficial water level data for Fort Loudoun Reservoir were gathered via LakesOnline.com (<http://www.fortloudoun.info/levelcal.asp>). From December to April, the river is kept near low pool—so it follows, that in a typical weather year, there is an exposed, isolated riverbank along the facility’s waterfront for a period of about four months. This bank is submerged beneath shallow waters during the months of April and November, and is covered by water too deep for raccoon foragers from May to October’s end, when the reservoir is raised to full pool.

Aerial images of the facility show its position with respect to the river (Figures 1-2). While the facility is located on the south waterfront, it is elevated about 27 m (90 ft) above the river. To access the shoreline, terrestrial mammals must travel either up to 0.20 mi (0.32 km) downslope, or no less than 0.54 mi (0.87 km) upriver over Cherokee Bluff. Given the waterfront topography and the UT Medical Center sprawl, the facility borders a narrow land corridor—really a trail—used by wildlife to reach the river west of Cherokee Bluff. This corridor leads to a year-round source of drinking water and aquatic foods during reservoir drawdown.

South Knoxville has surface waters that may attract terrestrial mammals. Goose Creek empties into the Tennessee River about 1.1 mi northeast of the facility and flows southward for a distance of 4.0 mi. When the Fort Loudoun Reservoir is at full pool, the creek flows freely. At low pool, Goose Creek is a mere 10 ft wide and five or six inches deep (ECATS 2008). Just east of Goose Creek—about 1.2 mi east of the facility—lies a large, abandoned limestone quarry, or Quarry Lake, that is fed by an underground spring. A southwest section of the nearshore is shallow; and fish and benthic aquatic organisms, including the invasive Asian clam (*Corbicula* spp.) inhabit the lake. A small, open meadow wetland lies near the quarry. These surface waters and wetlands attract much wildlife, but mostly small animal prey and their predators (ECATS 2008). Man-made ponds in the area include: two sediment ponds located across from each other and on Cherokee Trail about 0.4 mi southwest of the facility; two fish-stocked earthen ponds on

Cherokee Bluff that are just over 0.5 mi east of the facility; and a small livestock watering pond just under 0.4 mi northwest on UT's Cherokee Farm. The Cherokee Bluff ponds, Goose Creek, and Quarry Lake and wetland are all locations that presumably attract unspecified numbers of amphibians and reptiles; as well as small mammals.

ARF history

The human body donation program at the University of Tennessee was initiated by Dr. William Bass; the first donation was received in May 1981. The number of body donations to the program has increased every year since 2002 (Figure 6). While most bodies received by the Forensic Anthropology Center (FAC) are deposited at the facility to undergo soft tissue decay, a lesser number are placed on the ground surface where they can attract animal scavengers. For example, an increasing number of bodies are being buried for excavation training (Jantz and Jantz 2008). Despite these and other caveats, like increased numbers of donated fetuses and cremated remains, more bodies have become available to scavengers in recent years. Recently, Wilson and colleagues (Wilson, et al. 2008) documented that most bodies received are now of persons who wished their remains be donated to science—either to the Forensic Anthropology

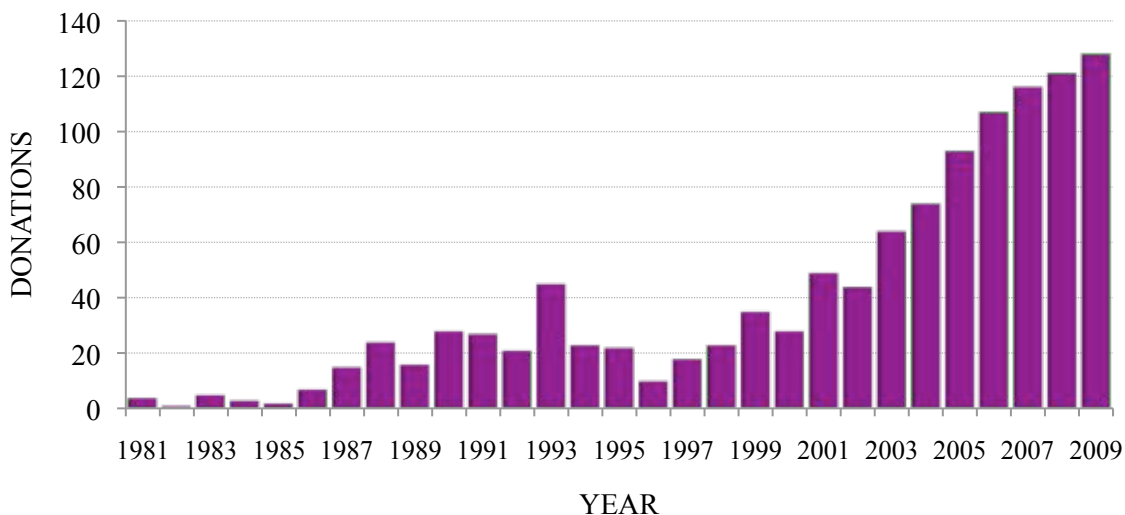


Figure 6. Number of body donations received by the Forensic Anthropology Center by year.

Center or an unspecified program. When an individual's remains are donated to the FAC, the donor is aware that the body will likely be placed at the outdoor facility for soft tissue decay.

At its inception, the facility was a 16 sq ft concrete slab upon which a small storage shed was built. Together, the pad and shed were enclosed with four vertical, chain-linked panels and a fifth was secured overhead (Bass and Jefferson 2003; Jantz and Jantz 2008). Protection against small rodents was achieved by wire coffins constructed of a 2"x4" lumber frame that was wrapped with ½" hardware cloth. These and similar enclosures prevented vertebrate scavengers from feeding on subjects used in early and more recent decomposition studies (e.g., Rodriguez and Bass 1983; Srnka 2003; Tomlinson 2003; Watkins 1983) (but see Miller 2002).

In a six month period starting August 1983, six bodies were buried outside the facility enclosure as part of a two-year study on the decay rate of buried bodies. Mammals interfered with the 4-1ft deep burials by digging in the grave soil. An uncovered right foot was heavily gnawed on by a carnivore. Tracks about the grave sites indicated the presence of raccoons, opossums, and domestic dogs (Rodriguez and Bass 1985).

By 1986, an 8 ft wooden privacy fence and a chain-link security fence was erected around 0.75 acres of open woods that included the original facility site (Bass and Jefferson 2003; Jantz and Jantz 2008). With fencing in place, incoming donations were placed about the grounds for natural decay. Mammals scavengers that dug beneath the fencelines or entered the grounds by way of the tree canopy could approach the human remains; and animals, including non-scavengers, could disturb the decay site. Some early studies suggest there was minimal interference of research subjects by animals (see Cahoon 1992; Vass 1991) but occasional references to opossums, mice, rats, and vultures are read (Bass 1997; Mann, et al. 1990). To discourage property intrusions by larger animals and unauthorized humans, graduate students walked the outside perimeter weekly to secure loose fencing and fill soil gaps (Bodkin 2004). This counter measure fell out of practice in the late 1990s, and the fencing was overrun with underbrush that made human passage difficult—particularly, during the peak growing season.

Longitudinal sampling for concurrent decomposition studies of body tissues and odor began in October 1998 and ended in December 2000 (Love 2001; Vass, et al. 2002). Animal scavengers interfered with multiple subjects and several measures, some unsuccessful, were

used to keep them away from sampled bodies. Some of the first bodies were placed on a supported 0.5" wire mesh screen which was elevated on saw horses. This was abandoned because the screen became encrusted with decomposition fluids and later bodies were placed directly on the ground. To entrap odor for air sampling, some bodies were kept in the zippered body bag in which they were delivered. These bags were often thin and animals ripped them apart overnight. Heavy duty body bags were then purchased and zippered up, but within days the zipper was repeatedly unzipped. A plastic electrical tie was then used to secure the zipper, but animals mangled the zipper so the bag could no longer be closed. A wooden frame wire coffin protected later bodies. Raccoons were highly suspected of interfering with the study subjects; and vultures, which were occasionally seen at the facility during sampling, scavenged once or twice on unprotected subjects.

In January 2001, a decomposition study of clothed bodies was initiated. Carnivores, vultures, and likely rodents scavenged on the study subjects. Live traps were used to remove two raccoons from the property (Miller 2002). It was known that raccoons were coming into the facility at night to scavenge on human remains. In fall 2001, sand-tracking and scat collection along with photographs of scavenged bodies were used to collect evidence that raccoons were the primary agents of bone and soft tissue modification at the Anthropology Research Facility.

A research proposal by Klippel and Hamilton, entitled "Postmortem scavenging of human remains: identifications, descriptions, and time since death indicators", sought to establish a relationship between small mammal scavenging and the postmortem interval by monitoring the nocturnal behavior of animals that entered the facility. The submitted proposal was funded, but final approval was not received until fall 2003.

Meanwhile, the FAC annexed land along the existing north fenceline, which doubled the facility's size to 1.3 acres. Fencing was erected around the new acreage; and to join the two properties, a large section of the original north fenceline was removed (Jantz and Jantz 2008). Around this time, shallow cement block surrounds—a total of 10 encirclements—were constructed that could be covered with wire screen. This effort was to protect bodies from animal scavengers, thus preserve skeletons to be accessioned into the William M. Bass Donated Skeletal Collection.

Three research studies commenced in fall 2003: two longitudinal studies of human decomposition and the present study, which monitored animal activity. The decomposition researchers wanted uninhibited access to multiple study subjects and minimal animal interference. Thus, renewed efforts were made to monitor the chainlink fencing and fill in larger holes dug beneath it. Further, two low-mounted electric fences were strung within the facility in mid-January 2004. About 30-40 bodies could be placed inside the fencing, and raccoons and opossums were excluded from these areas as long as electrical current flowed. The electric fences were maintained until about fall 2006, when they fell out of use.

General methods

The field data was collected from September 2003 into October 2009. Both unattended video and still photography were used to capture imagery of animal scavengers at the facility. Field photographs and written notes regarding animal disturbance were collected on a number of bodies that decayed at the facility, regardless of whether or not they were monitored by unattended cameras. The frequency of field visits varied, but near daily to bi-weekly site visits were made to maintain the equipment and to document scavenging damage.

Video footage was captured using various Sony handycam digital camcorders capable of low light filming. Only one camcorder operated at a time. The primary models used were a DCR-TRV350 and DCR-VX2100 (Sony Electronics Inc., Oradell, NJ). All camcorders were equipped with a LANC (Local Application Control Bus System) control jack to connect to peripheral equipment. The camcorder was used in conjunction with a TrailMaster video light controller and a passive infrared video trail monitor (model TM700v, Goodson & Associates, Inc., Lenexa, KS). The trail monitor controlled and monitored camera functions and contained a passive infrared (PIR) receiver that detected combined heat (heat differential) and motion up to 100 ft from the monitor and radiating 150 degrees (200 ft). The vertical angle of the PIR array was 4 degrees. The monitor allowed the user to input operational hours, select for the size and frequency of movement, and interface with the light controller. A third party adapted the light controller to accept their infrared lamp, which provided exceptional illumination (model IRLamp6, Wildlife Engineering, www.irlight.com). After the TM700v was serviced in fall

2004, however, this lamp could no longer be used and several outdoor 85 watt red flood lamp bulbs were used for illumination. The bulbs were controlled by a manual timer.

Unattended still images were captured using multiple cameras. The primary camera was a Canon™ EOS™ 10d SLR digital camera (Canon U.S.A. Inc., Lake Success, NY), which was hooked up to a camera and flash controller unit (The Time Machine, Mumford Microsystems, Santa Barbara, CA) and a passive infrared motion detector. In addition, two wildlife scouting cameras (DeerCam, Non Typical, Inc., Park Falls, WI), each of which contained a 35mm point-and-shoot Olympus camera and passive infrared receiver, were used. All nocturnal still images were captured with a white flash.

Three mobile setups and protective housings were eventually constructed so that one person could easily move the equipment to different locations (Figures 7-8). All equipment and/or housings were mounted or attached to camera tripods so it could be transported and repositioned with minimal aggravation and time loss.



Figure 7. Basic video equipment setup: a) a light source—here an infrared light, b) a passive infrared video trail monitor, c) a camcorder within a housing unit, and d) a video light controller.



Figure 8. Digital camera setup from top to bottom: Canon 10D and housing, passive infrared receiver, and camera control unit (inside battery box).

Camera locations at the facility were selected opportunistically in order to capture ongoing soft tissue scavenging and other happenings. Cameras overlooked bodies in various stages of decay placed either on the surface (N=22), in a shallow burial (N=2), or in a car trunk (N=1). Camera locations by body donation and date are listed in Table 1. The given dates do not reflect nights when the camera was temporarily removed or when it was inoperable. Video equipment operated nearly continuous from mid-September 2003 to mid-July 2004, then intermittantly from September 2004 to mid-October 2009.

Some problems were encountered during the study that prevented nightly video acquisition. The primary factor was a fickle electrical connection that was managed, but not fully resolved until August 2004. Moisture condensation inside the self-constructed housing units became problematic in the late spring and summer months. When present, the camcorder's did not record video footage. This problem was largely resolved after the housings were better weatherized and dessicant packets were introduced alongside the camcorder.

Table 1. Location of unattended photographic equipment at the Anthropology Research Facility (N=24).

Donor	Date Placed	Video Photography		D/N*	Still Photography		D/N*	Date Collected
322	27-Sep-02	17-Sep-03	25-Sep-03	8 n	-	-	-	10-Oct-03
393	20-Aug-03	-	-	-	25-Jan-04	30-Jan-04	5 d,n	
453	04-Sep-03	25-Sep-03	10-Oct-03	15 n	-	-	-	27-Aug-04
493	01-Oct-03	10-Oct-03	17-Oct-03	7 n	-	-	-	01-Oct-04
503	01-Oct-03	-	-	-		14-Feb-04	d,n	27-Aug-04
513	01-Oct-03	-	-	-	12-Feb-04 01-Mar-04	14-Feb-04 04-Mar-04	2 d,n 3 d,n	27-Aug-04
543	13-Oct-03	22-Nov-03	17-Dec-03	24 n	16-Dec-03	17-Dec-03	1 d,n	27-Aug-04
553	13-Oct-03	25-Oct-03 13-May-06 00-unk-06 19-Apr-07	06-Nov-03 23-Jun-06 05-Jul-06 24-Apr-07	12 n 41 d ? d 5 d				01-Mar-09
603	09-Dec-03	20-Jan-04	22-Jan-04	2 n	16-Dec-03	17-Dec-03	1 d,n	27-Aug-04
034	12-Jan-04	14-Jan-04	15-Jan-04	1 n	-	-	-	<i>buried</i>
044	15-Jan-04	24-Jan-04 16-Feb-04 04-Jul-04	16-Feb-04 00-unk-04 07-Jul-04	23 n ? n 3 n	30-Jan-04 17-Feb-04 01-Mar-04 17-Jun-04	09-Feb-04 28-Feb-04 02-Mar-04 30-Jun-04	10 d,n 12 d,n 1 n 13 n	16-Aug-04
084	27-Jan-04	18-Mar-04	02-Apr-04	15 n	-	-	-	
134	23-Feb-04	26-Jun-04	01-Jul-04	5 n	-	-	-	
234	21-Apr-04	26-Apr-04	8-May-04	12 n	-	-	-	12-May-05
274	05-May-04	09-May-04 30-May-04	23-May-04 09-Jun-04	15 n 7 n	-	-	-	27-Aug-04
414	06-Aug-04	31-Dec-04	02-Jun-05	2 d,n	15-Oct-04	10-Nov-04	26 d,n	<i>burial</i>
614	22-Oct-04	26-Mar-05 17-May-05	28-Mar-05 19-May-05	2 n 2 n	-	-	-	
694	27-Nov-04	23-May-05	02-Jun-05	10 n	-	-	-	<i>burial</i>
015	04-Jan-05	01-Feb-05 05-Mar-05	11-Feb-05 08-Mar-05	10 d,n 3 d,n	-	-	-	15-Sep-06
135	28-Feb-05	29-Mar-05	06-Apr-05	8 d,n	-	-	-	<i>car trunk</i>
156	21-Feb-06	06-Jul-06	18-Jul-06	12 n	-	-	-	
456	06-Jul-06	-	-	-				
427	25-Apr-07	27-Apr-07	06-Jun-07	40d,n	-	-	-	11-Mar-10
799	29-Jul-09	29-Jul-09 20-Oct-09	25-Sep-09 23-Oct-09	58d,n 3 d,n	-	-	-	04-Mar-11

*symbols represent: sunset to sunrise (n=night), sunrise to sunset (d=day) or 24-hour recording (d,n)

Pertinent body donor information was provided by the Forensic Anthropology Center and included data like sex, stature, weight, age-of-death, date-of-death, cause-of-death, perimortem trauma, date placed at the facility, and date removed. Body position, the presence or absence of clothing or coverings, decay stage and positional disturbances were recorded. Animal scavenging, including wound location, was regularly documented, as well as area disturbances, like soil digging and animal traffic. An effort was made to document the animals sighted, particularly when by closely monitored bodies. Rodent signs like active burrowing and movement beneath body coverings were also noted. Mammal scat was collected inside, and adjacent to, the facility for three years beginning fall 2003.

Climatological data for years 2003–2006 were downloaded from the National Climatic Data Center (NCDC) and are provided in the Appendix. The NCDC serves as the data repository for the National Weather Service (NWS), with the nearest station located at Knoxville's McGhee-Tyson Airport about 18.1 km (12.3 mi) south of the Anthropology Research Facility.

Live trapping was used to identify some of the small mammals at the facility. Two Havahart® live traps (Model #1020, Woodstream Corporation, Lititz, PA) were stationed along varying small mammal surface runs; and infrequently, in an outbuilding or at a feeding location. Traps were baited with peanut butter and rolled oats; occasionally, molasses was added. Trapping was carried out over a period of ten months (late-September 2004–July 2005). Traps were set roughly twice a week; and were removed for three weeks in December and on days of inclement weather and temperature extremes. Once deployed, traps were checked daily or twice daily. Trapped animals were released at their point of capture. Two passerine birds, two eastern chipmunks, one short-tailed shrew, and 22 white-footed mice were live-trapped.

Identified taxa are listed in Table 2. These identifications were largely obtained from captured imagery. Moles were not photographed, but moles and mole sign have been sighted. They are tentatively identified as eastern moles, because it is the most prevalent species in the valley region. The tentative identification of American mink is based on two nights of ill-focused, nocturnal photography. The body size, coat coloring and behavior were consistent with an American mink. All identifications are consistent with species accounts provided in the

Table 2. Animals identified at the Anthropology Research Facility.

Common Name	Taxon	Occurrence
Virginia opossum	<i>Didelphis virginiana</i>	common nocturnal visitor
Woodchuck	<i>Marmota monax</i>	several diurnal sightings
Eastern chipmunk	<i>Tamias striatus</i>	near daily diurnal sightings
Eastern gray squirrel	<i>Sciurus carolinensis</i>	daily diurnal or crepuscular sightings
Southern flying squirrel	<i>Glaucomys volans</i>	one nocturnal sighting
White-footed mouse	<i>Peromyscus leucopus</i>	common; largely nocturnal sightings
Brown rat	<i>Rattus norvegicus</i>	periodically common; nocturnal sightings
Eastern cottontail	<i>Sylvilagus floridanus</i>	common
Northern short-tailed shrew	<i>Blarina brevicauda</i>	common; multiple sightings
Eastern mole	cf. <i>Scalopus aquaticus</i>	common
Bat	Chiroptera	periodic, nocturnal sightings
Domestic cat	<i>Felis domesticus</i>	thrice seen: inside, or just outside, ARF
Domestic dog	<i>Canis familiaris</i>	once seen inside ARF; occasionally seen along outside fence perimeter
Red fox	<i>Vulpes fulva</i>	occasional nocturnal sightings
Northern raccoon	<i>Procyon lotor</i>	frequent nocturnal visitor
cf. American mink	cf. <i>Mustela vison</i>	a few nocturnal sightings
Wild turkey	<i>Meleagris gallopavo</i>	two birds once seen at dusk
Black vulture	<i>Coragyps atratus</i>	infrequent diurnal sightings
Red-tailed hawk	<i>Buteo jamaicensis</i>	diurnal sightings—often flew overhead
Mourning dove	<i>Zenaida macroura</i>	several diurnal sightings: inside, and just outside, ARF
Great horned owl	<i>Bubo virginianus</i>	periodically, molt feathers seen on ground
Eastern screech owl	<i>Megascops asio</i>	probably common; two nocturnal sightings
American crow	<i>Corvus brachyrhynchos</i>	on diurnal sighting; several snow tracks seen early January 2004
Carolina wren	<i>Thryothorus ludovicianus</i>	common; diurnal sightings
Hermit thrush	<i>Catharus guttatus</i>	common; diurnal sightings
Northern mockingbird	<i>Mimus polyglottos</i>	occasional, diurnal sightings
American robin	<i>Turdus migratorius</i>	common; diurnal sightings
European starling	<i>Sternus vulgaris</i>	periodic sightings
Eastern box turtle	<i>Terrapene carolina carolina</i>	once seen
Black rat snake	<i>Elaphe obsoleta obsoleta</i>	a few sightings—probably common
Garter/ribbon/lined snake	<i>Thamnophis</i> spp.	a few sightings—probably common
cf. Five-lined skink	<i>Eumeces</i> spp.	multiple sightings—common
Newt	red eft	once sighted

Peterson Field Guide Series ® (Burt and Grossenheider 1980; Conant 1975; Peterson 1980; Reid 2006).

The two mammals that often entered the facility at night were the northern raccoon and the Virginia opossum. Of the two, the raccoon was the dominant scavenger and the most significant modifier of human remains. Three rodents that modified human remains during this study were the brown rat, the white-footed mouse, and the eastern gray squirrel.

This dissertation was partitioned into multiple parts due to the atypical nature of data collection and the wide variety of species studied at the facility. Part one is a broad literature review of animal scavengers and their feeding signatures on largely human remains. Part two describes northern raccoon feeding and corpse modification. Part three describes Virginia opossum feeding. Part four describes modification by three rodent species: the brown rat, the white-footed mouse, and the eastern gray squirrel. Part five describes other animals identified at the facility and their activities.

This research aims to: 1) identify the animal scavengers at the Anthropology Research Facility, 2) characterize their scavenging mannerisms and feeding activities, and 3) describe modified soft tissue and/or bone.

PART 1. LITERATURE REVIEW

Introduction

About 45% of human skeletal remains analyzed by North American forensic anthropologists are recovered from semi-secluded outdoor locations, like woods, fields, river banks, and shallow burials (Bass and Driscoll 1983; Komar 2003). Roughly 70% of reachable corpses bear the tooth markings of a postmortem scavenger (Haglund, et al. 1988; Klippel and Synstelien 2007; Komar 1998; Willey and Snyder 1989).

A body deposited outdoors will be affected by the local wildlife. A corpse may provide food or shelter; or intrude upon animal territories or trails. Postmortem scavengers can alter or obliterate evidence of cause of death, accelerate decomposition and disarticulation; and scatter, modify and destroy much of the human skeleton for increased difficulty in establishing identification.

For the forensic anthropologist in the field, recognizing animal interference with a corpse enhances: 1) interpretation of the scene, including body position or bone distribution, 2) estimates of time-since-death, and 3) search strategies for increased skeletal recovery. For the forensic anthropologist in the lab, recognizing scavenger modification of bone is necessary for distinguishing between postmortem taphonomic changes and human-induced perimortem trauma.

A scavenger is an organism that feeds on decaying organic matter or waste. Few vertebrates are obligate scavengers whose subsistence depends upon dead animal matter, e.g., vultures. Mammal scavengers are facultative feeders as carrion is opportunistically eaten—and generally in low quantities or frequencies. The corpse fauna includes insects and their larvae, which feed and develop on or around a corpse. Insects alone can attract insectivorous shrews and moles and any number of insect-eating species, e.g., the striped skunk (*Mephitis mephitis*) and European starling (*Sternus vulgaris*). Insect-eaters may not ingest decaying tissues, but actions effected during search-and-retrieval of flies and beetles—either adult or larval—disrupt the scene. Uneaten flesh can acquire postmortem artifacts and skeletonizing parts may disappear by scatter or beneath overturned vegetal debris and soil.

Multiple animals—individuals and species—may scavenge a corpse. Feeding can occur simultaneously or successively (e.g., Haynes 1983). Tolerance factors include: ample food in the

environment or large carcass availability, kinship, near equal status in a scavenging guild (i.e., not a predator–prey relationship) and some passivity. Large-bodied, aggressive, or highly territorial animals will lay claim to a corpse for exclusive feeding.

The human skeleton

Mammalian compact bone is comprised of 60-70% mineral salts (largely calcium and phosphorus, some magnesium and minimal amounts of sodium, potassium, iron and other elements), 25-30% proteins, 5-8% water, and about 1% lipids, i.e. fat (Herring 1977).

Marrow infills trabecular pores and lines medullary cavities. At birth and up to the age of about eight years, the bones of the human skeleton contain gelatinous red marrow. This active, stem cell producing marrow gradually converts into inactive yellow marrow being largely fat-accumulating cells. Nutritionally, red marrow contains about 20% protein, 40% fat and 40% water; while that of calorie-rich yellow marrow contains about 5% protein, 80% fat and 15% water (Vogler and Murphy 1988).

Marrow turnover varies greatly by bone, but by 20-24 years of age red marrow is limited to the cranial vault, sternum, ribs, scapula, vertebral bodies, os coxa, and proximal shafts of the femur and humerus (Taccone, Oddone, Dell'Acqua, et al. 1995; Taccone, Oddone, Occhi, et al. 1995). Yellow marrow may be retroconverted to red marrow during times of stress like haemorrhaging or nutritional deprivation.

Taphonomy

Ivan A. Efremov was a Russian paleontologist keenly aware that after death, a corpse soon-to-be skeleton, would change in both appearance and matter over time. The destruction or survival of the skeleton would depend upon both perimortem and postmortem events, e.g., cause of death, location of death, and manner of disposal like whether it lay exposed on the surface or was buried beneath the soil. Efremov wrote in 1940 that accurate interpretation of recovered bones required knowledge of the many processes and agents of change between the time of death, burial, and recovery of the remains; and their effects on bone. For this new field of study, he selected the Greek words *taphos* (grave) and *nomos* (law) and coined the word taphonomy

meaning, "...the study of the transition (in all its details) of animal remains from the biosphere into the lithosphere..." (Efremov 1940:85).

Animal scavengers are significant biological agents of bone and soft tissue modification of vertebrate remains (Gifford-Gonzalez 1991). They can accelerate the natural course of decomposition and promote disarticulation. Increasing time results in a decreasing chance of skeletal survival as a succession of species will modify a corpse even after it becomes a pile of weathered bones. Given their proclivities for gnawing and transporting bones, archaeologists seeking to infer past events and behaviors have long been interested in identifying the hunters or scavengers that may alter or bias the archaeological record. And because bone survives long into the archaeological record, much emphasis has been placed on characterizing animal tooth mark damage to bone and recognizing signature bone scatter and accumulation patterns by diverse species.

Much of our present knowledge of postmortem scavengers draws upon seminal studies in archaeology, like Lewis Binford's *Bones* (1981), Charles (Bob) Brain's *The Hunters or the Hunted?* (1981) and Gary Hayne's *Bone Modifications and Skeletal Disturbances by Natural Agencies* (1981). Yet forensic taphonomy is focused on the modification and destruction of contemporary remains (Haglund and Sorg 1997). The linkage between forensic taphonomy and archaeology is actualism. Actualism is "the methodology of inferring the nature of past events by analogy with processes observable and in action at the present" (Rudwick 1976:110). Actualistic research involves documentation of present-day patterns and processes, such as death, decay, and burial—and events in between—to aide and guide interpretations of both the archaeological record and recent past.

Actualistic studies may be unrealistic. Research strategies in animal scavenging studies differ by the degree of investigator control over potential confounding variables, such as the presence of multiple species and undocumented events. The more highly controlled a research design, the less likely the results will reflect the complexities of wild animals in their natural environment, such as inter- and intra-species competition and fluctuating food resources.

Controlled experiments often involve feeding animal carcasses or limbs or bones, with or without tissue, to confined animals in a laboratory or zoo setting. (Direct observation of bone

gnawing by a domestic pet is a parallel approach.) The investigator has control over the gnawing species, the number of feeding individuals, total elements being fed and the feeding duration. A criticism of feeding experiments is that animals raised in an artificial environment may exhibit behaviors unlike their wild counterparts. Haynes (1981) combined zoo feeding studies with naturalistic observations of animals carcasses that were fed upon by wild carnivores. He found the bone modification patterns of carnivore species to be similar regardless of their environment. The intensity of bone gnawing, however, can vary. Confined animals habituated to a diet may be uninterested in novel foodstuff (Morse, et al. 1983). Similarly, domestic pets can be picky eaters as they do not lack food. Feeding animals at wildlife rehabilitation centers or game reserves, such as that done by Pickering and Carlson (2004), gives the investigator some control over experimental parameters while minimizing possible aberrant behavior.

Field experiments involve naturalistic observations of events or processes as they occur in the wild. Research on carcass utilization and bone modification by scavengers with minimal interference by the investigator increases the likelihood of obtaining realistic results. Identification of scavenging species may be made by direct observation, the remote capture of imagery or studying animal sign, i.e., tracks, scat or hair. The investigator has little or no control over happenings and the agents of undocumented modification remain unknown. Additionally, multiple species may feed on a carcass and compounding injuries become difficult to attribute to one species.

Actualistic studies may lie anywhere along the spectrum of these two research strategies. An example of how elements of each can be combined to strengthen the credibility of research conclusions is given by Domínguez-Solera and Domínguez-Rodrigo (2009:52):

“This unexpected result prompted us to conduct more experiments in the wild. It can easily be argued that this high percentage of tooth-marked mid-shafts could be due to ‘boredom chewing’ caused by the artificial environment of the enclosures. For this reason, and due to the extremely time-consuming process of conducting experiments with boars in the wild (see above), only two experiments were conducted which gave more support to the results obtained in captivity.”

Compiling forensic anthropological *case studies* can increase our understanding of extant scavengers and their disarticulation and modification of human remains (Carson, et al. 2000; Haglund, et al. 1989). Actualistic studies are often carried out using animal remains. By comparing actualistic research with real case studies, one can begin to perceive how to best translate research findings for increasingly accurate interpretations of human skeletal remains recovered in medicolegal investigations.

Knowledge gained by animal scavenging studies contributes to the fields of paleontology, archaeology and wildlife ecology (e.g., scavengers as agents of disease transmission or resource competition studies); and can assist in interpreting forensic wildlife and medicolegal investigations.

Animal modification

Carnivores and rodents are the most common scavengers of vertebrate remains in both the archaeological and forensic settings (Dixon 1984; Gifford 1981; Haglund, et al. 1988). Other mammals that may interfere with human remains include omnivorous scavengers such as the Virginia opossum and swine (*Sus scrofa*) and herbivorous ungulates including deer (Family Cervidae).

Carnivore

Carnivores (Order Carnivora), or flesh-eaters, range in size from the small 1-2 oz. least weasel (*Mustela nivalis*) to the brown bear (*Ursus arctos*) weighing more than 1,500 lbs. North American mainland carnivores include the cats, wolves and foxes, bear, raccoon and relatives, skunks and weasels, otters and relatives. Wild species are mainly crepuscular or nocturnal, but may be seen during the day; although those near human habitation may avoid daytime activity (Reid 2006).

Most carnivores are hunters and facultative scavengers. Prey species are largely ungulates and small-to-very small animals, including birds and fish. Many species include fruits, nuts and berries in their diet; some will eat vertebrate eggs, aquatic species, plants and insects. Many species, e.g. cats and badger, are largely solitary hunters and feeders. Wolves, and

occasionally feral dogs, are pack hunters. Most carnivores are territorial or have established home ranges in which they hunt or forage for food.

The anterior dentition of carnivores includes incisors for grasping and grooming and prominent canines for clutching and killing prey. The posterior dentition is comprised of premolars most with backward-hooking blades that aid in catching and holding prey and molars for crushing foodstuffs (Figure 9). There is some variability in the number of tooth types. Tooth cusps become progressively blunt with age (Hillson 2005).

Carnivores are characterized by carnassial teeth. In the permanent dentition, they are the upper fourth premolar and lower first molar. A species' dietary specialization determines the tooth form. Specialized hunters, like cats, have high-cusped blade-like carnassials for slicing skin and shearing meat and tendon from bone. Species with a more generalized diet, e.g. domestic dog, have large, blunted carnassials that assist in breaking up bone. Highly omnivorous species, e.g. the black bear and raccoon, have under-developed carnassial blades (Hillson 2005).



Figure 9. Carnivore dentition illustrated by the red fox (*Vulpes vulpes*). The large carnassial teeth are evident.

Soft tissue artifacts are produced by the teeth and claws as mammals often stabilize the object of gnawing with their forefeet (Haynes 1981). Domestic pets may use their forepaws to paw at their dead owners. Claws may puncture, scratch, tear or abrade skin producing areas of dermal drying. Most carnivores feed by muzzling their food. The canine teeth may produce linear or oval to V-shaped punctures in skin near absent tissue. Adjacent margins can appear lunate or ragged with rhomboid or V-shaped notches (Figures 10-11) (Haglund 1997a; Rossi, et al. 1994; Tsokos and Schulz 1999; Tsokos, Schulz, et al. 1999). There may be undermining of skin and the degree could be related to the size of the scavenger relative to the carcass.

Carnivore scavenging of human remains frequently begins with the soft tissues of the face and neck as this region is often exposed, is familiar to domestic pets and may incur perimortem trauma (Rossi, et al. 1994). Canid or felid feeding on animal remains begins with either the destruction of the thorax for consumption of internal organs or the eating of meaty regions (Haynes 1982; Pickering 2001; Willey and Snyder 1989). Many carnivores are attracted to open wounds and/or blood which can alter the typical scavenging sequence. Licking and



Figure 10. Lunate-shaped skin margin probably caused by the cheek teeth of a domestic dog .



Figure 11. Ragged skin margin with rhomboid notches probably caused by the cheek teeth of a domestic dog. Note the impressed arcade of the cheek teeth in the drying dermis.

chewing of the affected tissue will enlarge existing sites and may alter or obliterate perimortem wounds (Byard, et al. 2002; Mondini and Muñoz 2008; Willey and Snyder 1989). The rate of carcass consumption depends upon the scavenger's body size and number of feeding individuals; and may occur over a period of days or months (Haglund, et al. 1989; Haynes 1980).

Haglund and co-workers (1989) compiled 37 human remains case studies from the Pacific Northwest and grouped them into five stages of canid-assisted scavenging:

- 0 soft tissue consumed with no missing body units
- 1 chewed rib ends with evisceration and (in-)complete removal of upper limbs
- 2 (in-) complete removal of lower limbs
- 3 only the vertebral column remains partly articulated
- 4 total disarticulation with only the cranium and other bones or fragments found

This sequence largely reflects the ease of separation of the joints of the human body. The pectoral girdle is easiest to disengage being attached to the axial skeleton only by the clavicle. The deeply set ball-and-socket iliofemoral joint is difficult to separate and the lower limb is generally removed by destruction of the knee. This sequence is altered when a body is heavily

clothed or wrapped, placed in a shallow burial, partially submerged or other unique circumstances.

Several carnivores may transport body units or bones away from the death site (Bauer, et al. 2005; Haglund, et al. 1988; Haynes 1981; Kjørliien, et al. 2009). This is particularly true when competition for carrion is high or food resources are scarce (Marean, et al. 1992). Some carnivores are habitual cachers. The wolverine (*Gula gula*) will remove, and cache, as much of a carcass as it can carry away (Haynes 1981). Canids and occasionally, bear or large cats will bring bones back to den sites (Carson, et al. 2000; Haglund, et al. 1988; review in Mondini and Muñoz 2008). Domestic dogs frequently bring bones back to their owner's yard and may stash them in favorite chewing locations. These bones will be more severely gnawed than those left at the death scene (Binford 1981). Binford (1981) attributes the destructiveness of domestic dogs to boredom of yard. Cats will often cover prey remains at the scene or after removal to a secluded feeding location (Bauer, et al. 2005). Even small carnivores (e.g., ermine) feeding on a larger carcass may carry off small body parts or individual bones (Haynes 1981).

Carson and colleagues (2000) provide element representation data for seven cases of black bear scavenging of human remains. This data combined with Haglund's (2007) data for Stages 3-4 of canid-scavenged remains (N=22) provides element recovery frequencies for carnivore scavenged human remains. The most frequently recovered elements are consistently the cranium, mandible, femur and os coxa. Some bones or fragments thereof, of the sacrum, vertebrae, tibia, scapula and fibula may also be recoverable. Haglund (1988) states the axial elements of the postcrania are often found near the primary site of decomposition. Predictably, the most frequently recovered bones are the larger, more robust and easily recognizable elements (Bass and Driscoll 1983).

Pickering and Carlson (2004) showed that bone size and anatomical location were important predictors of large cat consumption of bones from feedings of whole baboon carcasses. Bone fragmentation and/or deletion occurred in areas of focused feeding intensity, i.e., the ventral thorax and terminal limb ends; with bone destruction and ingestion incidental to overlying soft tissue consumption. In depth discussions of carnivore bone gnawing behavior and carcass consumption patterns are provided by both Binford (1981) and Haynes (e.g., 1982, 1983).

While carnivores preferentially attack bones with soft tissue attached, even freshly defleshed bones, or those scarcely weathered, remain attractive to species with a taste for grease (Domínguez-Solera and Domínguez-Rodrigo 2009; Haynes 1981; Ioannidou 2003). Trabecular regions enriched in yellow marrow are often enveloped by thin cortical bone and are areas targeted by carnivores for gnawing (Marean, et al. 1992). Extensive gnawing on grease-enriched long bone ends creates a hollow cylinder of cortical bone (Figure 9; Binford 1981; Haynes 1983). The progressive destruction of long bone shafts in attempts to further breach the medullary cavity terminates when the carnivore can no longer collapse the increasingly thick cortex which peaks near the mid-shaft (Figure 12). This activity, i.e., carnivore gnawing, produces identifiable tooth markings and characteristic bone destruction.

A study of the literature shows researchers use multiple terms to describe carnivore tooth marks and too, have varying interpretations of other author's definitions. There are calls for standardized terminology so that researchers are better able to critique or build upon the findings of similar published studies (Blumenschine, et al. 1996; Bonnicksen 1989). The terms given in Table 3, and illustrated in Figures 13-21, are drawn from Binford (1981) and are commonly used in the tooth mark literature. There is some variation in the description of these terms, including refinements by some authors seeking to better distinguish tooth marks from other bone surface modifications (see Blumenschine, et al. 1996).

Binford (1981) defines carnivore tooth marks types and describes characteristic bone breakage and feeding by canids (i.e., wolves). Some of Binford's terminology and descriptions for tooth marks and bone modification were drawn from previous authors, who are referenced throughout his text.

Channeling occurs when a bone cylinder is aligned parallel to, and placed directly between, the posterior teeth on one side of the mouth and the jaw closes directly unto the bone crown driving the carnassial teeth into the bone and puncturing the central shaft. The teeth move down the shaft channeling the long axis until they can no longer puncture bone (Figure 17).

Step fractures appear when an external layer of cortical bone is peeled away from some internal layer. The transverse breakage plane resembles a ledge or "step". This breakage occurs when a bone cylinder is positioned in the mouth as above, but the jaw is shifted laterally away from the



Figure 12. Sectioned tibia showing cortical thickness distribution (left) and a carnivore gnawed long bone cylinder with ends having both irregular and stepped fractures (right).

Table 3. Common terminology used to describe tooth mark modification and jaw action (Binford 1981:44-49; Blumenschine, et al. 1996:496).

Category	Pit¹	Puncture	Score¹	Furrow
<i>Definition— Inclusive</i>	[sub-]circular depression in compact bone	bone collapsed under tooth	linearly extended pit in compact bone	groove in cancellous tissue; OR groove which exposes underlying cancellous tissue
<i>Definition— Exclusive</i>	crushing of internal surface; bowl-shaped to angular topography	distinct (circular) hole through cortical bone; hole through cortical bone into underlying trabeculae; bone collapsed forming depressed fracture	crushing of internal surface; U-shaped cross-section; follows bone contour or oriented transverse to long axis	groove in cancellous tissue of long bone ends
<i>Action</i>	biting down upon, or into, a surface impressing with cusps of canine or cheek teeth; OR biting into	biting down with canine or high-cusped cheek teeth	turning bone against cusps of canine or cheek teeth	dragging the cusps of canine or cheek teeth across bone
<i>Variant</i>		<i>Crenulated edge</i> (on thin bone) each removed piece of bone about equals the area of the occluded tooth (see Binford 1981:44)		

¹pit versus score: *pit*—length about equals breadth; *furrow*—length at least 3x greater than breadth



Figure 13. Multiple puncture marks along an iliac crest and one distinct pit.



Figure 14. Multiple score marks on human bone with crushing of the internal surface.



Figure 15. Furrowing of cancellous bone on the medial condyle of the left distal femur. One deep furrow is present on the lateral condyle.



Figure 16. Crenulated edge of the vertebral border of a right scapula.



Figure 17. Beef rib showing channelled breakage on the ventral end (right) and chipped back edges (now rounded off) on the vertebral end for a denticulated effect.



Figure 18. Scooping out of cancellous tissue of a right proximal femur. Note the irregular edge which is slightly rounded and polished.



Figure 19. Lunate-shaped scar on a carnivore-chipped back edge on a distal femur.



Figure 20. Crushing damage due to tooth cusps contacting and puncturing bone to produce multiple, and intersecting, depressed fractures.



Figure 21. If teeth are viced down on the inner and outer surfaces of cortical bone, and the head is then tilted away from the bone, the resultant mashed edge break will have a granular surface.

bone and with teeth grasping the upper and lateral edges of the cylinder, the head is tilted into the bone. A longitudinal flake is pried from the shaft exposing the marrow cavity. The plane of separation on the shaft resembles a step. This fracture type is distinct from a “stepped fracture” (see Johnson 1985:177).

Scooping out is the removal of cancellous tissue for marrow consumption by turning the canines around in the extremely furrowed cavity and by licking at the bone end. The resultant hollow space abuts against thick compact bone (Figure 18).

Chipping back is when an edge is aligned parallel to the tooth rows and a protrusion of dense compact bone is flaked off. The lunate-shaped scars make the chipped fracture edge irregular in appearance (Figures 17, 19).

Mashed edges are created by breaks caused by a double set of stresses where one end of the bone is secured against the ground and with teeth viced down on the opposite end, the animal tilts its head away from the bone (Figure 21). The surface of the break appears granular.

Rounded and polished edges are produced by repeated licking of mashed edges (Figures 18-19).

Additionally, there may be crushing damage and splintering of bone and bony margins (Figure 20). Extensive carnivore gnawing produces much pitting, scoring, scooping out and fracturing of bone. Carnivore-splintered long bone shafts frequently, but do not always, bear diagnostic gnawing damage (Blumenschine 1988; Haynes 1981; Morey and Klippel 1991). Long bone fracture terminology used here follows that of Marshall (1989) (see also Lyman 1994). Fracture patterns and edge traits unique to carnivore-gnawed bones have not yet been identified.

Rodent

Rodents (Order Rodentia), or gnawing mammals, are a large and diverse group of very small to small-bodied mammals. North American members include the sewer rat (rodentia), American beaver, marmots (woodchucks), prairie dogs, squirrels and chipmunks, pocket gophers, mice and rats; voles, muskrats and lemmings, North American porcupine, and coypu or nutria (Reid 2006).

Rodents eat diverse foods. All eat plant foods such as bulbs, tubers, berries, nuts, seeds, and bark. Herbivores that feed exclusively on plant matter include the beaver, sewer rat, marmots, prairie dogs, and porcupine. Most rodents are omnivorous and eat insects. Some rodents occasionally prey on small birds and bird eggs, but grasshopper mice (*Onychomys* spp.) regularly pursue invertebrates and even very small animals. Many rodents will opportunistically scavenge on carrion, especially small animal carcasses (review in Landry 1970).

All rodents are equipped with two sets of parallel chisel-like incisors used for gnawing (Figure 22). The canine teeth are replaced with a diastema, or gap, for enfolding the lips and preventing unwanted material from entering the oral cavity. Some rodents have premolars and all have molars for three to five cheek teeth per dental quadrant. The posterior tooth crowns may be molariform or have lophs or side infoldings. Most species have rooted cheek teeth. Tooth form is loosely correlated with diet. More herbivorous rodents have lophed molar crowns adapted for grinding abrasive plant foods (Hillson 2005).

Rodents have characteristic incisor teeth. Open-rooted, they grow continuously throughout life at a rate of 3-8" per year to prevent excessive attrition from constant use



Figure 22. The brown rat has two sets of parallel, ever-growing incisors. The molars are hidden behind the enfolded lips or buccal fold.

(Harari, et al. 2005; Miller 1958; Wallace 1994). Incisal gnawing and purposeful sharpening maintains tooth length and hones a sharp cutting edge (Bivin, et al. 1979; Druzinsky 1995). The anterior side of the incisor is flat-to-curved and comprised of enamel reinforced with metal ions. This reinforcement accounts for the orange pigmentation which varies in intensity from off white to burnished copper—the incisors of the marmot and beaver, respectively (Figure 23). The upper incisors may bear one or more pronounced longitudinal grooves. A few species also have grooved lower incisors. Exposed dentin forms the posterior side of the tooth. Incisal sharpening occurs when the dentin of the upper incisor is drawn against the enamel of the lower, and vice versa. The softer dentin wears more quickly producing a self-sharpened tooth. Severe mal-alignment due to trauma or genes disallows proper sharpening of the spiral-growing teeth and leads to death.

The loosely encapsulated temporomandibular joint allows for a large gap opening and rapid unilinear cyclic gnawing motion of lower jaw. With the upper incisors planted on a surface



Figure 23. The sciurid skull showing exposed dentin on the posterior side of the incisors wears faster than the harder enamel. Sharpening occurs when enamel moves along dentin. After swiping the upper dentin, the mandible is protruded and the lower dentin is swiped by the upper enamel.

to keep the head semi-stationary, the lower jaw moves anteriorly and superiorly to position itself behind the upper incisors for slicing of the intended object. Rapid, cyclic posterior and inferior movement of the jaw returns it to its original position. Complete transection of the object may not occur. Rather, the rodent may tear off a piece of softer material by stabilizing it with one or both forepaws and then lifting and pulling away the head at the end of a closing stroke (Eisenberg 1993).

Rodent gnawing is habitual; and used for object exploration, food procurement, shredding of nesting material and seeking food and shelter (Storer 1952). A prerequisite for gnawing is the presence of an edge or an item smaller than gap width (Roberts and Carey 1965). Rodent gnaw marks can be confirmed by observing the side opposite the conspicuous grooves (Dent 1993). Marks formed by the upper incisors appear as two small indentations, punctures or interrupted grooves that are often slightly curved, indicating placement of the upper incisors while the lower incisors removed material (Bang and Dahlstrom 2001; Dent 1993).

Rodents that feed on soft tissue include the commensal brown rat and house mouse, the hamster and other species (Haglund 1992; Klippel and Synstelien 2007; Ropohl, et al. 1995; Tsokos, Matschke, et al. 1999). Soft tissue gnawing of a human corpse by rodents is concentrated on exposed and prominent areas like the face, ears, hands and any fatty deposits (Patel 1994; Ropohl, et al. 1995; Tsokos, Matschke, et al. 1999). Skin and underlying tissues may be removed in layers, with areas of feeding circumscribed by finely scalloped or serrated margins (Haglund 1992).

At least two patterns of rodent bone modification appear in the literature (see Haglund 1997b; Klippel and Synstelien 2007). As illustrated in Figure 24, these divergent patterns likely correspond to motivational differences for gnawing, i.e. seeking fat versus seeking minerals (Klippel and Synstelien 2007). Rodent gnawing is located along edges and promonatories of the cranium and mandible, along crests and muscle attachment sites of appendicular bones, and along fractured edges (Bartelink and Bright 2009; Gutiérrez and Gómez 2007; Haglund 1992).

Rodent gnaw marks on compact bone appear as chiseled, repeat sets of sub-parallel grooves with flat-to-slightly concave floors (Bunn 1981; Shipman and Rose 1983). Extensive mineral gnawing can create *windows* into the medullary cavity (Figures 24-25; Singer 1956). Fine longitudinal striations may line the channel floor. Shipman (1981) suggests these striations, when present, reflect imperfections of the incisal cutting edge. When seeking minerals, rodent gnawing is generally concentrated along areas of thick cortical bone. When thin cortical bone is gnawed for minerals, the underlying cancellous tissue is easily scraped away, but it is not excavated out (Figure 24; Klippel and Synstelien 2007).

Fat-seeking species like the brown rat and house mouse will gnaw on fresh bone as well as cartilage and other fibrous tissues and membranes (Klippel and Synstelien 2007; Tsokos, Matschke, et al. 1999). While scraping tissue from bone, thin cortical bone is easily breached exposing the underlying cancellous tissue and fatty yellow marrow. Feeding becomes focused on fat removal and long bone ends can be rapidly hollowed out (Haglund 1992; Klippel and Synstelien 2007). Subchondral bone which remains attached to the shaft by a thin strip of cortical bone forms a *pedestal* (Figure 23; Haglund 1992). When scraping off bits of flesh and periosteal tissue, shallow incisal gnaw marks may form along bone edges.



Figure 24. Rodent gnawing consistent with seeking minerals (left) versus seeking fat (rat).

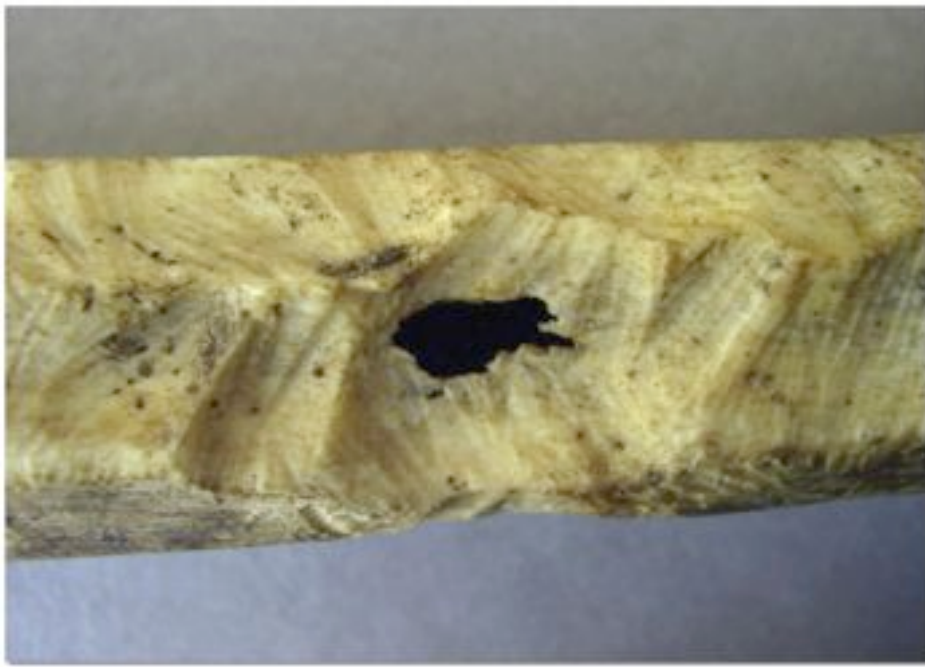


Figure 25. Rodent gnaw marks showing repeat sets of sub-parallel grooves and a gnawed “window” exposing the medullary cavity.

Rodents may scatter smaller bones or collect them in burrows (Smith 1948) and nests (Horne, et al. 1998). Well-known bone collectors in North America are the woodrats (*Neotoma* spp.) whose generally stick mounds, or middens, are constructed in underbrush or in rock shelters and caves. Atypical nesting was found in an attic crawl space (Warren and Falsetti 1999) with human bones from mummified remains scattered throughout the attic and incorporated into nests of torn fabric and spanish moss. Woodrats may move a significant number of human bones (Leher and Murad 2004). Bones up to 54.5g-101g have been moved up to distances of 3.5 m (11.5') to nearly 5 m (16.4') (Hockett 1989; Hoffman and Hays 1987). While woodrats are notorious bone collectors, they may be less inclined to gnaw them (Hockett 1989; Hoffman and Hays 1987; Warren and Falsetti 1999).

In contrast, C.K. Brain's (1981) highly cited studies of African porcupines report them to be both significant collectors and gnawers of old bones. As many as 60-70% of bones found in porcupine rock shelter denning sites bear their tooth marks. The North American porcupine

(Erethizon dorsatum) is distantly related to the Old World species, and has evolved its own unique behaviors and ecology. Much time is spent in trees, but they may den in deep rock crevices in the southwest and far north. While porcupines are notorious salt cravers and will gnaw on dessicating or skeletalized remains to satisfy its sodium appetite it is not known to hoard bones (Dirkmaat and Sienicki 1995; Haynes 1981; Roze and Ilse 2003; Taylor 1935).

Ungulate

Ungulates (Order Ungulata) are hoofed animals and the majority are herbivores. The notable exception is the omnivorous pig family (Suidae). The wild pig (*Sus scrofa*) population in the United States is estimated at four million animals—the largest of any free ranging non-native species (Pimentel, et al. 2000). This is because wild pigs are a popular game animal as they are fast, tough and wary and do not follow game trails. Pigs eat practically everything—including carrion—but their diet is largely vegetation and a variety of fruits, nuts and agricultural crops. About 10% of their diet is obtained by predation on small vertebrates and invertebrates (Taylor and Hellgren 1997).

Pigs have round cusped cheek teeth, procumbent incisors; and in the wild, prominent canines that protrude laterally, and anteriorly, beyond the lips. The canines—rather tusks—of wild pigs are sexually dimorphic being highly developed in males for fighting and used by both sexes for rooting in the ground with the aid of the lower incisors (Hillson 2005).

Domestic pigs will scavenge human remains feeding on the soft tissues of the face, neck and viscera (Berryman 2002; Karkola, et al. 1973). Likewise, wild pigs consume the viscera of animal carcasses (Galdikas 1978; Lotan 2000). Berryman (2002) presents a case of domestic pig scavenging of human remains which resulted in the destruction or loss of the splanchnocranium, mandible, rib cage, pelvis and hands. Suid bone modification consists of crushing and fragmentation. Small bones and bone fragments or ends are placed in the back of the mouth and ground between the large cheek teeth. Fragments that are not swallowed are spewed out splintered and tooth marked (Domínguez-Solera and Domínguez-Rodrigo 2009; Morse, et al. 1983). The hoofed forefeet may be used to anchor the carcass, while flesh is removed with the procumbent incisors (Domínguez-Solera and Domínguez-Rodrigo 2009). Rooting action with

the lower incisors produces either long, shallow, flattened grooves following bone contours or perforated areas of thin cortical bone overlying trabeculae (Berryman 2002; Domínguez-Solera and Domínguez-Rodrigo 2009; Greenfield 1988).

Osteophagia, the eating of bone or antler, is a behavior observed in many herbivores. It has been reported for the camel, sheep, cattle and multiple members of the deer family (Blair-West, et al. 1992; Johnson and Haynes 1985; Kierdorf 1993, 1994; Krausman and Bissonette 1977; Sutcliffe 1973; Warrick and Krausman 1986). This behavior appears to be linked to periods of increased physiological demands on a species for minerals, e.g., during rapid growth, gestation and lactation, or antlerogenesis. It may also be due to a mineral-deficient environment which would primarily affect grazers (Grasman and Hellgren 1993; Sweeny, et al. 1998). Bone chewing occurs when the long axis of a bone is aligned with the cheek teeth row and the bone is ground between the high-crowned, abrasive-resistant molars. The cheek teeth will grind away at the end of a tubular shaft to create a two-prong fork. If bone is turned slightly cross wise, a grazing-sawing action of the teeth leaves transverse-to-oblique scars down the shaft (Brothwell 1976; Kierdorf 1994; Sutcliffe 1973).

Avian

Birds (Class Aves) attracted to a corpse either feed upon the flesh itself or on the related insects and their larvae. Some species use olfaction to locate a carcass: more rely on vision alone. Many birds are opportunistic scavengers and will feed on carrion particularly when supplementing or preparing for periods of food shortage, such as winter (Brown, et al. 2006; Heinrich 1988; O'Brien 2010; Selva, et al. 2005). Most avian scavengers are diurnal and will leave shed feathers, tracks or droppings as evidence of their presence at a scene (Asamura, et al. 2004; Komar and Beattie 1998; Reeves 2009).

Flesh-eating birds are often the first scavengers to arrive at a carcass and include: vultures (Mundy, et al. 1992), some birds of prey (i.e., kites, caracaras, eagles and occasionally hawks and nocturnal owls; Bent 1938; Kaufman 1996); a few gulls, shorebirds and tubenoses (Bent 1921; Hewson 1984; Kaufman 1996; Mercer 1966; Walsh-Haney, et al. 2010); select storks

(Binford, et al. 1988; Capaldo 1998; Mundy, et al. 1992) and an unknown number of perching birds, including the notorious crow family (Asamura, et al. 2004; Bent 1946; Kaufman 1996; Kilham 1989; Komar and Beattie 1998). Several species will also feed on the mature and larval forms of carrion seeking beetles and flies (Alvarez, et al. 1976; Bent 1929, 1938, 1946; Brown, et al. 2006; Chapin 1932; Houston 1988; Kilham 1989; Morton and Lord 2006; O'Brien 2010).

Vultures are obligate scavengers subsisting primarily on carrion (Houston 1986; Mundy, et al. 1992). Two common North American species are the turkey vulture (*Cathartes aura*) which locates carcasses by sight and smell and the black vulture (*Coragyps atratus*) which relies on sight alone. Vultures have a hooked bill for pulling and tearing flesh, but the tip is blunt relative to that of birds of prey. Black and turkey vultures may move and scatter remains while on the ground and can place a small bone or piece of carrion in their bill and fly for short distances (Lewis 1936; Morse, et al. 1983; Mundy, et al. 1992; Stolen 2003).

The corvids (Family Corvidae) are the largest and most advanced perching birds (Order Passeriformes) with robust, and slightly curved, bills and include the jays, nutcrackers, magpies, crows and ravens (Bent 1946; Kaufman 1996; Kulemeyer, et al. 2009). Scavenging corvids may deflesh a corpse relatively quickly as many species are habitual cachers and will fly away with pieces of carrion to place in their nest or at storage sites (Brain 1969; Brown, et al. 2006; Heinrich 1989; Kilham 1989; Komar and Beattie 1998; Morse, et al. 1983).

Small birds may leave few feeding traces on a corpse even when present in small flocks. Suet-eating birds like titmice, starlings and some nuthatches and woodpeckers will peck on exposed fatty tissue on a carcass (Heinrich 1989; Kaufman 1996; Westell 1908). Insect-eating birds like chickadees may feed on Diptera larvae or eggs (Kaufman 1996). At the Anthropology Research Facility, passerine birds have only been seen feeding on fly larvae (Bass 1997).

Birds of prey and scavengers, such as corvids and gulls, will bring bones back to their nest for tissue eating or for use in its construction or decoration (Cruz 2008; Erlandson, et al. 2007; Kirkman and Jourdain 1910; Komar and Beattie 1998; Sanders, et al. 2003). Additionally, a number of passerines line their nests with soft materials like hair (Grant 1966; Kaufman 1996).

Most avian scavengers have difficulty breaking through the fresh or tough hide of a carcass, but human skin is fairly thin and relatively easy to penetrate (Ankerson, et al. 1999; Bass

1997; Brett, et al. 1997; Heinrich 1988; Reeves 2009). Birds characteristically begin eating on vulnerable soft tissues like the eyes, tongue and lips and feed from the inferior pelvis until the skin or hide of an animal can be breached or scavenging mammals have opened up the carcass. Vultures have been seen at the Anthropology Research Facility pecking on the abdominal cavity and then consuming the intestines (Bass 1997; Craig 2005).

Birds have diverse feeding strategies largely dictated by bill form. Alvarez and co-workers (1976) detail the feeding behavior of magpies, kites and Old World vultures. Houston (1988) documents feeding by New World vultures: and Zusi (1987) by corvids. Pecking or striking skin with one or both mandibles of the bill may create triangular-shaped punctures (Komar and Beattie 1998) that can be incorporated into the wound margin. Birds enlarge sites of penetration or pre-existing trauma by inserting, then opening, their bill or by probing with it inside the wound or dipping their whole head into the carcass to access deeper tissues (Alvarez, et al. 1976; Komar and Beattie 1998; Reeves 2009). Probing and undermining of skin creates symmetrical circular to ovaloid wound margins (Hewson 1984; Komar and Beattie 1998; Reeves 2009). Flesh is pulled from the carcass while secured in the bill tip or torn or twisted away while grasped between the edges of the bill (Zusi 1987). Muscle may be excised by placing one edge of the bill against bone and using scissor-like motions as the bird moves the cutting edges of the bill along the bone; or it can be pulverized by pounding muscle or attachment sites using vertical blows with the bill (Alvarez, et al. 1976). Both pulling muscle from tendon and pecking and tugging at remaining tendon and periosteum can cause the tissue to become string-like and have tufts that appear fluffy or frayed (Alvarez, et al. 1976; Asamura, et al. 2004; Kilham 1989; O'Gara 1978).

While avian predators modify bone during prey capture and manipulation (O'Gara 1978; Sanders, et al. 2003), scavenging birds can be fastidious feeders (Alvarez, et al. 1976; Houston 1988; Reeves 2009) and may pick a skeleton clean of accessible soft tissue leaving few, if any, marks on bone. The extent and frequency of feeding traces on scavenged then skeletalized remains is unknown, but likely depends on the scavenger and size of the carcass. Actualistic studies of North American vultures suggest macroscopic feeding traces may be superficial or restricted to fragile bone (Morse, et al. 1983; Reeves 2009); although scavenging eagles and Old

World vultures can break the ribs of human-sized carrion (Alvarez, et al. 1976; O'Gara 1978; Selva, et al. 2003). Komar and Beattie (1998) suggest corvids produce conical punctures through thin cortical bone and into underlying trabeculae. This damage may be attributed to vertical blows with the bill tip in the bird's attempt to separate fibrous tissue from bone (Alvarez, et al. 1976). Haynes (1980) states that ravens can produce bone damage on white-tailed deer (*Odocoileus virginianus*) mandibles.

PART 2. NORTHERN RACCOON

Abstract

This study documented animal scavengers at the University of Tennessee's Anthropology Research Facility. Remotely-captured digital video and still photography equipment was stationed at the outdoor human decomposition facility intermittently from September 2003 through October 2009. The northern raccoon (*Procyon lotor*) was identified as the primary scavenger of corpses and its unique manner of feeding produced soft tissue artifacts unlike previously reported carnivore modification of human remains.

Captured imagery of raccoons documented four feeding behaviors at corpses: 1) scavenging soft tissue, 2) foraging in body cavities for late instar maggots en masse, 3) foraging for individual prepupae as they migrated away from the corpse, and 4) foraging for prepupae and puparia and other insects burrowed beneath ground litter and in the soil. These behaviors were largely sequential in appearance and their presence or absence depended on the conditions under which the corpse decayed, e.g., foraging for insect larvae did not occur at bodies placed in winter because few maggots were present.

Raccoons at The Facility preferentially scavenged on the musculature of relatively fresh bodies. Their feeding sites often appeared atypical of a mammalian carnivore, because once they chewed a hole through the skin, they repeatedly placed a forepaw—even a forelimb—deep inside the wound and extracted tissue by way of the newly-formed hole. Although fresher bodies were more extensively scavenged, raccoons modified corpses throughout flesh decomposition—especially, by chewing the fingers and toes.

Bodies placed during winter were more intensively scavenged by raccoons in terms of total tissue removed and bone damage than those placed during fall or spring. Positional disturbances were noted at many bodies, but those placed in the spring incurred greater and more rapid skeletal disturbance and scatter due to warming temperatures and raccoons' foraging within body cavities and the soil for maggots and pupae.

Introduction

The forensic literature on carnivore scavenging of human remains largely provides case reports on modification by canids and felids (e.g., Byard, et al. 2002; Haglund, et al. 1989; Rippley, et al. 2012; Rossi, et al. 1994; Steadman and Worne 2007; Tsokos and Schulz 1999; Willey and Snyder 1989). Other carnivores are mentioned in the literature, like bear (Carson, et al. 2000) and weasel (Kiuchi, et al. 2008), but infrequently and more commonly in studies that have used vertebrate carcasses as human proxies (e.g., Hobischak and Anderson 2002). But even when multiple proxies are used and experiments are replicated, it is difficult to generate a large body of data on a particular scavenger so that the investigator can decipher behavioral patterns and species-typical feeding.

The present study was unique because it photographically documented the nocturnal scavenging of multiple decaying corpses by a common, yet atypical, North American carnivore—the northern raccoon (*Procyon lotor*). This study was possible because it occurred at the University of Tennessee’s Anthropology Research Facility where the fenced perimeter prevented medium- and large-bodied terrestrial scavengers from entering the property. This was not true of the raccoon, which was an excellent climber and an acceptable digger. Thus, multiple raccoons entered The Facility at night, where they engaged in the uninhibited scavenging of human remains.

Species account

The northern or common raccoon is a medium-sized carnivore that is native to the Americas. It is a member of the taxonomic family Procyonidae, which in North America includes the ringtail (*Bassariscus astutus*) and the white-nosed coati or coatimundi (*Nasua narica*) (Reid 2006).

Subfossil records demonstrate modern *P. lotor* first appears in the Mid-Pleistocene and becomes widespread across the southern and eastern parts of the United States by the end of the Late Pleistocene (Kurtén and Anderson 1980). The northern raccoon has increased its range throughout the Holocene and is presently distributed in southern Canada and most of the United

States, Mexico and Central America into Panama (Reid 2006). It is a common sighting in the Southeast United States and is the official state mammal of Tennessee.

The raccoon is currently an invasive alien species in Japan, northern France, the Caucasus Mountains region, and in Germany and its adjacent countries. In these areas, the raccoon was imported throughout the twentieth century as either a hunting or fur animal, as a zoological attraction, or as a domestic pet. Established wild populations of released animals and escapees are presently experiencing high population growth and range expansion.

The highly adaptable raccoon inhabits diverse environments, but its survival declines in areas with an inconsistent water supply, like regions that experience long, cold winters or lengthy periods of drought (Goldman 1950). In favorable climates, the raccoon inhabits areas proximal to a reliable water source and denning sites, like wooded areas along streams and lakes. Species density is greatest in the mixed forest-wetland environment and in modern urban areas into which the raccoon began migrating in the 1920s (Goldman 1950).

The raccoon dens in agreeable nooks and crannies that provide both privacy and shelter from inclement weather and temperature extremes. Such examples include trees, limestone bluffs, burrows, and manmade structures (Shirer and Fitch 1970). In East Tennessee, ground burrows and rock dens are most often used in the fall and winter by juvenile and adult males (Rabinowitz and Pelton 1986). Females frequently nest in tree cavities, particularly in the late spring and summer (April–July) during paturition and the rearing of young (Endres and Smith 1993; Rabinowitz and Pelton 1986). Even when rearing young, the contents of den interiors are sparse and restricted to minimal or no nest lining (Giles 1942). The raccoon uses a series of dens, or daybeds, and commonly beds alone; but it may share a den with one or more raccoons or another species—on either congruent or incongruent nights. It will relocate to either a novel or familiar daybed as frequently as every one-to-two days. In warm weather, the raccoon will slumber openly on tree limbs (e.g., Fritzell 1978; Rabinowitz and Pelton 1986; Shirer and Fitch 1970).

The nocturnal raccoon actively forages throughout the night. It generally leaves its daybed within an hour of sunset and beds down within an hour of sunrise (e.g., Berner and Gysel 1967; Fritzell 1978; Sharp and Sharp 1956). It becomes increasingly inactive as the temperature

drops below freezing (Berner and Gysel 1967) The raccoon does not hibernate during the winter, but engorges itself on high protein foods in the fall to put on a large body fat reserve. It relies on this energy store during intervals of freezing temperatures and inclement weather, after which it emerges from its den to forage (Davis 1907; Schwartz and Schwartz 1981). In northern regions, it will arouse itself about once every two weeks to seek water (Davis 1907). By spring, it may lose up to 50% of its pre-winter body weight.

The raccoon is a semi-solitary species. The adult male usually maintains the largest territory or home range by season and location, averaging from 2,560 hectares (1,036 acres) [linear distance ca. 5 km] in prairie lands (Fritzell 1978) to about three square blocks in dense urban populations. Adult female ranges average 806 hectares in prairie land (Fritzell 1978). A female with young seldom travels over 1 km (0.62 mi) from the den in the first month after giving birth (Fritzell 1978).

Raccoons are a socially flexible species and appear to form many short-term acquaintances and a few long-term associations (Prange, et al. 2011). Unrelated males (generally yearlings) may form groups up to four to maintain their position against intruding males, but females are more likely to form cohesive social groups and share home ranges (Ratnayeke, et al. 2002). Females raise their cubs alone, but may share a common area with related females. Females with overlapping home ranges have a greater likelihood of being more genetically related to their neighbors than to females with nonoverlapping ranges (Ratnayeke, et al. 2002).

Adult males are promiscuous and can breed from about January until July: most breeding occurs in February. Generally, one litter of three to four kits are born in April or early May after a gestation period of 63 days. The two-and-a half ounce kit is born blind and furred; and remains in the den for about eight to ten weeks. At this time—July—it begins eating solid food and foraging with its mother and siblings. The raccoon less than four months of age is easily distinguished from an adult by its smaller body size (Schwartz and Schwartz 1981). By the year's end, visual determination of young-of-year cubs becomes difficult and a reliable age estimate requires a physical examination. Young generally stay with their mother their first winter and gradually disperse in the spring. Females may remain with their mother longer and/or stay in closer proximity to her than their male counterparts.

The raccoon usually defecates in selected locations atop logs or debris piles, at the base of trees, along streams, or on rocky prominences. Commonly, such sites become latrines where one or more raccoons repeatedly deposit scat which accumulates and decays over time (Giles 1940). Promiscuous defecation is infrequent, but can occur, for example, when an individual is frightened; and may be more prevalent in the spring and early summer (Davis 1907; Giles 1940).

Raccoons are highly omnivorous and their diet is determined by food availability which varies by season and the local resources (Schoonover and Marshall 1951; Schwartz and Schwartz 1981). Davis (1907) found captive raccoons that are accustomed to a single food item will readily eat a replacement novel food with little or no loss of appetite; they thrive best, however, when served variety. Raccoons eat fruits, berries, nuts, fishes, crayfish, clams, insects, snails, amphibians, and smaller reptiles and mammals, like rodents and young rabbits: they are a significant predator of weak or injured birds and bird and turtle eggs (MacClintock 1981; Schoonover and Marshall 1951; Schwartz and Schwartz 1981). Major foods in Tennessee are persimmons, corn, insects, crayfishes, and the pokeberry and sugar hackberry (Tabatabai and Kennedy 1988). Animal foods are most important in the raccoon's diet during late winter and early spring when other foods, like nuts and plant foods, are depleted (Giles 1940; Lyall-Watson 1963; Schoonover and Marshall 1951). Raccoons are opportunistic scavengers and will incorporate nontraditional food items like corn, grains, pet food, melons, and garbage; and freshly dead vertebrate remains (MacClintock 1981)—which constitute less than 10% of their diet (e.g., Wood 1954).

Raccoons are always ready to eat and can store much body fat. Further, they are unrestrained in testing potential edibles and are resourceful at acquiring seemingly inaccessible food items (Davis 1907). Such qualities make urban and captive populations prone to obesity as food is generally abundant and can be procured with minimal physical activity (Whiteside 2009).

An extensive literature search was unable to find evidence to indicate that raccoons cache their food. Rather, they eat on-site or at a nearby spot. For example, Yeager and Elder (1945) report that when a raccoon came upon a goose carcass, it usually ate the flesh in-situ with little-to-no carcass transport. Den interiors contain minimal nest lining, if that (Giles 1942; Zeveloff 2002), which is evidence that raccoons do not transport food back to the den.

Anatomy, physiology, and feeding

The raccoon is a medium-sized, stocky carnivore with a flexed vertebral column that gives it's back a humped or rounded appearance. The raccoon has a head and body length of 16-24 inches, a tail length of 6-16 inches, and a weight of 5-33 pounds: it shows much geographic variation in body size with a northern clinal increase (Reid 2006).

The raccoon pelage is generally grizzled iron gray to black. The broad-jowled head has a prominent black facial mask over the eyes which is sharply delimited by patches of white hair. The heavily furred tail is ringed with alternating light and dark bands—between five and seven dark bands. The ears are short, prominent, and somewhat pointed (Lotze and Anderson 1979; Schwartz and Schwartz 1981). Raccoons wear a lighter-weight coat during the summer. New underfur and guard hairs appear in the fall (October and November) and their winter coat is generally prime by December. Their winter coat molts from the first of March until the end of May (Schwartz and Schwartz 1981). Minor shedding can occur well into summer.

Raccoons probably can not discriminate between colors, but they can perceive changes in brightness (Zeweloff 2002). They are relatively indifferent to bursts of light and show little reaction to, and no fear of, illumination without having had a prior bad experience (Davis 1907; Tevis 1947; Whitney 1931). This may be due to their heavy reliance upon tactile object discrimination for object exploration and food location; as well as their use of smell and hearing. Raccoons react strongly to sound (Tevis 1947).

The raccoon dentition is typical of carnivores, except the carnassial teeth—upper fourth premolar and lower first molar—have much reduced blades. The dental quadrants mirror each other and each contains three incisors, one canine, four premolars, and two molars for a total of 40 teeth (Figures 26-28) (Gorniak 1986; Hillson 2005). The maxillary incisors curve slightly posteriorly and the mandibular incisors are relatively straight and directed anteriorly. The upper canines are relatively vertical and are triangular in profile. The base of the lower canines slants antero-laterally and the tooth curves posteriorly at the tip (Figures 26-27) (Gorniak 1986). The first three premolars are narrow in breadth and single-cusped. The lower fourth premolar has two cusps and is relatively narrow, as are the lower molars, which bear five cusps and have a rectangular occlusal surface (Gorniak 1986; Hillson 2005). The upper fourth premolar and upper



Figure 26. The anterior dentition of the northern raccoon.



Figure 27. The posterior dentition of the northern raccoon.



Figure 28. The maxillary dentition of the northern raccoon.

molars are enlarged, are multi-cusped, and have occlusal surfaces of near equal length and breadth (Figure 28).

When fully occluded, the postero-incisal surfaces of the maxillary incisors make contact with the cutting surfaces of the mandibular incisors (Figure 26), and the long canines and interdigitating cusps of the cheek teeth prevent mandibular displacement in the anterior and horizontal directions (Figure 27) (Gorniak 1986; Hillson 2005). Upon jaw separation, some mandibular movement is allowed in the anterior and horizontal directions (Gorniak 1986). The mandibular cheek teeth can shift laterally to the extent that the buccal cusp ridges lie slightly lateral to their maxillary counterparts which is greater lateral movement than allowed in the canid jaw and permits some grinding action (Gorniak 1986; Scapino 1981).

Eruption of deciduous teeth begins about four weeks of age and ceases around eight weeks (Montgomery 1964). The permanent dentition erupts from late August until October (Schwartz and Schwartz 1981)—between four and five months of age. The raccoon less than two and a half years of age has little or no dental attrition. Pristine cusps of the fourth upper premolar and molar teeth are of near equal height and shear and grind foodstuffs of the raccoon's low demanding, generalized diet (Scapino 1981). Tooth cusps and cutting edges become increasingly blunt with age and considerable wear is seen by year three (Grau, et al. 1970). By then, the occlusal surfaces better function to grind and crush foodstuffs (Grau, et al. 1970; Scapino 1981).

The raccoon reduces its food using cat-like or scissor-like jaw movements with motion largely restricted to the vertical plane (Gorniak 1986). Mastication between cheek teeth is unilateral and occlusion is roughly in a horizontal plane. The raccoon thoroughly masticates its food while feeding (Tevis 1947; Whitney 1933).

The raccoon is pentadactyl, bearing five digits on each paw (Figure 29). The digits are elongated and lack webbing. The sharp, recurved claws are non-retractile and assist in climbing and acquiring food. The ventral surfaces of the paws are hairless and the forepaw has about four times as many sensory receptors as that of the hind paw, making it a highly efficient, tactile organ (Zaveloff 2002).



Figure 29. The right ventral forepaw (left) and the left ventral hind paw (right) of the northern raccoon.

The raccoon is an accomplished climber and uses its forelimbs for reaching, its forepaws for grasping, and its tail for stabilizing the torso while moving overhead. The hind paws are capable of 180 degree rotation which enables head-first ascent and descent of trees and other vertical objects (McClearn 1992).

The raccoon finds most of its food on the ground and travels by walking on semidigitigrade forepaws and plantigrade hind paws (McClearn 1992). When engaged in foraging, the raccoon commonly assumes a bipedal stance in which the hind limbs support the weight of the body, so the forelimbs are free to search for food. The raccoon is notable for incessant patting motions in which the palms are repeatedly pressed against surfaces while in search of food (Iwaniuk and Whishaw 1999; McClearn 1992). The raccoon has great mobility of the shoulder and forelimb which allows it to reach in and explore holes and crevices for potential food items. Further, a set posture or orientation to a fissure or eatable is not required prior to reaching (Iwaniuk and Whishaw 1999).

The raccoon forepaw does not have a converging grasp as it lacks an opposable thumb and the digits are incapable of complete flexion over the palm. When handling small food items, the raccoon will press the item between both palms, press the item between the apical digits and the distal palmar pad, or grasp the object between the second and third digits (Iwaniuk and Whishaw 1999). Food manipulation largely occurs by rolling the object between both palms. Rolling behavior is highly instinctive, and occurs with both edible and inedible objects (Breland and Breland 1961). Once manipulated, the forepaws are drawn to the mouth and the foodstuff is consumed (Iwaniuk and Whishaw 1999). Raccoons rarely pick up small foods using their incisors (Gorniak 1986; Iwaniuk and Whishaw 1999); rather, they rely on their forepaws.

Methods

Nocturnal video: raccoon behavior

Nocturnal digital video imagery of raccoons at the Anthropology Research Facility was evaluated for scavenging behaviors. The video captured raccoon behavior at nine surface-placed bodies in various stages of decomposition, ranging from fresh to advanced decay (Table 4). The imagery was remotely-captured using a passive infrared receiver and a control unit (TrailMaster, Goodson & Associates, Inc., Lenexa, KS), which powered a Sony Handycam digital camcorder (Sony Electronics Inc., Oradell, NJ). Video was recorded on 8mm (Digital8®) and miniDV cassette tapes of 60 or 90 minutes in total viewing length. The amount of accumulated time captured on each tape varied greatly from about two and-a-half hours of one night up to five nights of filming. About 50 hours of video was reviewed and roughly 30 hours of this captured raccoon behavior.

Soft tissue modification

Fourteen bodies were selected to study patterns of raccoon soft tissue modification using field notes, photographs, and recorded video, if available (Table 4). The human form was divided up into 11 anatomical regions and each individual was evaluated for the presence, or absence, of scavenging by region for both right and left sides, if applicable. A scavenging frequency was calculated for each region by dividing the number of occurrences by the total

Table 4. Body donations used to study raccoon behavior and soft tissue modification.

Donor	Placed	Sex	Age	Wt (lb)	Death circumstances	Autopsy	Position	Video
423	Aug	M	40's	209	unknown	Yes	Prone	No
453	Sep	F	73	206	Stroke	No	Prone	Yes
493	Oct	M	86	~150	Motor vehicle accident	No	Prone	Yes
503	Oct	M	62	241	Natural	No	Prone	No
513	Oct	M	63	300+	Natural	No	Supine	No
533	Oct	F	60	150	Cancer (bone and liver)	No	Supine	No
543	Oct	M	54	240	Natural	No	Prone	Yes
553	Oct	M	67	114	Natural	No	Prone	Yes
603	Dec	M	79	185	Hypothermia	Yes	Prone	Yes
044	Jan	M	49	~150	Heart attack following a fight	Yes	Prone	Yes
124	Feb	F	60	125	Natural	No	Prone	No
234	Apr	M	59	n/a	Motor vehicle accident	No	Prone	No
274	May	M	78	124	GSW to right temple	No	Prone	Yes
015	Jan	M	44	459	COPD, congestive heart failure	No	Prone	Yes
799 ¹	Jul	M	57		ASCVD, contributing diabetes	No	Supine	Yes

¹not used for soft tissue modification study

possible. For paired regions, like the hands, the frequency was taken to be the number of occurrences divided by the number available. For example, some bodies were positioned with a hand and/or forearm beneath the torso so were not available to raccoons.

The following factors were also examined: when a body was first scavenged, what anatomical regions were first scavenged, and whether or not perimortem trauma affected where scavenging first began. To do this, the 14 bodies used to determine frequency by anatomical region were evaluated along with eight additional bodies photographed at the Anthropology Research Facility with typical raccoon modification. No information regarding perimortem trauma was available for these eight additional bodies.

Results

After viewing the footage, raccoon activity at corpses progressed as follows: 1) feeding on soft tissue, 2) feeding on maggot masses, 3) collecting migrating prepupae, and 4) digging in

soil for pupae. Additionally, a number of observations were made on raccoon foraging strategies at the facility, including social groups, and their manner of feeding.

Nocturnal video: foraging patterns and social groups

Particular raccoons could not be identified in video recordings, but roughly a dozen individuals entered the facility nightly during fall 2003. This estimate is based on video captured of raccoons traveling up-and-down a hillside in October. During August 2009, a camera was stationed near one of several entrances used by raccoons. Up to nine raccoons were sighted at this location on any given night; and up to five, possibly six, similarly-sized raccoons formed a loose group.

The author often remained at the facility until just past dusk to adjust lighting and re-align the passive infrared receiver, if necessary, with the help of a handheld laser pointer beam. Raccoons were sometimes spotted or heard by way of faint rustling in the underbrush. This along with captured imagery indicated the first in a procession of raccoons would arrive at the facility shortly after dusk. Video demonstrated the last raccoon usually exited before dawn.

Cameras positioned over bodies captured a procession of individuals or groups of two or three raccoons arriving at, and departing from, a particular location throughout the night. The author's impression was that individuals and groups visited multiple locations inside the facility each night and that they rotated themselves and staggered their foraging times to minimize or avoid overlap. Groups were not always maintained, however, as individuals sometimes lagged behind and other raccoons approached the site. (The ramifications of group overlap are described below.) It could not be determined with any certainty whether or not raccoons revisited feeding sites during the night; but it appeared that they sometimes did, depending on the body's location within the facility.

The facility provided raccoons with a semi-protected setting for foraging, but they remained alert and watchful as they fed. They frequently surveyed their surroundings, especially after hearing an approaching or unfamiliar sound. To do this, they balanced their torso on the hind limbs and gazed in the direction of a noise or movement. They sometimes even climbed atop the corpse for additional height. After a pointed survey, raccoons either continued to forage or they quickly left the site.

In the fall, sows brought their young to the facility and siblings foraged together. In October, young-of-year sometimes engaged in play behavior, like wrestling. Video captured a young raccoon as it sidled up to a sibling, plopped its torso on the ground next to the other's hind legs, and pushed its feet up against the raccoon's rear-end and lower back. The feeding raccoon struggled to remain upright as it dislodged itself from the sitting raccoon and then moved away without meting out a rebuke. Young-of-year foraged alongside similarly-aged non-siblings, lone opossums, and some juvenile and adult raccoons. Spats sometimes occurred, but overt aggression was rare.

As cubs aged, they became more intolerant of non-siblings, especially presumed males; and more conflicts were seen during the winter and spring. In mid-January 2004, two electrified fences were erected within the facility and nearly all of the newly received bodies were placed within these enclosures. Essentially, only one fresh body was accessible to raccoons and a handful of dominant individuals consumed most of the flesh.

Video captured in February 2005, showed submissive and/or younger raccoons remained vigilant and they hastily retreated from the corpse when they became aware of an approaching raccoon. When a dominant raccoon fed, it greeted unwelcome newcomers with harsh acoustic vocalizations and bared teeth along with a lunge or chase. Physical hostility, like biting, was not seen, but more than one raccoon passed by the corpse at a distance. An approaching raccoon generally had a greater change of feeding at a corpse if it assumed a submissive stance, with the head, neck, and shoulders lowered. However, raccoons created only one feeding location at this particular corpse and it was not readily relinquished.

A dominant raccoon feeding at the above mentioned corpse allowed presumed siblings (or perhaps one sibling that returned several times) to approach the corpse. As they did, the nose of the new arrival and that of the feeding raccoon were brought close together. The newly-arrived raccoon was discouraged from feeding, but when it persisted in its attempts, tempers sometimes flared. However, siblings generally tolerated each other and displayed few signs of aggression, like lunging. Several hours of footage were captured on three consecutive nights of presumed sibling pairs that tried to supplant each other from feeding at the corpse (Figures 30-33). Rather than initiate feeding at the unscavenged leg, the second raccoon repeatedly



Figure 30. Presumed siblings vying for a choice feeding site. Video still captured on 8 February 2005.



Figure 31. Presumed siblings vying for a choice feeding site. Video still captured on 8 February 2005.



Figure 32. Presumed siblings vying for a choice feeding site. Video still captured on 8 February 2005.



Figure 33. Presumed siblings vying for a choice feeding site. Video still captured on 8 February 2005.

attempted to displace the first raccoon from its position at the right thigh by variably inserting its upper body between the corpse and the feeding raccoon's torso or by pushing against it in order to dislodge, or pry, it away from the feeding site.

Up to six raccoons traveled together as they entered or left the facility, but they often formed smaller groups while they foraged inside. Up to five raccoons fed concurrently around a corpse, but it was more common to see only one or two raccoons feeding at a time. Feeding duration varied widely between individuals and corpses, and ranged from a few seconds to 30 or more minutes.

Nocturnal video: foraging versus scavenging

Foraging was defined here as seeking and collecting foods other than corpse tissues. Scavenging as used here was restricted to feeding on corpse tissues. This distinction was made because raccoons modified the corpse both while feeding on flesh and as they gathered late instar fly larvae feeding within body cavities. Captured video showed raccoon feeding varied according to the condition of the corpse. Raccoons scavenged soft tissues while flesh was fresh-to-putrid and prior to extensive tissue liquifaction by feeding maggots en masse. Once maggot masses were widely established in scavenged soft tissue cavities, raccoons redirected their efforts into foraging for late instar maggots inside the corpse and gathering up prepupae as they migrated away from the body. Finally, raccoons returned to the site days-to-weeks after larval migration to recover unemerged pupae beneath the ground litter and burrowed within the soil.

Nocturnal video: foraging

Raccoons sometimes engaged in the opportunistic hunting of very small animals; and catching grasshoppers and flying insects—probably beetles or moths (Figures 34-35). However, the vast majority of foraging time was spent collecting late instar maggots and pupae from corpses and nearby soil. It soon became apparent that raccoons invested a good deal of time engaged in foraging for insects inside the facility. The soil and leaf litter near bodies would be completely overturned by raccoons as one might expect if they were grubbing for insect larvae in the soil. The first two weeks of captured video at a body undergoing active decay elicited the following email communication from the author to her major advisor:



Figure 34. A raccoon alerts to movement under the leaf mat. Video still captured on 8 June 2004.



Figure 35. A raccoon thrusts its head beneath the leaves in search of motile prey. Video still captured on 8 June 2004.

The rats and raccoons are roaming all over that facility at night. ...For footage we have rats, raccoons, and birds (in the a.m.). They are all digging in the sand to some extent. The rats and raccoons were also digging all around in the soil picking up things and placing them in their mouths (the raccoons were picking them up anyway). They didn't really spend a lot of time on the body but they did spend some time picking under the bag around the knee area. I can't really tell what they were picking at. The knee is somewhat fleshed but full of maggots—would they really eat them? And as for the dirt—pupae?

Raccoons spent much time collecting individual migrating maggots off the ground (Figure 36). They used their forepaws to pluck them off the ground and place them into their mouth. Sometimes it appeared as though they licked the maggots off their palms. They also often rolled maggots between their ventral forepaws before they brought their paws together up to the mouth and ingested the maggots (Figure 37). Raccoons commonly patted surfaces with the palms of their tactile forepaws to locate the peristaltic motions of fly larvae, either on a body or the ground.



Figure 36. A raccoon plucks up migrating maggots from off the ground using its forepaws. Video still captured on 20 May 2004.



Figure 37. A raccoon rolling maggots between its ventral forepaws. Video still captured in November 2003.

Soil test excavation

Field notes with recorded daily observations described the ground litter and soil as being turned over near decomposing bodies. In particular, notes for a donation placed fresh on 1 October 2003 read there was little digging in the soil and only minor leaf disturbance around the body, which was covered with plastic sheeting. Maggots were first photographed on the raccoon-exposed left arm on 13 October and four days later an active maggot mass was beneath the skin margin of the raccoon-scavenged left elbow.

On 29 October (PMI=28 d), much digging of dirt by raccoons was noted and a 50 cm x 50 cm square (19.6" x 19.6"), located 16 cm from the bent left elbow and 43 cm from the head, was excavated with hand trowels in 2 cm (0.8") depth increments for three levels (Figure 38). Each level contained 5,000 cubic centimeters of dirt which is equivalent to 5 liters or 1.15 gallons, dry measure. During excavation, no attempt was made to capture fast moving insects or to collect earthworms. At a depth of 6 cm, the soil floor was undisturbed with no maggot



Figure 38. Litter-cleared surface of the excavated 50 cm square soil sample. The left elbow of the body is exposed and lies near the upper right wooden stake. Photograph taken on 29 October 2003.

burrowing holes. This is consistent with studies by Travis and co-workers (1940) and Vogt and Woodburn (1982) who found fly larvae did not pupate deeper than 5 cm.

The excavated dirt was placed in plastic bags and two days later each level was dry-screened using 1.6 mm (1/16") mesh screen. Because the soil was dry and clumped, about half the dirt was water-screened the following week. After each screening, recovered larvae and pupae were scalded in sub-boiling water and preserved in 70% ethanol as recommended by Amendt and colleagues (2007).

Recovered insects and their larvae were grouped into three categories: Diptera (flies), Coleoptera (beetles) and Unidentified/Other. During the 48-hours prior to dry-screening, numerous flies emerged from their puparia. Live flies escaped from the bags when opened; four dead flies were recovered from the Level 3 bag. Given the circumstances, adult flies were excluded from all counts. Larvae and puparia (emerged and unemerged) of flies and beetles were counted for each level. Numerous puparial fragments were also present and represented the remnants of both emerged flies and puparia which may have fragmented during soil excavation.

For a rough estimate of the number of whole puparia represented, both anterior and posterior ends were counted and their sum was divided by two. Parasitized pupae, identified by the presence of a small, circular drill hole in the puparium (brief review in Dowell, et al. 2000), were excluded from all counts.

A total of 277 larvae, pupae or puparia were recovered from the 15 L (3.39 gal, dry) of soil excavated from the 50 cm x 50 cm x 6 cm pit (Table 5). As expected, the number of insects decreased with increasing soil depth; with 59.6% recovered from the top 2 cm (Level 1), 31.8% recovered from a depth of 2-4 cm (Level 2) and 8.7% recovered from a depth of 4-6 cm (Level 3). Two unidentified emerged puparia were recovered from Level 1 and a hide beetle larva and a rove beetle larva were both recovered from Level 3.

The purpose of the pit excavation was to identify carrion soil fauna as potential attractants for foraging raccoons. Raccoons can be a pest species when they uproot manicured lawns while grubbing for common insects, especially beetle larvae. Soil disturbance by foraging

Table 5. Insects and their remnants recovered from 15 L (3.39 gal, dry) of soil.

Category	Level 1	Level 2	Level 3
Diptera			
Larva	91	39	14
Pupa	25	9	0
Puparium	46	40	8
Coleoptera			
Larva	1 ¹	0	2 ^{2,3}
Unid/Other	2 ⁴	0 ⁵	0
Total ⁶	165	88	24

¹ clown beetle larva, *Hister* spp. (N=1)

² rove beetle larva, c.f., *Creophilus maxillosus*, hairy rove beetle (N=1); hide beetle larva, *Trox* sp. (N=1)

³ dermestid beetle larva, *Dermestes* spp. (N=1), excluded

⁴ emerged puparium (N=2)

⁵ soil centipede (N=1) excluded

⁶ number of insects per 5 L (1.15 gal, dry) of dirt

raccoons continued at and near the location of excavation for a couple days after dirt removal, then abated until 11 November when moderate digging began in the soil on the west side of the body (as opposed to the east). Video footage captured at the facility throughout this research showed raccoons fed upon both maturing and postfeeding diptera larvae; and raccoons dug nightly in the ground litter near several of the filmed bodies, but what was being recovered and ingested could not be seen.

The insect counts tallied in Table 5 assume that most all of the recovered carrion fauna is potential protein for a foraging raccoon. Yet whether a raccoon will expend energy to recover individual pupae within the soil is questionable, even in fall when it is building up an energy reserve in preparation for the upcoming winter. Entomologically, only flies and their larvae, wasps and ants were seen on the body although much of it was covered with plastic until mid-November. However, few beetles were documented at this time on other monitored bodies at the facility. While most immature beetles may have been collected by foraging raccoons prior to the soil excavation, a low abundance of beetles in the fall is consistent with published literature (Rodriguez and Bass 1983). Monthly temperatures around the time of excavation did not deviate markedly from that of the 30-year normal.

A single larva each of a rove beetle, a hide beetle and a dermestid beetle were recovered from the excavated soil. The rove beetle larva was collected alive, but the other two larvae were presumed dead. Both adults and larvae of the rove beetle are predaceous on maggots (Byrd and Castner 2001). Hide and dermestid beetles are typically attracted to bodies or carrion that have reached the dry stage of decay (Reed 1958; Rodriguez and Bass 1983); and are unlikely to have originated from the body. Examination of facility maps of body locations showed two bodies—one placed in July 2002 and one in February 2003—decomposed near this location up until two days prior to placement of the current body so some recovered diptera puparial fragments may have originated from these earlier donations.

This single test excavation suggested raccoons were indeed after the pupae in the soil.

Nocturnal video: soft tissue scavenging

Raccoons used their forelimbs to reach or provide contralateral torso support, secure tissue for removal by the incisors and canines and for full body leverage (Figure 39). Similarly,



Figure 39. A raccoon clasps the posterior right leg with a right forepaw. Video still captured in February 2005.

hind paws were used to stabilize and balance the torso while the forepaws engaged in tissue manipulation (Figure 40). Raccoons engaged in soft tissue scavenging while in a semi-erect position with the bulk of body weight resting on the hind limbs; and they often rested their torso on the ground or against the carcass.

Raccoons modified the skin in unexpected ways; and removed it either inadvertently or intentionally. Raccoon claws inadvertently produced extensive surficial markings, like dermal abrasions and scratches, when they walked or climbed atop the corpse; and because they clutched skin with their forepaws and sometimes levered a hind paw against the body (Figures 39-41). Inadvertant removal of the epidermis occurred when the ventral surfaces of a raccoon's paws or a body member made pressurized contact with a corpse surface after dermoepidermal cleavage had commenced. Raccoon paws were commonly in contact with corpse surfaces, and the friction pads of the hands and feet hastened the shedding of slipped skin, particularly when bearing weight (e.g., when a raccoon climbed atop the corpse).



Figure 40. A raccoon bracing a right hind paw against the right posterior thigh. Video still captured on 8 February 2005.

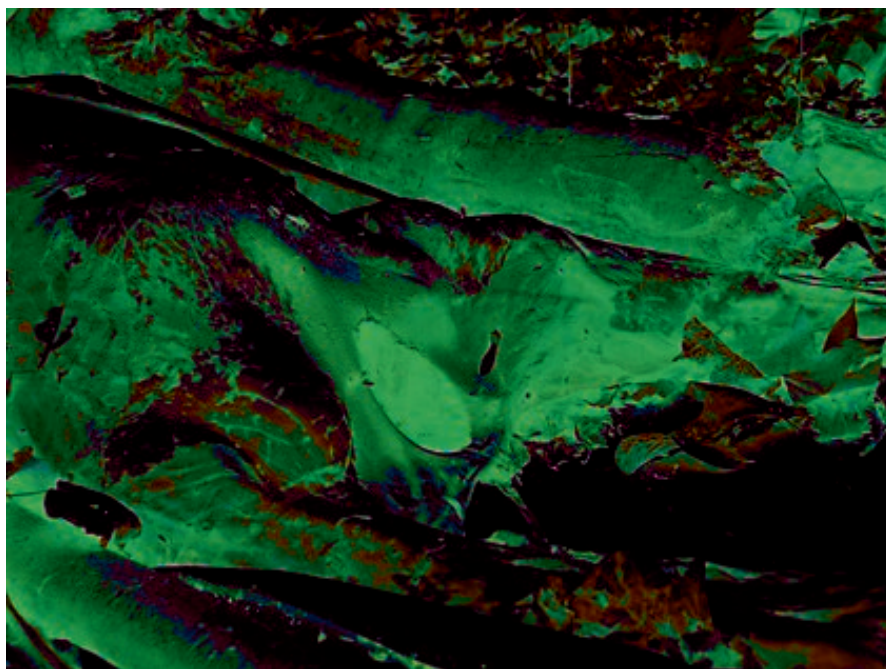


Figure 41. Skin abrasions and epidermal loss. Photograph taken on 21 October 2003.

Skin that was intentionally removed was often consumed in its near entirety. Raccoons removed small pieces of fresh skin, sheets of epidermis, and sometimes patches of skin. The epidermis was often intentionally removed from the foot and ankle areas and less commonly, the hand, torso, or limbs. Raccoons nipped the distal ends of manual and pedal digits and palms or soles to remove the epidermis. This behavior provided an easy means of evaluating skin integrity for it appeared that the epidermis was not easily detached prior to cleavage of the dermoepidermal junction. This was verified by examining the photographs of two raccoon-scavenged bodies in the present study, who were research subjects in a histological study of postmortem changes of the skin. One of the microscopic findings of Kovarik and co-workers (2005) for acral skin, was that the epidermis did not cleave from the dermis of either individual during the first seven days of decomposition: the extent of their monitoring period. Figure 42 shows the left toes of a body on day 7, after two nights of raccoon disturbance (first chewed on nights four and five). Small pieces of epidermis were scraped from the distal toes injuring the



Figure 42. Left toes on day 7. Toes were chewed on nights four and five. A stellate rip is present on the far right toe. Photograph taken on 7 October 2003.

dermis and leaving remnants of loosened skin. (Note the single canine puncture present on digit four and the stellate skin rips.) In contrast, Figures 43-44 show the right foot of a second body on day 8, after one night of raccoon modification, and day 10, with newly removed skin. Raccoons removed most of the epidermis from digits two through four leaving a relatively smooth dermal surface; and the slipping epidermis of the dorsal foot and ankle was peeled away in thin, sheet-like pieces. This particular event was not captured on video, but epidermal slough was removed over several nights. Figure 45 is a video still taken of a raccoon just after it removed sloughed skin, and before it ingested much of it.

Raccoons nipped at and pulled on the distal digits of corpses using their incisors and chewed on fingertips and toes with their cheek teeth. If the epidermis was firmly attached to the dermis, it was not easily removed. Raccoon biting and chewing produced linear cuts and stellate rips that were roughly 2-3 mm in length (Figures 42, Figures 46-47). Ripped skin was thought to be caused by a dragged canine cusp and most cuts were attributed to the thin-bladed cusps of the premolars, but other teeth may have contributed. In Figure 46, the fresh skin on the fingertips



Figure 43. Right foot on day 8. Photograph taken on 8 October 2003.



Figure 44. Right foot on day 10. Photograph taken on 10 October 2003.



Figure 45. Raccoon with a large sheet of detached skin held in its jaw. Video still captured on 11 October 2003 (3:06 AM).



Figure 46. Left fingers with scraped off fingertips. The dark lacerations are about 2-3mm long. Photograph taken on 8 May 2004.



Figure 47. Right foot with removed dorsal skin. Photograph taken on 8 October 2003.

was scraped off exposing the subcutis.

A sloughing epidermis could be slipped from the tip or a finger or toe, especially if the teeth grabbed hold of shedding nail (Figure 48). Slipping skin and loose edges were secured between the incisors or the terminal digit pads of the forepaws. In early February 2005, a raccoon climbed atop the posterior calf of an obese woman and ran its forepaw across the leg's surface. When the skin was discovered loose, it opened its mouth and bit the surface with its incisors and then pulled the epidermis away from the dermis until a patch tore away (Figure 49). Four nights later, video captured a raccoon at the same location running its flattened forepaws along the leg until it grasped an edge of skin and peeled it away from the corpse (Figure 50). This time, only a small piece of the epidermis was ingested.

Raccoons sometimes completely defleshed the extremities, particularly, the distal extremities (Figure 50); or removed only an area of skin and the immediate underlying tissues from the dorsal surfaces of hands and feet (Figure 51). A patch of dorsal skin was removed from



Figure 48. Left hand: the thumbnail and epidermis were pulled off by a raccoon. The nail remains attached to the sloughed skin and rests just below the thumb. Photograph taken on 10 May 2004.



Figure 49. A raccoon (right) pulls off the slipped epidermis gripped between the incisors. Video still captured on 3 February 2005 (11:58 PM).



Figure 50. A raccoon using its forepaws to pull off the slipped epidermis. Video still captured on 7 February 2005 (5:41 AM).



Figure 51. Defleshed right distal extremity. The epidermis was pulled off the left leg, and that of the right thigh was at least partly removed inadvertently. Photograph taken on 5 February 2005.

two feet and raccoons probed the intermetatarsal spaces with their forepaws and removed the accessible tissues. The cavities then attracted flies, which oviposited their eggs within. For the foot pictured in Figure 47, raccoons were seen collecting the prepupae that emerged from the feeding cavity to seek a place to pupate.

Raccoons removed two scalps: one from a body in active decay and one from a corpse in advanced decay. On 20 April 2004, a raccoon-scavenged corpse was missing about half of the scalp and carnivore tooth marks were impressed in tissue near the torn margin (Figures 52-53). This event was not recorded by a camera, but one year later (30 May 2005) a raccoon was seen tearing off the scalp of a partly exposed body undergoing decay in a shallow burial. Figure 52 also demonstrates how raccoons probed in small body crevices—their forepaws probed above the mandibular notch for maggots.

Raccoon-scavenged bodies often retained much of the skin, even when the corpse was stripped of a fair amount of musculature. The torso nearly always remained covered, except in



Figure 52. Torn scalp. Photograph taken on 20 April 2004.



Figure 53. Tooth marked and torn scalp (superior view). Photograph taken on 20 April 2004.

instances of intense soft tissue scavenging. Such cases reported here are probably exceptional, because all three examples are of autopsied individuals. The lengthy autopsy incision made to open the chest and abdominal cavities likely provided raccoons with a starting point from which they could pull and work the skin away from the vertebral column as they removed the torso musculature (Figures 54). In autopsied bodies, torso skin was pulled and pushed away from the vertebral column until it lay alongside the torso as a partly rolled up, discarded sheet that remained attached to the corpse at both ends—generally, at the neck and thigh (Figure 55). For non-autopsied bodies, the corpse appeared as a nearly or fully articulated skeleton encased by a variably perforated, loose-fitted skin carapace.

When raccoons perforated fresh skin to remove muscle, the openings were generally 2-4” in diameter and canine punctures were sometimes found along skin margins (Figure 56). With repeated probing, the skin margins became rolled under as more and more muscle was removed (Figure 57). Skin sagged and what remained was skin covering defleshed bone (Figure 58).



Figure 54. A raccoon (right) reaches beneath the skin of the posterior torso to remove the vertebral column musculature. Unattended photograph taken on 5 February 2004.



Figure 55. Extensive raccoon modification of an autopsied body placed on 15 January 2004. Photograph taken on 14 February 2004.

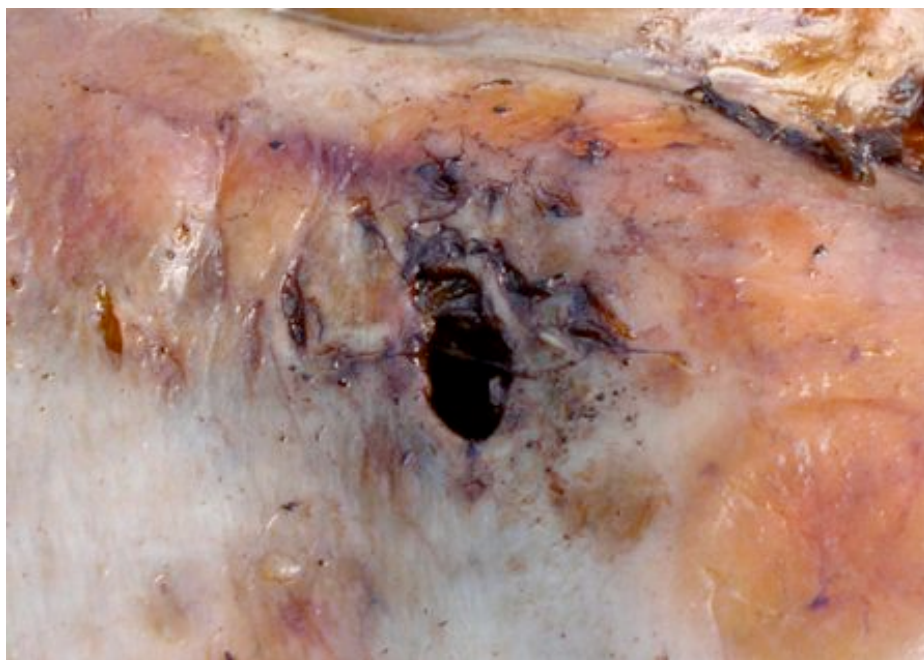


Figure 56. Raccoon entry into the left buttock. Photograph taken on 17 March 2004.



Figure 57. Left triceps removed through a circular entrance of the muscle bellies. Photograph taken on 11 October 2003.



Figure 58. A raccoon entry into a right inner thigh for complete removal of the hamstring and quadricep muscle groups. Photograph taken on 1 February 2004.

Marked differences existed between raccoon-scavenged and unscavenged regions (Figure 59). Figure 58 illustrates skin on a relatively fresh body, which decayed in winter. When raccoon-scavenging was accompanied by skin collagen breakdown, the skin became stretched and the openings greatly enlarged—so much that the long bone shaft was often exposed (Figure 60). Rolled under and smooth skin margins were not seen in newly scavenged areas—even if the wound was atypically large. Figure 61 shows a right calf that was first scavenged by raccoons the night prior. Raccoons most commonly created holes in muscle bellies, but they also appeared at joints, at armpits from which the shoulder girdle muscles were removed, and along the torso.

After skin and the immediate underlying tissue—often muscle—were ripped open and removed by the dentition, the raccoon probed created cavities and recesses with its forepaws. If it was unable to remove tissue with a forepaw, the raccoon placed its rostrum or head—even upper torso—into the cavitation to remove tissue with its teeth (Figure 62).



Figure 59. Marked discrepancy of soft tissue volume due to raccoon scavenging of the right thigh. The integument covering the right buttock has been inverted. Photograph taken on 7 October 2003.



Figure 60. Raccoon modification of the right calf. Photograph taken on 12 October 2003.



Figure 61. Freshly-scavenged right calf. Photograph taken on 10 May 2004.



Figure 62. Raccoon placing its snout beneath skin to remove tissue.

The raccoon nipped, tore off, and jerked or pulled on tissue gripped between the teeth (Figure 63). Skin or tissue that was not easily removed, and sometimes muscle, was gripped between the anterior teeth and the head and upper torso was reared or jerked backwards to its severance. When muscle was pulled away near a joint, remaining muscle and tendon remained splayed about the joint.

Raccoons usually scavenged the torso near an armpit or through the inferior pelvis, where they removed the buttocks, shoulder muscles, and other tissues, like subcutaneous fat. Torso modification was affected by the conditions of corpse decay. Raccoons completely defleshed the ribs and vertebrae of three autopsied, fresh bodies placed in December and January. Moderate amounts of tissue was removed in the fall and spring. Little torso flesh was removed after, and if, a corpse achieved full bloat.

Raccoons were uninterested in consuming the internal organs of scavenged bodies. The torso was commonly probed, but viscera was not sighted—with one exception. On 11 January, a



Figure 63. Raccoon pulling on tissue.

nearly intact liver was discovered lying atop the torso of a prone-positioned autopsied body (with returned, severed organs) covered by an opened body bag and chicken wire. The body was placed at the facility one month prior, and raccoons began scavenging the corpse during the later part of December. Raccoons had created about a 20x14” opening in the wire near the right shoulder and had removed the soft tissues of the head and right arm, and probed deep beneath the body to reach into the opened torso. The mis-shapen liver had minor damage consistent with biting and chewing by an opossum. It was inferred that raccoons had pulled the organ from the chest cavity and discarded it atop the corpse where an opossum chewed on it.

Raccoons concentrated on removing musculature (Figure 64), particularly limb musculature and thoroughly removed the tissues from between the tibia and fibula and the radius and ulna. Video footage showed raccoons removed these muscles alternating between using incisors, posterior teeth, and forepaws. Such feeding sometimes left tooth score marks on paired long bone shafts.

Raccoons were inconsistent in scavenging the soft tissues of the head. Soft tissue feeding



Figure 64. Raccoon-removed flexor and plantar muscles of the left sole. Photograph taken on 5 March 2005.

was largely restricted to removal of the temporo-masseter muscle, tongue and perhaps, esophagus (Figure 65). Exceptional feeding occurred under some circumstances (see below).

Chewed fingers and toes were common; and missing digits included the distal phalanx, all the phalanges, and sometimes even chewed metatarsals or metacarpals. Fingers and toes were chewed before, during or after other scavenging activity. Damaged hands and feet showed much variation in the type and extent of damage as well as when scavenging occurred along the decay spectrum. Many instances of modification were not captured by nocturnal photography as hands and feet were often the first and/or last regions to be scavenged. Chewed digits were sometimes discovered on corpses in advanced decay with or without previous soft tissue scavenging.

In general, raccoons began feeding on human soft tissue within the first week of corpse exposure. However, there were four instances in which raccoons did not scavenge the remains until about 25 days after exposure. These bodies were in active or advanced decay and there was



Figure 65. Right lateral face. Photograph taken on 8 October 2003.

minimal insect activity near the site of feeding. Further, little tissue was consumed and it was often the fingers, toes, or feet that were chewed—but sometimes they fed on muscle. Also, feeding generally occurred only once or twice at the disturbed site. There were a number of bodies that decayed at the facility with minimal-to-no raccoon disturbance.

Raccoons primarily fed on human soft tissues while bodies were in the fresh and early decomposition stages—they preferred fresh muscle tissue. Bodies that remained in the fresh stage for a greater number of nights were more extensively stripped of muscle tissues than bodies that underwent rapid decomposition. Raccoons scavenged on human soft tissues well after maggot masses were established, but they did not appear to feed on tissue that contained active masses. However, they further modified these areas when they began feeding on late instar maggots.

The bodies listed in Table 4 decayed in mostly similar circumstances, i.e., nude, prone body position, and many were originally covered with black plastic (polythene) sheeting and/or an opened body bag weighted with bricks, rocks, or large branches. However, bodies positioned

otherwise and which decomposed under different circumstances—even different years—were generally scavenged by raccoons similarly, with some exceptions. The following cases have little evidence in the way of nocturnal photography to document the scavenging events.

Four clothed bodies were photographed as they decayed at the facility. Three bodies retained loose-fitting clothing—a long-sleeve sweatsuit, an short-sleeve t-shirt and cotton knit pants with an elastic waistband, and a long-sleeve t-shirt only—and had soft tissue scavenging consistent with raccoon feeding. The fourth body was dressed in an untucked, long-sleeve dress shirt and tightly-fitting khaki pants and was minimally disturbed by one or more raccoons that foraged on the body for insects. None of the clothing was noticeably chewed or ripped apart, but when raccoons scavenged on soft tissue, loose pant cuffs and such were pushed or pulled away from the feeding site. And when raccoons foraged for insects, clothing ends and fabric folds showed disturbances that were consistent with probing forepaws. Raccoons did bite upon and puncture some body bags with their teeth to reach a corpse, but even persistent raccoons were unable to fully breach the thicker body bags. It is reasonable to assume that a determined raccoon can damage clothing, but a raccoon is more likely to employ its forelimbs to access available tissues and/or insects and then move on to another food source.

A number of corpses were placed in settings meant to deter raccoon scavenging. Unusual feeding was sometimes seen under these circumstances. For a nude, supine-positioned body covered with plastic sheeting and chicken wire, it was mostly the prominent areas of the corpse that were attacked, because it was at these sites—the right big toe, jaw line, and knees—that raccoons were able to grasp and began chewing on tissue. Undaunted by the chicken wire which pressed against the corpse under the animal's weight, and without damaging the wire, a raccoon defleshed the right side of the jaw and face by chewing off the integument and much muscle (Figure 66). (Defleshing of the scalp and/or face was documented for four bodies that winter: three were placed under chicken wire and one was not.) Further, the oral tissues were severely mangled and much tissue had been removed. The hexagonal openings of the chicken wire were roughly 1¼ - 1½" in diameter, so only a raccoon's forepaw could have probed so deeply into the oral cavity.

A second example of unusual scavenging involved a nude, supine-positioned corpse that



Figure 66. Raccoon-defleshed face. Photograph taken on 14 January 2004.

was completely exposed and lay within an electrified fence enclosure. The body was placed mid-January 2004 and due to at least two electrical disruptions, one or more raccoons gained access to the corpse at decay weeks three and four. The musculature of the arms and left calf were largely removed; and that of the right inner thigh was partly extracted by way of the right groin. Highly uncharacteristic, was the deeply torn and chewed lower lip. Further, the oral cavity tissues were mangled: the upper palate was missing a large portion of skin, the tongue was no longer attached inferiorly, but at least a portion of the tongue was visible and pooled with tissue remnants at the back of the mouth. Extraction of the tongue by way of the mouth seemed to be a difficult endeavor, particularly since the rest of the body was readily accessible and not heavily scavenged.

These examples show the raccoon is an opportunistic and highly adaptable scavenger that is not easily deterred from a potential food source. Further, it will learn new ways to access the tissues of the human body by its habit of probing in natural or formed cavities. It is worth noting that the five bodies discussed in the previous two paragraphs were all placed at the facility in

December 2003 and January 2004. It was assumed that more examples of oral cavity destruction and facial defleshing were not seen because of the prone position of most bodies placed at the facility and because in warm weather, the facial cavities frequently undergo rapid tissue dissolution due to maggot feeding. Further, raccoons may have scavenged more extensively on human remains during winter because there are generally fewer alternative foods available.

A compelling case can be made for the suggestion that raccoons selected meat or maggots based upon item availability and preferred timing. The left leg pictured in Figure 67 represents from top-to-bottom in reference to the top image, 1 day and 25 days apart. Raccoons first removed the quadriceps and hamstrings from around the femur, then maggots fed and developed within remaining tissue and then raccoons either fed upon the maggots or allowed them to migrate from the body prior to exposing the tissue surrounding the knee joint. Finally, pulled muscle and tendon became strand-like in appearance as raccoons pulled upon it as the tissue dessicated and the skin surrounding the femoral shaft demonstrates paw probing for remaining maggots.

Soft tissue modification: frequency by anatomical region

A histogram of scavenging frequency by anatomical region is given in Figure 68. Raccoons at the facility most frequently modified tissues of the appendicular limb, particularly, that of the lower limb. Raccoons most often scavenged the calf (82.1%), foot (82.1%), and toes (77.8%). The head was least frequently scavenged (28.6%). When anatomical regions were grouped (i.e., summed together) (Figure 69), hands and feet were most often affected (71.2%), followed by the digits (66.0%).

Skeletalization and scatter

Raccoons accelerated skeletalization as they consumed muscle masses and to a lesser extent, fat and viscera. Unlike canids, raccoons did not chew off limbs nor were they seen transporting detached body units away from the site. The opportunity was present as several bodies suffered major perimortem trauma due to, for example, a motor vehicle accident. Donors that sustained broken ribs prior to introduction to the research facility were not uncommon. For two donations, incomplete ribs and bone fragments were found lying next to the torsos. Some



Figure 67. Left leg showing raccoon-scavenged tissue appearance over time: 26 March, 27 March, and 20 April, of 2004 (top-to-bottom).

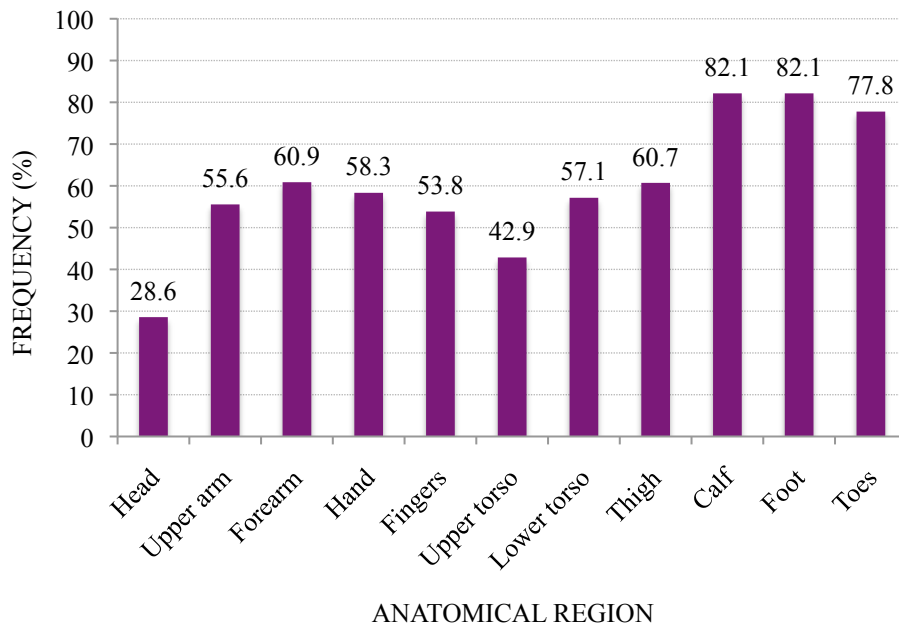


Figure 68. Frequency of raccoon soft tissue scavenging by anatomical region for 14 bodies.

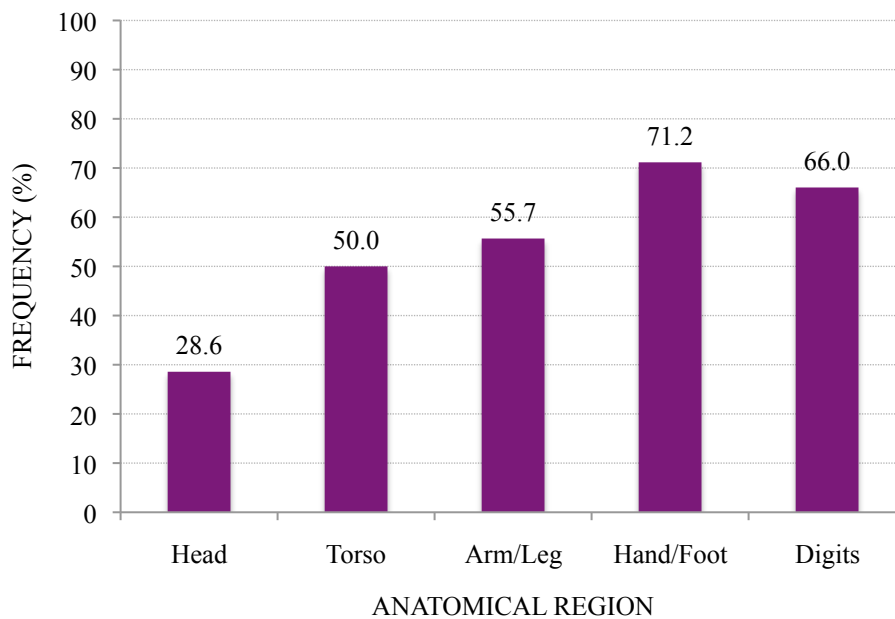


Figure 69. Frequency of raccoon soft tissue scavenging by grouped anatomical regions for 14 bodies.

bone movement did occur and the transporters could be raccoons. Such examples included the movement of three skull calottes and a clavicle that were all discovered inside the facility during scat collections.

Serial photographs of fifteen unclothed donors either known to have been scavenged by raccoons or with soft tissue damage consistent with raccoon scavenging were examined for evidence of raccoon-produced disarticulation. In nearly all instances, disarticulation was aided by natural decay (Figures 70-71). In the spring, warming temperatures and rainfall promoted tissue liquification and joint disarticulation occurred as raccoons probed within tissue cavities for prepupae.

Raccoons were the primary agent of skeletal scatter as they foraged beneath the ground litter and superficial soil layer. While bones remained at or near the site, they could become quite jumbled and even partly buried. Raccoon foraging in the soil downhill of a donor placed in August 2003 is illustrated in Figure 72. Digging in dirt near decomposed bodies and above shallow burials was an activity that peaked in the fall and in the spring into summer.



Figure 70. Raccoon-scavenged remains. Only loose ribs are scattered out of anatomical position. Photograph was taken on 26 June 2004.

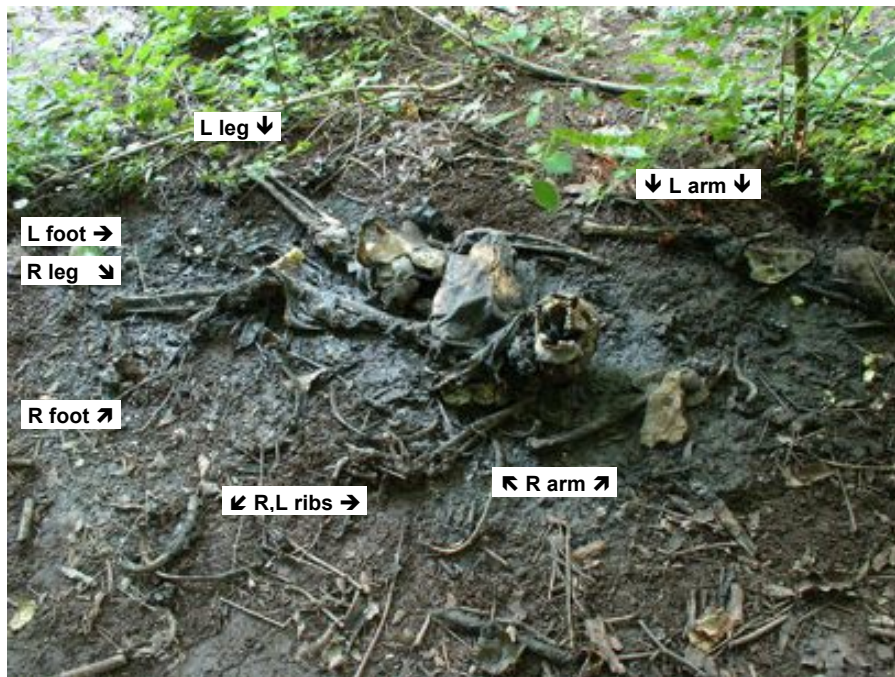


Figure 71. Increasingly jumbled remains. Photograph was taken on 29 June 2004.

Bone modification

The skeletons of seven individuals that were closely monitored while they decayed at the Anthropology Research Facility were examined in the William M. Bass Donated Skeletal Collection. Biographical data and the circumstances surrounding the donor's death is included in Table 6 along with their decay interval at the outdoor facility. These individuals were scavenged by raccoons and were accompanied by documentation in the form of field notes and diurnal photographs. In addition, five out of seven bodies had nocturnal video footage of raccoon scavenging behavior and one additional body had a series of nocturnal 35 mm prints that placed raccoons at the site. The extent of unattended video and still photography available for these seven individuals is given in Table 1.

Bone modification was documented in the form of descriptive notes and some digital photographs. Tooth mark type and location were diagrammed on skeletal figures. During examination of the bones, superficial scores were noted on multiple long bone shafts. These



Figure 72. Scattered remains due to raccoon foraging for insects. Note the churned-up soil. Photograph was taken on 26 September 2003.

Table 6. Carnivore tooth marked skeletons from the William M. Bass Donated Skeletal Collection.

Donor	Placed	Sex	Age¹	Death event	Autopsy	Decay period (m)²
453	Sep	F	73	stroke	no	11.8
493	Oct	M	86	MVA trauma	no	12.0
603	Dec	M	79	hypothermia	yes	8.6
044	Jan	M	49	post-fight heart attack	yes	7.0
124	Feb	F	60	natural	no	6.1
274	May	M	78	GSW (right temple)	no	3.7
015	Jan	M	44	congestive heart failure	no	20.3

¹mean age-at-death of 66.1 years

²mean decay period of 9.9 months

these marks were produced early in decay.

score marks did not meet the criterion outlined by Blumenschine and co-workers (1996) as there was no crushing of the internal surface. Nevertheless, they were recorded as scores because they appeared to be significant based on video observations of raccoon feeding mannerisms and their being located at scavenged areas. In addition, dark staining of the internal surface suggested

Some of the skeletons suffered a fair amount of skeletal processing damage. Most damage was easily distinguished, but some was less confidently ascribed to a taphonomic agent. Most marks were identified based on macroscopic observation alone, but some marks were examined with 10X magnification. When shaft is used here, it refers to the true long bone shaft with reduced diameter and increased cortical thickness.

Raccoons modified human bones during soft tissue consumption. The most common sites of raccoon modification were the hands and feet that suffered crushing and chewing damage (Figures 73-75). Bone damage could be quite minor and limited to crushed and chewed off manual and pedal phalanges, but it could also include the metacarpals or tarsals (Figure 76). Tarsals and carpals were chewed when raccoons extensively scavenged the foot, removing the tissues about the ankles.

The human arm and forearm was a frequent site of raccoon soft tissue scavenging. Gnaw marks on bone were most often located on the distal humerus and proximal end and shaft of the



Figure 73. Chewed toes. Photographs taken on 11 October 2003.



Figure 74. Crushed and splintered distal pedal phalanx of the right first digit. Photograph taken on 9 November 2003.



Figure 75. Raccoon modification to (left-to-right): three pedal phalanges (one distal, two proximal) and one fifth metatarsal.



Figure 76. Carnivore modification of a left foot. Photograph taken on 15 October 2003.

ulna. Tooth marks along the shaft presented as scores transversing the long axis and were often linear in course (Figures 77-78). The base of the grooves varied from a soft, and somewhat deep, V-shape to either a shallow U-shape or a superficial, nearly flat-bottomed trace. The floor and walls of toothmarks were rarely marred by crushed-in bone which is a characteristic of carnivore gnaw marks. Rather, raccoon teeth formed impressions in bone; occasionally, the marks could be described as the channeled removal of bone. Observations of filmed footage of raccoon feeding behavior showed raccoons made extensive use of their anterior dentition to remove soft tissue from bone. The V-shaped tooth marks to the left in Figure 77 may have been produced by the raccoon's protruding canine teeth. The curvaceously pathed, shallow grooves to the right in that same figure may reflect multi-directional movement of the incisor teeth as they were pulled across and along a tubular shaft to achieve soft tissue removal.

A typical raccoon-scavenged arm appears in Figure 79. Raccoons continued to remove soft tissue from this arm—they gripped tissue in their teeth and pulled backwards away from the



Figure 77. Posterior midshaft of the left radius with two distinct grooves (left arrow) that are somewhat V-shaped in cross-section and multiple, irregular and curvaceous lines (right arrow).



Figure 78. Scored left ulnar midshaft.



Figure 79. A raccoon-scavenged right arm. Photograph taken on 9 May 2004.

joint, which was secured by their forepaws. In Figure 80, part of the articular circumference of a right radius was removed by a raccoon and the underlying trabeculae was exposed. This damage occurred after the joint's disarticulation and took place when soft tissue was further gnawed from the forearm. This modification was unusual in that bone almost appeared to have been shaved away—it was either removed by a raccoon occluding its incisors or cheek teeth. A clear score mark crosses the proximal articular surface. A typical carnivore furrow was found on the right proximal ulna (Figure 81).

Shallow impressed scores were located on the periosteal surface of long bone shafts (Figure 82). These light scores were oriented roughly perpendicular to the long axis of the shaft and were most commonly found on the tibia, fibula, radius and ulna. Such marks are consistent with raccoon attempts to remove muscle tissue from articulated long bone shafts by repeatedly grasping and tugging on pieces of flesh with the anterior dentition. These marks are light, because of the raccoon's smaller body size and their intent was only to remove soft tissue—they spent little time gnawing bone. Raccoon damage was most noticeable on cancellous-rich areas



Figure 80. Scored right radial head. Photograph taken on 25 May 2004.



Figure 81. Furrowed right proximal ulna. Photograph taken on 25 May 2004.



Figure 82. A shallow, impressed score across the tibial midshaft (distal end up).

covered with thin cortical or subchondral bone, like the sacrum (Figures 83-84); and on thin bones, like the scapula (Figure 16). Bone was more easily damaged on older individuals; and those immobilized before death, as the individual shown in Figures 85-86.

Raccoons spent much time scavenging an autopsied body placed in January 2004. Some of the ribs had been broken in a fist fight and the sternal ends were cut during autopsy. Raccoons broke off most of the ribs by grabbing ahold of the ventral end and levering it back-and-forth. Some ends were also chewed. Video captured one such rib as a raccoon pulled it out from the torso. While held in the forepaws, it scraped the rib surface with its incisors as it attempted to remove flesh and periosteum. The incisors were occluded and drawn perpendicular across the long axis of the rib (Figure 87). It also placed one end in its mouth, and the rib was drawn out while its mouth tried to remain closed. After a few seconds of feeding, the raccoon discarded the rib even though some tissue remained, and continued feeding on the body (Figure 88). The corpse was abandoned once nearly all muscle was removed as there were no insects to forage.



Figure 83. Raccoons feeding: the center raccoon repeatedly bit down on musculoskeletal tissue attached to the posterior sacrum and tugged on the tissue by pulling away with the head and shoulders. Video still captured on 26 January 2004.



Figure 84. The raccoon-damaged sacral apex. The coccyx was not recovered.



Figure 85. Right knee furrowed along the tibial plateau margin. Photograph taken on 5 March 2005.



Figure 86. Right tibia and fibula.



Figure 87. A raccoon scraping tissue off a detached rib. Video still captured in February 2004.



Figure 88. Raccoon-removed rib lays discarded on-site (near head). Video still captured in February 2004.

Carnivore-scavenged human remains

To better clarify raccoon bone modification and tooth mark distribution patterns that may be unique to the raccoon and atypical of other carnivores, a comparative study was undertaken using the seven raccoon-scavenged skeletons from the William M. Bass Donated Collection and 29 carnivore-scavenged skeletons from the William M. Bass Forensic Skeletal Collection. The collections were compared in light of skeletal element recovery, the presence or absence of tooth marks, gnawing distribution and the type of damage by bone region of select tubular bones. Basic information on the forensic cases is given in Table 7.

A frequency table of recovered skeletal elements for both the donated and forensic skeletons is given in Table 8. The percent recovery ranges from 87.5% (sternum) to 100.0% (all major bones). In addition to the sternum, other elements with percent recovery less than 100.0% are the hands, patella and feet. The recovered skeletal element frequencies for the forensic collection range from 31.5% (patella) to 100.0% (cranium). In addition to the patella, other low recovery skeletal elements are the sternum, hands and feet. In addition to the cranium, other high recovery skeletal elements are the tibia, mandible and femur.

The high percentage rates for elements recovered in the donated sample is expected for four reasons: 1) observations at the facility suggested that raccoons did not delete whole bones, excluding phalanges, 2) raccoons appeared uninterested in gnawing bones lacking flesh and were not seen transporting bone, 3) the mean decay interval for the sample was 9.9 months and 4) two individuals decomposed inside a rectangle formed of abutting cement blocks which prevented bone migration. The percentage rates of recovered skeletal elements for East Tennessee forensic cases are somewhat similar to those of thirty-three carnivore scavenged human remains cases from Washington state (Haglund 1991) as illustrated in Figure 89. For this comparison, Haglund's raw data (1991:210-249) was critically examined and carnivore scavenged individuals without tooth marked bone, subadults, individuals who decayed indoors and a few other cases were excluded to provide a comparable dataset.

A frequency table of tooth marks for the William M. Bass Donated and Forensic Skeletal Collections is given in Table 9. The tooth mark frequencies for the donated collection range from 0.0% (cranium, mandible and sternum) to 92.3% (hands and feet). Other elements with

Table 7. Carnivore tooth marked skeletons from the William M. Bass Forensic Skeletal Collection.

Case	Died	Sex	Age	Death event	Deposition site	Decay
1	Jul	F	20	sharp force trauma?	thick underbrush (near academy)	6
2	Jun	--	--	unknown	ditch near road (wet weather creek)	1
3	--	M	50+	unknown	--	≥24*
4	--	M	55-65	unknown	--	3*
5	Jun	F	58	unknown	--	16
6	Jun	M	36	unknown	--	18
7	May	M	25	unknown	--	9
8	--	M	39	--	--	24-36*
9	Sep	M	80	unknown	--	2
10	May	M	--	plane crash	wooded mountain side - isolated	3
11	--	--	--	GSW to head	heavily wooded - isolated	--
12	Apr	M	73	unknown	--	8
13	Oct	M	31	sharp force trauma	wooded gully along road	2
14	Aug	M	--	unknown	wooded property near large factory	4
15	Jun	M	--	GSW to head	near mountain parkway	7
16	Jul	M	49	unknown	west Tennessee	56
17	Oct	--	--	unknown	unknown (near wheatfield)	36
18	--	M	--	GSW to head?	thick underbrush of wooded slope - isolated	24-60*
19	Jun	F	26	sharp force trauma	thick underbrush of wooded area near road	43
20	--	--	--	unknown	--	several*
21	--	F	18-25	unknown	shallow grave along bank of water near road	6-12*
22	Nov	M	29	unknown	vacant property with condemned house	34
23	Sep	F	16	fall from cliff?	woods at bottom of 100' cliff - isolated	1
24	Apr	M	21	GSW to head	wooded mountainside - isolated	13
25	Apr	F	28	--	thick underbrush along drainage ditch	97
26	Jun	M	25-36	GSW to head	ditch of vacant, overgrown lot	2
27	Feb	F	75	--	vacant lot?	33
28	ca. Mar	M	40's	unknown	wooded, water drainage area near large plant	≥12
29	Dec	F	37	strangled	strip of woods between neighboring homes of rural development	0.6

¹mean age-at-death of ca. 40.2 years²mean decay period of ca. 18.9 months

Table 8. Recovered skeletal element frequencies for carnivore-scavenged human remains in the William M. Bass Donated (N=7) and Forensic Skeletal Collections (N=29).

Element	DONATED			FORENSIC		
	Exp	Obs	%	Exp	Obs	%
cranium	7	7	100.0	28	28	100.0
mandible	7	7	100.0	29	24	82.8
sternum	6	5	87.5	23	8	34.8
ribs	14	14	100.0	54	28	51.9
vertebrae	21	21	100.0	68	36	52.9
sacrum	7	7	100.0	28	14	50.0
clavicle	14	14	100.0	56	29	51.8
scapula	14	14	100.0	57	37	64.9
humerus	14	14	100.0	57	37	64.9
ulna	14	14	100.0	57	33	57.9
radius	14	14	100.0	57	34	59.6
hand	14	13	92.9	52	22	42.3
os coxa	14	14	100.0	56	34	60.7
femur	14	14	100.0	56	47	83.9
patella	14	13	92.9	54	17	31.5
tibia	14	14	100.0	57	44	77.2
fibula	14	14	100.0	57	38	66.7
foot	14	13	92.9	52	24	46.2

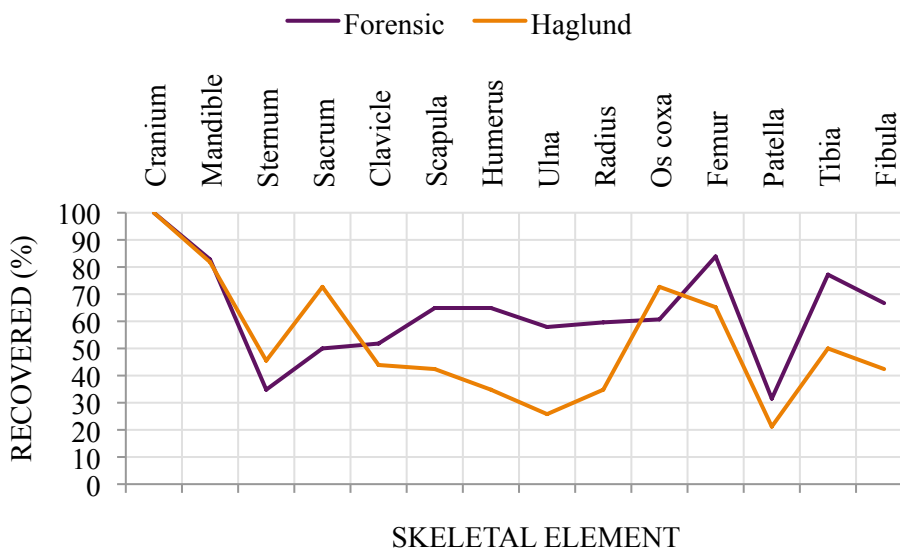


Figure 89. Percent skeletal element recovery for the William M. Bass Forensic Skeletal Collection (N=29) and outdoor cases (N=33) from Haglund's (1991) dataset of scavenged human remains cases from Washington state.

Table 9. Tooth mark frequencies by skeletal element for carnivore-scavenged human remains in the William M. Bass Donated (N=7) and Forensic Skeletal Collections (N=29).

Element	DONATED			FORENSIC		
	Exp	Obs	%	Exp	Obs	%
Cranium	7	0	0.0	27	4	14.8
Mandible	7	0	0.0	23	5	21.7
Sternum	5	0	0.0	8	1	12.5
Ribs	14	8	57.1	28	13	46.4
Vertebrae	21	7	33.3	36	13	36.1
Sacrum	7	2	28.6	14	4	28.6
Clavicle	14	5	35.7	29	10	34.5
Scapula	14	5	35.7	37	16	43.2
Humerus	14	5	35.7	37	15	40.5
Ulna	14	7	50.0	33	15	45.5
Radius	14	4	28.6	34	14	41.2
Hand	13	12	92.3	22	5	22.7
Os coxa	14	1	7.1	33	13	39.4
Femur	14	5	35.7	45	29	64.4
Patella	13	4	30.8	17	1	5.9
Tibia	14	9	64.3	43	30	69.8
Fibula	14	7	50.0	38	25	65.8
Foot	13	12	92.3	24	5	20.8

relatively low tooth mark rates (< 30%) include the os coxa, sacrum and radius. Other elements with relatively high tooth mark rates ($\geq 50\%$) include the tibia, fibula, ulna and ribs. The tooth mark frequencies for the forensic collection range from 5.9% (patella) to 69.8% (tibia). Other elements with relatively low tooth mark rates (< 30%) include the sternum, cranium, mandible, hand, foot and sacrum. Other elements with relatively high tooth mark rates ($\geq 50\%$) include the femur and fibula. The percent recovery rate and percent of gnawed to ungnawed bones by skeletal element for the donated and forensic collections are graphed in Figures 90-91. The percentages of toothmarked bones along the axial skeleton are graphed by collection in Figure 92 with vertebrae distinguished by type (numbers given in Table 10). About 50% of ribs are tooth marked in both the donated and forensic collections, and a similar percent of thoracic vertebrae are also tooth marked in the forensic collection.

Tooth mark frequencies by bone region for the William M. Bass Donated and Forensic Skeletal Collections are given in Table 10. Tooth mark frequencies in the donated collection range from 0.0% (clavicular shaft, proximal humerus and proximal femur) to 42.9% (tibial

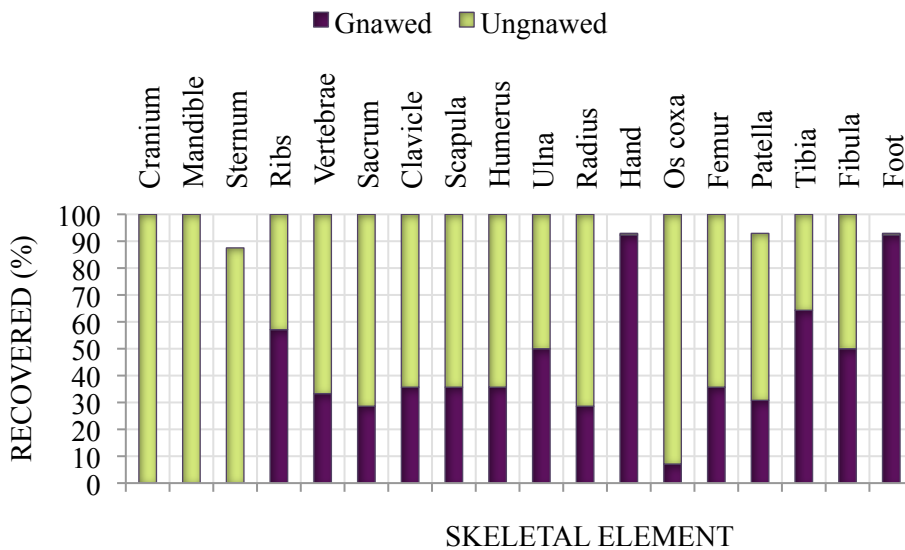


Figure 90. Recovered skeletal element frequencies and percent of gnawed versus ungnawed bones for raccoon gnawed cases in the William M. Bass Donated Skeletal Collection (N=7).

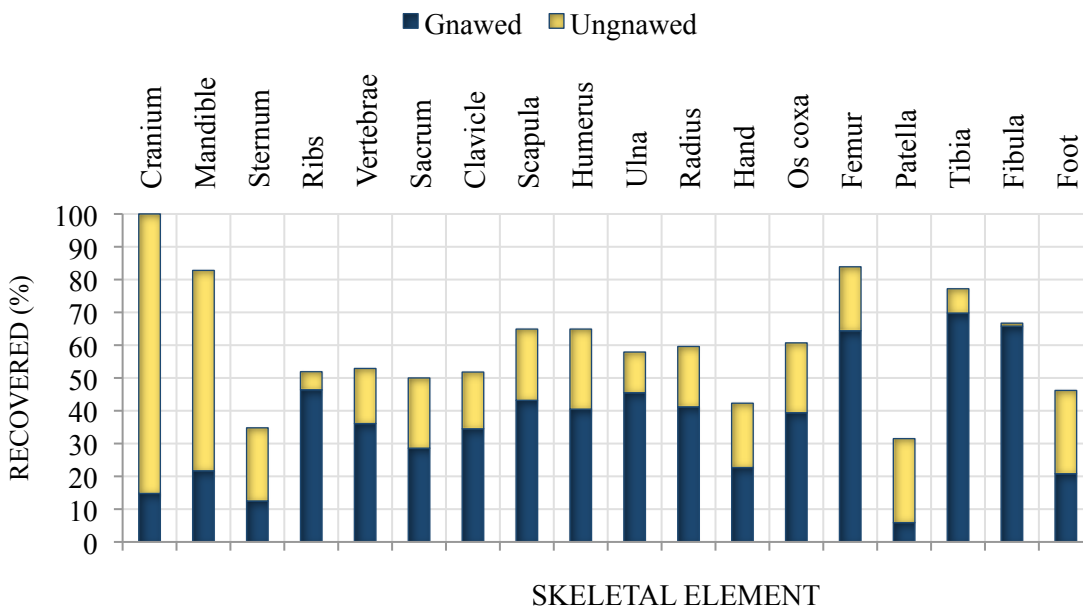


Figure 91. Recovered skeletal element frequencies and percent of gnawed versus ungnawed bones for carnivore gnawed cases in the William M. Bass Forensic Skeletal Collection (N=29).

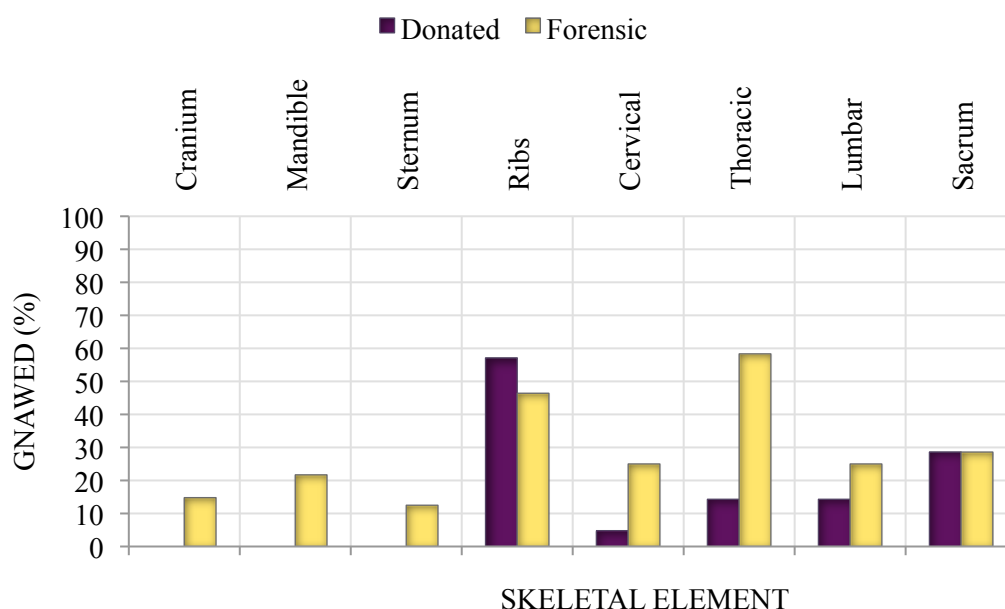


Figure 92. Tooth mark distribution along the axial skeleton for examined carnivore gnawed cases in the William M. Bass Donated (N=7), and Forensic (N=29), Skeletal Collections.

shaft). Other low (< 10%) tooth marked regions include the cervical vertebrae, the radial shaft, the distal radius and the proximal tibia (Figure 93). Other high ($\geq 30\%$) tooth marked regions include the distal humerus. Tooth mark frequencies in the forensic collection range from 0.0% (femoral shaft and tibial shaft) to 62.8% (proximal tibia). Other low (< 10%) tooth marked regions include the shafts of the clavicle, humerus, ulna and radius (Figure 94). Other high ($\geq 50\%$) tooth marked regions include the thoracic vertebrae, distal ulna, distal femur and proximal fibula.

The percentage rate of tooth marks along the shafts of bones from the forensic collection are underreported as no magnification was used during bone examination and individual tooth marks were not the object of the original study. Rather, the numbers reflect shafts bearing multiple, conspicuous tooth marks. Few tooth marks were present in the donated collection so any number present, were reported and described. Ignoring shaft regions, Figure 95 the greatest differences between the two collections are the ungnawed proximal humerus and femur of the

Table 10. Tooth mark frequencies by bone region for examined carnivore gnawed human skeletons in the William M. Bass Donated and Forensic Skeletal Collections.

Bone portion	DONATED¹			FORENSIC²		
	Exp	Obs	%	Exp	Obs	%
Clavicle						
Medial	14	3	21.4	29	7	24.1
Shaft	14	0	0.0	29	2	6.9
Lateral	14	3	21.4	29	8	27.6
Vertebra						
Cervical	21	1	4.8	12	3	25.0
Thoracic	21	3	14.3	12	7	58.3
Lumbar	21	3	14.3	12	3	25.0
Humerus						
Proximal	14	0	0.0	38	13	34.2
Shaft	14	2	14.3	40	3	7.5
Distal	14	5	35.7	40	15	37.5
Ulna						
Proximal	14	3	21.4	24	11	45.8
Shaft	14	3	21.4	24	2	8.3
Distal	14	2	14.3	23	14	60.9
Radius						
Proximal	14	2	14.3	34	9	26.5
Shaft	14	1	7.1	34	2	5.9
Distal	14	1	7.1	33	12	36.4
Femur						
Proximal	14	0	0.0	45	18	40.0
Shaft	14	4	28.6	45	0	0.0
Distal	14	2	14.3	44	26	59.1
Tibia						
Proximal	14	1	7.1	43	27	62.8
Shaft	14	6	42.9	43	0	0.0
Distal	14	4	28.6	43	21	48.8
Fibula						
Proximal	14	2	14.3	38	20	52.6
Shaft	14	3	21.4	38	5	13.2
Distal	14	4	28.6	38	18	47.4

¹Body donors who decayed outdoors at the Anthropology Research Facility (N=7)

²Human remains who decayed outdoors in East Tennessee (N=29)

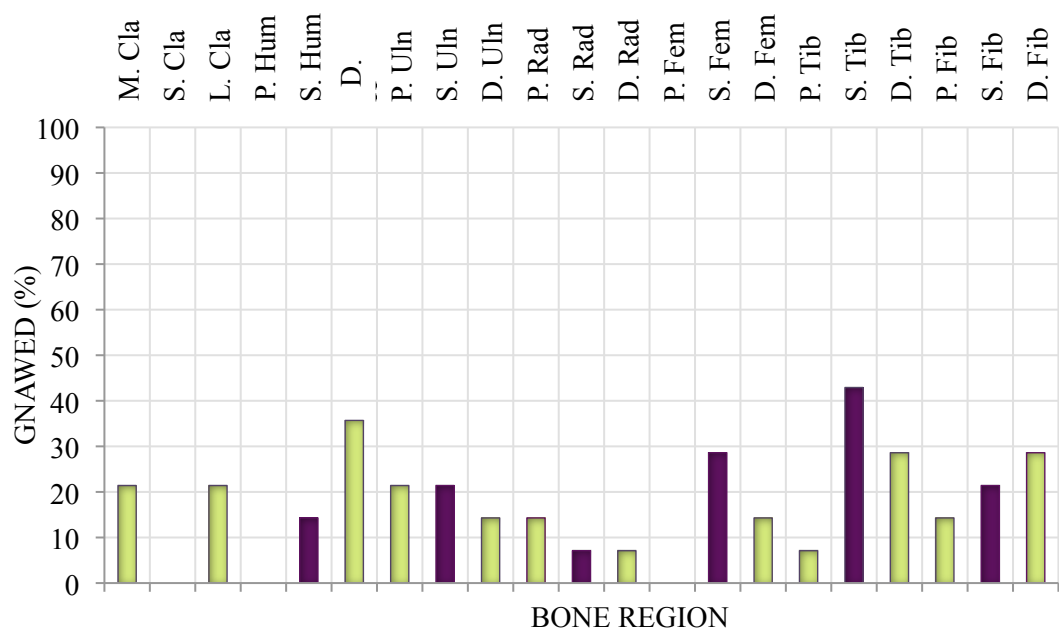


Figure 93. Tooth mark distribution of select tubular bones in the William M. Bass Donated Skeletal Collection (N=7). The dark bars indicate shafts and the light bars, bone ends.

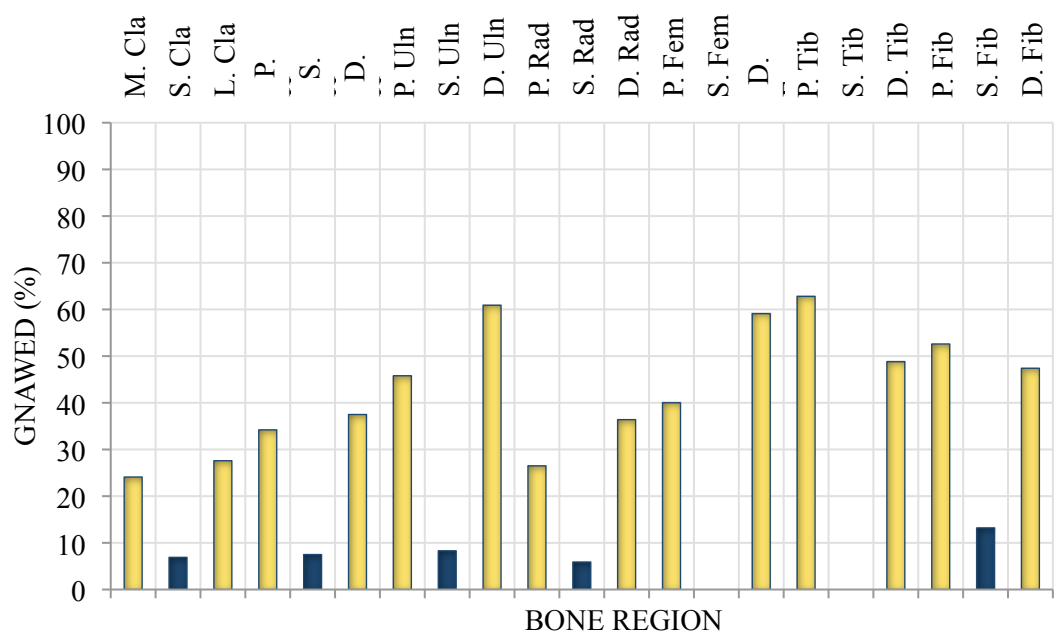


Figure 94. Tooth mark distribution of select tubular bones in the William M. Bass Forensic Skeletal Collection (N=29). The dark bars indicate shafts and the light bars, bone ends.

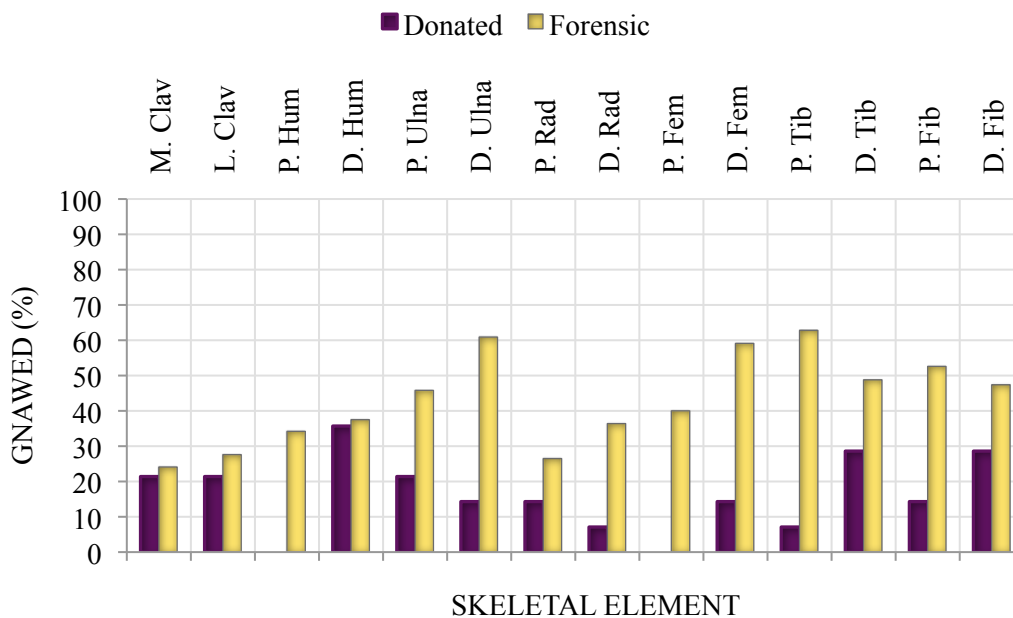


Figure 95. Tooth mark frequency on select tubular bone ends in the William M. Bass Donated (N=7) and Forensic (N=29) Skeletal Collections.

donated collection, which also bear relatively few tooth marks on the distal radius and proximal tibia. For the forensic collection, the ulna and bone ends forming the knee and ankle joints are the most highly gnawed regions.

Percentages that reflect the presence or absence of tooth marks on bones and their regions is one means of quantifying carnivore gnawing intensity and skeletal distribution in a sample. However, presence or absence data alone is insufficient for describing real differences in gnaw mark appearance and in the degree of bone destruction. Four categories of gnawing damage were created for tubular bones by region: 1) tooth marked, 2) tooth marked with an area of missing bone, 3) tooth marked with a carnivore-induced fracture, and 4) region absent with nearest bone edge tooth marked. A count of all occurrences of a category of damage was made for each bone region and the results were expressed in the form of a proportion of 100%. Bone ends and bone shafts were evaluated separately.

Examination of the gnawing damage restricted to the ends of tubular bones in the donated collection showed that tooth marks were the predominant form (94.4%), the exclusions being one partly chewed off distal humerus, one chewed off proximal fibula and one chewed off distal fibula (Figure 96). The former damage occurred over the 2004-2005 holiday break and the gnawing agent remains unidentified. The latter damage to two fibulae was produced by raccoons on two separate donors with fragile skeletons having long bone ends covered with extremely thin cortical bone. In contrast, 56% of gnawing damage to bone ends in the forensic collection is characterized by the complete absence of at least one long bone end with multiple tooth marks lining the adjacent bone margin (Figure 97).

Gnawed shafts from the donated collection only bore tooth marks, although none were found on the clavicle (Figure 98). Tooth marks were present on 26.7% of gnawed shafts from the forensic collection (Figure 99). Additionally, 20.0% had a reduced shaft length due to carnivore gnawing and 53.3% had at least one shaft end that bore a carnivore-induced fracture. All gnawed radial shafts terminated at fractures. Gnawing damage was not present on the shafts

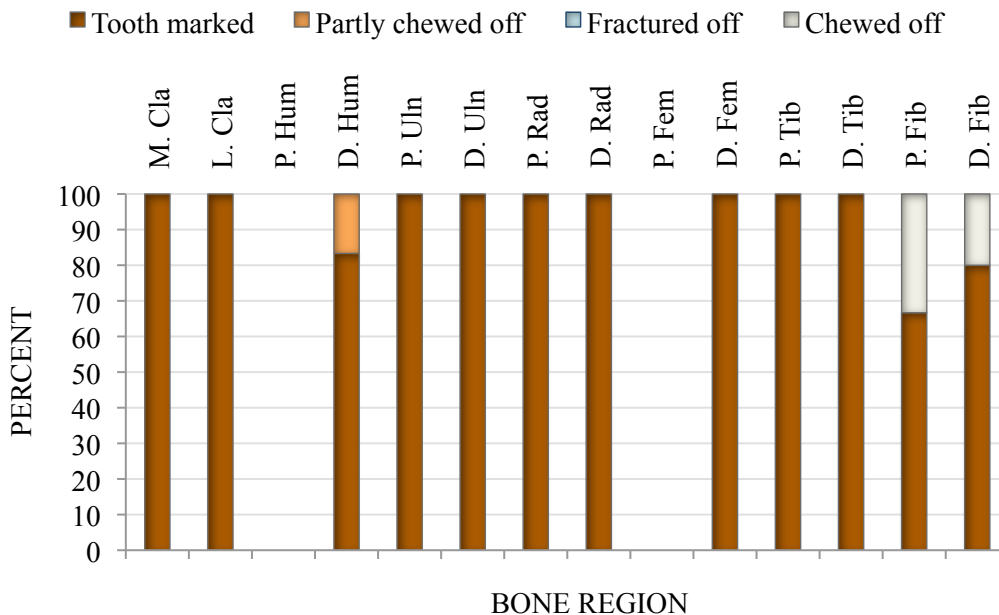


Figure 96. Typical gnawing damage on select tubular bone ends in the William M. Bass Donated Skeletal Collection (N=7).

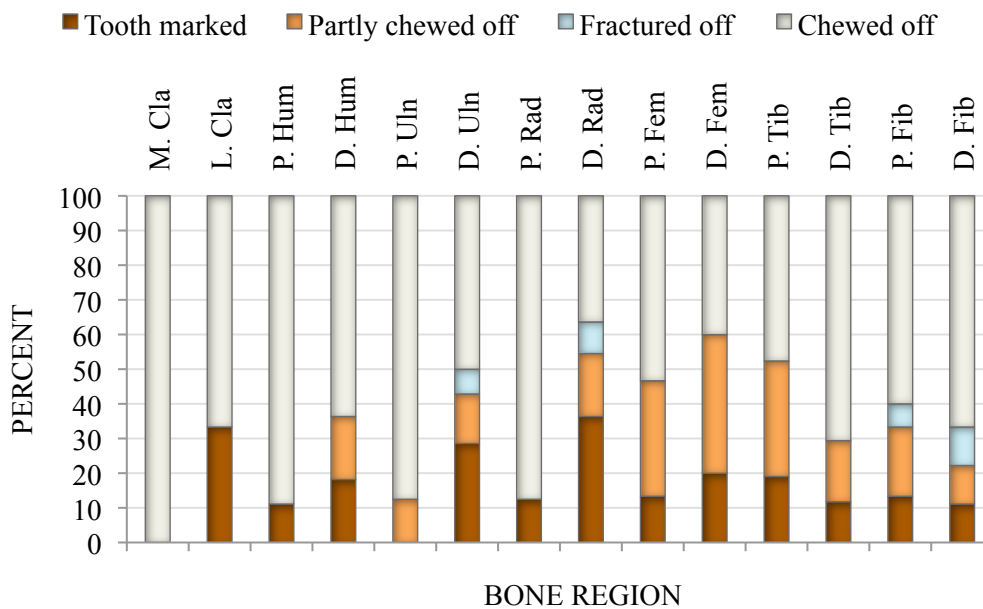


Figure 97. Typical gnawing damage on select tubular bone ends in the William M. Bass Forensic Skeletal Collection (N=26).

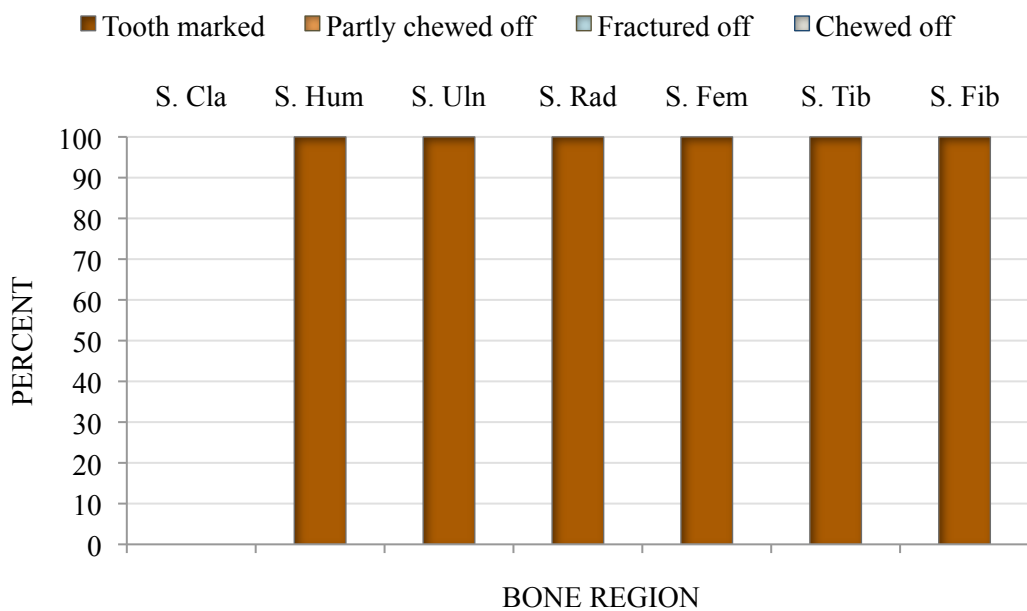


Figure 98. Typical gnawing damage on select tubular bone shafts in the William M. Bass Donated Skeletal Collection (N=7).

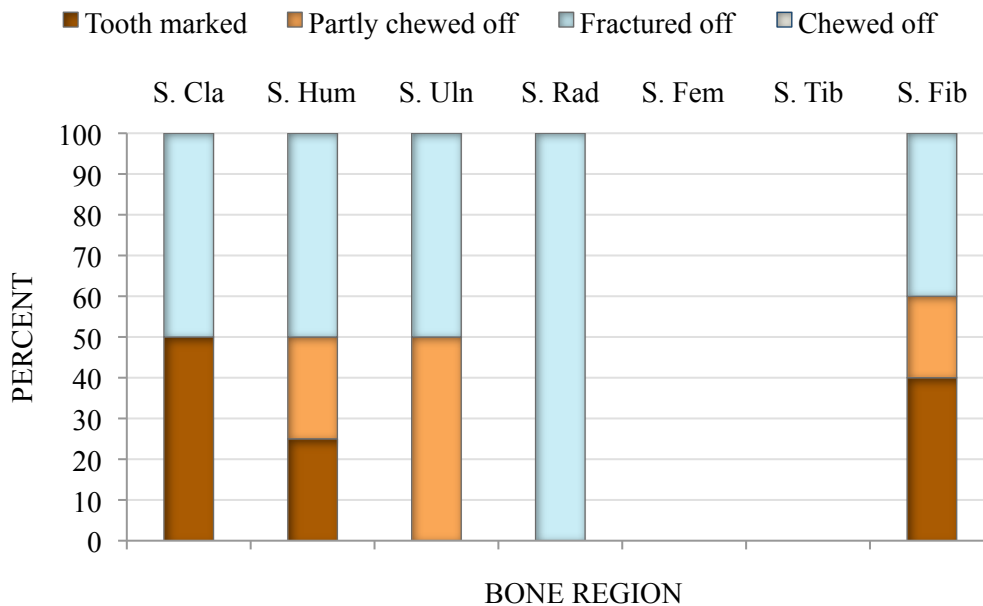


Figure 99. Typical gnawing damage on select tubular bone shafts in the William M. Bass Forensic Skeletal Collection (N=26).

of the femur and tibia, and is best interpreted as the lack of multiple, conspicuous tooth marks on the largest, and most robust, bone shafts.

Raccoon scat

Beginning September 2003, mammal scats were regularly collected inside the fenced, 1.35-acre Anthropology Research Facility for about 10 months; after which, intermittent collections of scats from the facility and nearby woods took place into March 2009. Scat location was recorded in field notes; and a brief description or a photograph of most scats were obtained either in situ or prior to processing (Figure 100). Each scat was placed in a ziplock bag labelled with the collection date and a unique number, then frozen in a chest freezer chilled to about 30°F (-1°C) to await processing.

Scat were defrosted at room temperature. Firm or dessicated feces were placed in jars of water for reconstitution in a closet maintained at 80°F where they remained for a period of one to



Figure 100. Raccoon scat with grooming hairs. Scat collected on 21 April 2004.

several weeks. Scat with soft tissue inclusions—likely human skin—were subjected to prolonged tissue maceration. All scat were screened and carefully disaggregated in a $\leq 1/16''$ mesh beneath a stream of warm tapwater from either a faucet or a low pressure sprayer head until the water ran clear. Once sieved, scat were air-dried over several days and later sorted beneath a dissecting microscope (up to 40X magnification) into categories of: 1) bone, tooth, and claw, 2) fur, hair, or feather, 3) plant, 4) mollusc or crustacean, 5) insect, and 6) other. Scats with animal bone and probable human bone were flagged and set aside (Figures 101-103).

Scats were assigned to a species, i.e., raccoon, opossum, or canid, based on scat morphology and the collection locality. If the species was indeterminate, grooming hairs, if present, were examined under both reflected and transmitted light. Small animal taxa were identified by Dr. Walter Klippel. Roughly 150 raccoon scat were processed and many of these were sorted. Bones and bone fragments were found to be either of small-to-very small animal origin or too fragmented to be identified to species or even skeletal element. In general, mice and rats, shrews, perching birds, amphibians and small fish were identified (Table 11).



Figure 101. A raccoon scat broken in half and containing probable human bone fragments. Scat collected on 16 January 2004 at the facility.



Figure 102. Probable human cortical bone fragments recovered from a raccoon scat collected on 8 February 2004 at the facility.



Figure 103. Probable human trabecular bone fragments and hairs recovered from a raccoon scat collected on 24 January 2004 at the facility.

Consistent with their omnivorous diet, raccoon scat collected at and around the facility contained large amounts of plant material, insects, some small vertebrates and unidentified bone fragments. Common plant materials present included acorn fragments (*Quercus* spp.) and hackberries (*Celtis* spp.). Other recognized plant foods were seeds of the common pokeweed (*Phytolacca americana*), persimmon (*Diospyros virginiana*), lambsquarter (*Chenopodium* spp.), grape and several grasses. Other food items included snails (*Gastropoda*) and crayfish (*Crustacea*).

Raccoon scat bone displayed minor digestive attributes like polishing and rounding off of thick edges or the sharp edging, and effected translucency, of thin bone. Semi-thick cortical bone, like that found in the ribs, metacarpals, and metatarsals of middle-aged individuals, was highly splintered and fragment length was greater than width. Thin cortical bone, in particular, displayed numerous microfissures that appeared consistent with blunted molar chewing and crushing damage.

Table 11. Vertebrate taxa identified in raccoon scat.

Common name	Taxon ¹	Count
AMPHIBIAN		
cf. Red-spotted newt	cf. <i>Notophthalmus viridescens</i>	2
Salamander/newt	Caudata	3
Treefrog/cricket frog/frog	Hylidae	1
Very small frog/toad	Anura	1
Small salamander or small toad/frog	Amphibia	3
REPTILE		
Skink/lizard	Squamata	1
Skink/lizard	Sceloporus/Eucemes	1
FISH		
Freshwater drum	<i>Aplodinatus grunniens</i>	1
cf. Madtom	cf. <i>Noturus</i> sp.	1
Minnow	Cyprinidae	1
Very small fish	Osteichthyes	1
Unidentified fish	Osteichthyes	7
BIRD		
Perching bird	Passerine	7
Unidentified bird (domestic pigeon-sized)	Aves	1
MAMMAL		
Southern shorttail shrew	<i>Blarina carolinensis</i>	1
Least shrew	<i>Cryptotis parva</i>	1
Shrew	Soricidae	1
Commensal rat	<i>Rattus</i> sp.	5
White-footed mouse	<i>Peromyscus</i> sp.	5
Rat/mouse/vole	Muridae	1
Small mammal	Mammalia	2
Very small mammal	Mammalia	2
UNIDENTIFIED		
cf. Human	cf. <i>Homo sapiens</i>	21
Small- to medium-sized animal	Vertebrata	1
Small animal (squirrel-, rabbit-sized)	Vertebrata	1
Small animal (rat-sized)	Vertebrata	2
Small animal	Vertebrata	2
Very small mammal or perching bird	Mammalia or Aves	1
Very small animal	Vertebrata	11
Unidentified animal	Vertebrata	19
Total bone scat		74

¹identifications provided by Dr. Walter Klippel, UT Professor of Zooarchaeology

The diversity of insect species present in separated scat proved interesting. Exoskeletal fragments of carrion beetles and their larvae were recognized in some feces. Sap beetles (Family Nitidulidae) and small rove beetles (Family Staphylinidae) were found in a number of samples. Given their relatively intact condition and the beetles' life history along with the scat contents, they were likely acting as scavengers. While the recovered insects in scat are often highly fragmented, more work can be done on taxon identification for learned insight into whether they are present as carrion fauna, dung scavengers, or if they were ingested elsewhere.

Most interesting, was when parts of soldier fly larvae (Family Stratiomyidae) kept appearing in scat all the way down to finding isolated head capsules. While the nutritional contents of a soldier fly prepupa depends upon its food source, a post-feeding larva is roughly 42% protein, 35% fat, 5% calcium and contains about 1,300 calories. For this reason, prepuparia have been successfully used as feedstuff meal for various species of fish, poultry and swine (Newton, et al. 1977; Sheppard, et al. 1994; Tomberlin, et al. 2002).

Raccoon scat also contained maggot cuticular remnants and some puparial casings. Some scat contained soldier fly larval remnants (Figure 104). The larvae in the raccoon scat must have been thoroughly chewed to achieve the level of cuticular fragmentation seen in raccoon scats. This was verified by a feeding trial with a domestic dog. Domestic dogs gulp down their food and in the feeding trial, soldier fly larvae were recovered intact in the dog's feces. Greenwood (1979) reports the northern raccoon thoroughly masticates most foods prior to ingestion which is consistent with both the soldier fly larvae's appearance as well as that of the recovered maggots and puparial casings (puparial casings also remain intact when they travel through a dog's digestive tract).

Discussion and summary

The northern raccoon is a unique scavenger. Is it a highly omnivorous, opportunistic feeder that eats both insects and carrion. It's unique anatomy allows it to balance on its hind feet and reach into deep recesses, where it can clasp and retrieve food with its forepaws. Because of this, raccoon-scavenged human remains appeared unlike those reported of other carnivores. Raccoons did not initiate soft tissue feeding at sites of perimortem trauma and they



Figure 104. Remnants of soldier fly larvae and a fragmented fly puparium recovered from a raccoon scat collected from the Anthropology Research Facility on 12 November 2003.

did not gravitate towards open wounds. However, flesh wounds were sometimes explored by a forepaw in an attempt to access and extract subcutaneous tissue or to collect late instar maggots feeding within. The raccoon focused on meat removal. It stripped muscle from bone, which was often removed from a circular-to-ovaloid opening in the skin. The raccoon lacks a carnassial tooth, for reduced ability to gnaw and break-up bone. Raccoons often chewed on the hands and feet, which were crushed, fragmented, and sometimes absent. Ribs were sometimes chewed and tooth marks were found on tibiae, ribs, ulnae and fibulae.

When raccoons frequented a corpse, there was an area of heavily-compacted soil and ground debris proximal to moderately or heavily scavenged body regions. This occurred because the raccoon often rested its hind end and other body members on the ground while it fed. Raccoons incessantly patted surfaces with their forepaws while foraging and scavenging. And they commonly climbed atop bodies or crossed over human remains that lay in their path. This

meant raccoon paw prints could be seen after a recent snowfall or in the fresh mud, and were found on the bodies or the coverings over them.

Raccoons had much body contact with the human corpses that were heavily scavenged. They stood on them. They sat on them. They leaned up against them. Mostly, they used their forelimbs to reach deep inside body cavities—sometimes they even placed their head and upper torso into the large cavities. Because of this contact, the raccoon's fur—particularly, that of the forelimbs—became soiled with fatty fluids. This greasy residue sometimes transferred from their fur and stained nearby soil and surfaces, like rocks. Raccoons often licked their forepaws and forelimbs throughout the feeding process. The forepaws may have been licked to increase their tactile sensitivity, but licking of the dorsal forepaws and forelimbs was a means to cleanse their fur. Because corpse surfaces were habitually contacted, including internal surfaces, individual raccoon furs were sometimes recovered from scavenged bodies.

The northern raccoon is a carnivore species that is uniquely-equipped to exploit the abundant flesh and insect populations concentrated at the Anthropology Research Facility. The raccoon's natural foraging behavior involves traveling to multiple food sources each night to exploit what can be readily hunted, fished, collected, or accessed. In Tevis' (1947) study of wild raccoons in California, he watched them for several nights in July and August as they foraged along a lakeshore and stream. He reports that while several individuals or groups of raccoons often visited the same feeding locations nightly, they seldom confronted each other during the night because they continually progressed along the shoreline and maintained both temporal and spatial distances. The raccoons at the facility appeared to forage in a manner similar to that reported by Tevis, in that they appeared to feed at multiple locations—in this study, they rotated amongst multiple bodies in varied stages of decay and fed on either flesh or insects.

An intensive search of the forensic literature failed to find forensic case studies or research describing scavenging artefacts similar to the soft tissue modifications seen at the facility. In a Japanese case study of scavenged human remains (Kiuchi, et al. 2008), the raccoon was considered to be the possible scavenger, but it was dismissed by the authors—and rightly so, based on the present study findings. Raccoons at the facility have not acquired unique feeding mannerisms as experiments with food acquisition and manipulation by raccoons even better

describe their eating postures and forelimb usage (Iwaniuk and Whishaw 1999; McClearn 1992). As an agricultural pest, raccoon damage to melons is similar to feeding artefacts left on human soft tissue (<http://watermelons.ifas.ufl.edu/AnimalPest/raccoon%20damage.htm>). And ecological research in Wisconsin (see Jennelle, et al. 2009; Nolden and Samuel 2005) captured photographs in which raccoons appeared to be reaching beneath the hide of a whitetail deer carcass in a manner similar to that seen at the facility.

The raccoon is highly inquisitive and remarkably adaptable; and has established itself in increasingly urban areas. The expectation is that published descriptions of raccoon bone and soft tissue modifications will elicit forensic case studies of potential scavenging once their feeding artefacts become widely recognized.

PART 3. VIRGINIA OPOSSUM

Abstract

This study documented animal scavengers at the University of Tennessee's Anthropology Research Facility. Remotely-captured digital video and still photography equipment was stationed at the outdoor human decomposition facility intermittently from September 2003 through October 2009. The Virginia opossum (*Didelphis virginiana*) was identified as a common scavenger of corpses that decayed on the property. Individual opossums scavenged alone or concurrently with one or more northern raccoons (*Procyon lotor*). Opossums primarily licked maggots off corpse surfaces. They sometimes consumed putrid or decaying soft tissue, but they were ineffectual scavengers of relatively fresh bodies.

Introduction

The Virginia opossum (*Didelphis virginiana*) is a well-known scavenger of vertebrate carrion. It is one of the primary mammal scavengers of animal remains in non-remote areas of the eastern United States (DeVault 2004; Jennelle, et al. 2009; Morton and Lord 2006; Nolden and Samuel 2005). The Virginia opossum's scavenging behavior has received some attention (e.g., Morton and Lord 2006), but reports of their feeding have been anecdotal, to date. Bass (1997) reports that opossums will feed on human flesh at the University of Tennessee's Anthropology Research Facility. The present study used unattended digital video and still imagery to capture opossum feeding at this facility, to better understand its feeding habits and traits.

Species information

The Virginia opossum is North America's only extant marsupial or pouched mammal. Its range extends from southern parts of Canada to much of Mexico and northwestern Costa Rica. In the United States, the opossum is widespread in the central and eastern states; and was introduced along the west coast and to isolated islands there (Gardner and Sunquist 2003).

For many years, the Virginia opossum was placed in Order Marsupialia along with the pouched mammals of South America and the Old World (e.g., Burt and Grossenheider 1980). Marsupials are now divided into seven orders and only Didelphimorphia is found in North

America (Reid 2006). Species accounts in the literature appear under the specific names of *Didelphis virginiana* and *D. marsupialis* (common opossum) as the Virginia opossum was once thought to be a subspecies of the common opossum, whose range does not extend into the United States. These two very similar appearing opossums co-occur south of the U.S. border (see Burt and Grossenheider 1980; Gardner and Sunquist 2003; Reid 2006).

The Virginia opossum is very adaptable and thrives in both rural and urban areas where there is a reliable water source, available den sites and winter food. It does not hibernate, but seeks shelter during inclement weather to protect its sensitive, hairless ears and tail. The Virginia opossum uses multiple, leaf-lined dens in hollow trees and abandoned burrows or structures for both shelter and daytime sleeping (Gardner and Sunquist 2003). The opossum is a solitary species and usually dens alone, but they will sometimes share a den with a conspecific or a similarly-sized species (Reynolds 1945)—like raccoon (Stuewer 1943).

The Virginia opossum is a sexually dimorphic species with adult males being larger than adult females. Body weights range from 2-15 lb. (1-7 kg) (Gardner and Sunquist 2003; Reid 2006). This opossum is capable of accumulating large body fat stores to prepare for winter (Gardner and Sunquist 2003). In New York state, captive opossums doubled their feeding activity time from mid-September to mid-March, although their total activity was reduced in the fall and winter (McManus 1971). The opossum lives chiefly as a scavenger during the winter months: by spring, it may be underweight and in poor health (Fitch 1954).

Female opossums usually mate twice a year. Peak breeding occurs from late January through late March and from mid-May to early July. Gestation is 12 to 13 days. The average litter size is about eight. Young opossums begin to leave the pouch about two months post-birth, and they disperse one month later. Sexual maturity is attained about eight months of age (Linzey 1998), but skeletal maturity is not attained for several years. Most opossums rarely live past two years (Schwartz and Schwartz 1981).

The omnivorous opossum is a nocturnal forager and scavenger. It feeds on insects, small animals, like mice and birds, millipedes, earthworms, gastropods, like snails and slugs, carrion and a variety of plant matter, including berries, seeds and grasses (Fitch 1954; Hamilton 1951; Hopkins and Forbes 1980). Insects, when available, are eaten more often than any other food;

and carrion (when maggots accompanied the primary food in the viscera) appears with a frequency of less than 10% (Hamilton 1951).

The Virginia opossum has a total of 50 teeth: there are 18 incisors, four canines, and 28 postcanine teeth (Hillson 2005). The incisors are small and peg-like (Figures 105-106). The canines are comparatively long: the upper canines are most prominent and are compressed medially-to-laterally. The upper canines of adult males are consistently longer and heavier than those of the female (Gardner and Sunquist 2003). The first three postcanine teeth bear a prominent, pointed cusp, and the latter four bear three-to-five small, pointed cusps, each of which arises as a high ridge (Hillson 2005; Whitehead, et al. 2005). The upper 'molars' are triangular in outline, and the lower are rectangular (Figure 107). Teeth erupt up until about 10 months of age and 'molar' cusp wear first appears shortly thereafter (review by Gardner and Sunquist 2003).

The paws of the Virginia opossum each have five, elongated digits that are fitted for climbing and grasping and can be fully flexed. The forepaw can spread 180 degrees and is used



Figure 105. Anterior dentition of the Virginia opossum.



Figure 106. Anterior mandibular teeth (incisors and canines) of the Virginia opossum.



Figure 107. Mandibular cheek teeth of the Virginia opossum (first 'premolar' not shown). The cusps show age-related wear.

to grasp branches during climbing as well as other objects, like prey (Figure 108). The hind paw has a sharply divergent, opposable pollux, which is short, stout, and lacks a claw. Other digits of the hands and feet bear non-retractile claws, which are curved, sharply pointed, and stand away from the tip of the digit. The hairless ventral surfaces are sensitive to pressure and vibration and have large tori that possess dermatoglyphs (Cutts and Krause 1983). The forearm has perfect pronation and supination. The forepaw gathers food, which is conveyed to the mouth, but the digits do not move independently—they converge (Coues 1869).

At slow speeds, the opossum walks with a primitive plantigrade gait. Their prehensile tail can wrap around and grasp objects and it is used for balance when either walking or climbing. The opossum often climbs trees, but it is not a rapid or agile climber—it's movements are slow and methodical; and it sometimes falls (McManus 1970).



Figure 108. The left forepaw of the Virginia opossum.

Methods

From September 2003 through October 2009, nocturnal digital video and still imagery was obtained at the Anthropology Research Facility. A description of the equipment used is given in the General methods section of the Introduction. Virginia opossum scavenging and foraging activities were captured at 13 bodies: two were placed in shallow burials and eleven were surface-deposited (Table 12).

Results

Multiple opossums, as indicated by differing coat colorations or conditions, body size, pouch young etc., entered the facility on any given night. They are adequate climbers, but inefficient diggers and opportunistically enter the facility using holes that raccoons excavate or shape beneath the fence lines. The number of individuals entering at night is estimated at one to three or more solitary opossums.

Table 12. Filmed and/or photographed body donations with Virginia opossum activity.

Donor	Placed	Sex	Age	Wt (lb)	Death circumstances	Autopsy	Position	Imagery
453	Sep	F	73	206	Stroke	no	prone	yes
493	Oct	M	86	~150	Motor vehicle accident	no	prone	yes
503	Oct	M	62	241	Natural	no	prone	yes
553	Oct	M	67	114	Natural	no	prone	yes
603	Dec	M	79	185	Hypothermia	yes	prone	yes
044	Jan	M	49	~150	Heart attack following a fight	yes	prone	yes
124	Feb	F	60	125	Natural (found dead at home)	no	prone	no
234	Apr	M	59	n/a	Motor vehicle accident	no	prone	no
274	May	M	78	124	GSW to right temple	no	prone	yes
414 ¹	Aug	M	68	unk	COPD	no	prone	yes
694 ¹	Nov	F	62		unknown	no	supine	yes
015	Jan	M	44	459	COPD, congestive heart failure	no	prone	yes
799 ¹	Jul	M	57	unk	ASCVD, contributing diabetes	no	supine	yes

¹shallow burial

At the facility, opossums would feed next to, or atop of, fleshed decomposing bodies. An opossum was commonly seen feeding at a body along with one or more raccoons, but opossums were generally cautious and maintained their distance from raccoons (Figure 109). If an opossum was feeding alone, an approaching raccoon often displaced the opossum from the body to a peripheral location from which it could watch the raccoon. The opossum would then either leave the scene or attempt to approach the body to resume feeding. The exception was when one large mature opossum intimidated any approaching raccoons by aggressive hissing and bared teeth. A large opossum once lunged at, and even chased away, an approaching juvenile raccoon. Young juvenile raccoons and solitary opossums generally tolerated each others presence and both species fed at multiple, shared locations. The opossum rarely fed for lengthy intervals. Rather, opossums came and left throughout the night and it was seldom determined whether or not the same individual was being filmed.

The opossum concentrated its foraging efforts on the insect fauna of bodies undergoing



Figure 109. An opossum and a raccoon foraging. The opossum is licking maggots off the nude torso. Video still captured in October 2003.

active decay. It primarily foraged for maggots and probably other carrion insects from body surfaces and cavities. Feeding bouts generally lasted from several seconds to minutes. Foraging for insects occurred on bodies with, or without, soft tissue scavenging. Opossums repeatedly licked body surfaces and collected maggots on the surface of their long tongue (Figure 110). An opossum was video-taped multiple nights licking maggots off the surface of a crushed rock roadway on which a corpse lay. Extensive feeding on maggots produced opossum scats which were entirely comprised of cuticular remnants (Figure 111). Opossums did not forage in the surface litter near bodies, but it did lick maggots from the ground-body interface. The opossum appeared to prefer diptera larvae and it ingested large numbers of motile maggots that were easily captured on the tacky lingual surface of the tongue.

Opossums probed crevices with their snout. Opossums were photographed several nights at a shallow burial (< 0.5 ft) in which two areas of the body had been exposed by raccoons and flies had subsequently colonized them to unequal extents. An opossum was photographed with its snout in a hole that contained the torso. It licked the flesh and consumed the few maggots



Figure 110. An opossums licking maggots. Video still captured on 3 May 2004.



Figure 111. Opossum scat composed of maggot cuticles. Scat was collected on 21 June 2005.

present (Figures 112-113). Another opossum was photographed that same night straddling the grave and probed the out-of-view thigh and pelvis with its snout. The corpse was photographed the next day and thigh and pelvis contained maggot masses.

Opossums sometimes used their forepaws to assist their scavenging of human corpses. Opossums placed one or both forepaws on the corpse for support, they clasped corpse surfaces and sometimes held loosened tissue in a forepaw. They often climbed atop the torso to feed on carrion insects. This caused superficial scratches in the skin. Unlike the raccoon, the Virginia opossum did not pull or tug on attached tissue while gripped in a forepaw and it did not insert a forelimb into the corpse to grab ahold and remove tissue. An opossum feeding on a partly exposed thigh of a body in active decay once stopped feeding in order to grasp the edge of the body bag with a forepaw and push it aside. It then resumed feeding. It sometimes used a forepaw to assist in holding tissue. An opossum clasped a piece of partly attached relatively fresh integument in its forepaws, while it masticated on the freed end (Figure 114).



Figure 112. Opossum at grave licking the unearthed human torso. Unattended photograph taken on 15 October 2004 (8:24 PM).



Figure 113. An opossum-licked human torso lying in an exposed shallow grave. Photograph taken on 16 October 2004.



Figure 114. Opossum chewing on attached soft tissue held by the left forepaw. Video still captured on 8 February 2004 (ca. 8:45 PM).

Opossums did not consume fresh soft tissue of human corpses, unless it co-occurred near tissue previously scavenged by raccoons. Because of this, it was difficult to separate damage caused by a raccoon from that of an opossum. Opossums sometimes fed on the undamaged integument and tissue of corpses undergoing active decay.

In mid-January 2004, two electric fencelines were erected inside the facility and most bodies were placed inside these enclosures. One exception was an autopsied, fresh body placed 15 January just outside a fenceline. The naked body was positioned prone on the ground and covered with an unzipped body bag and chicken wire (ca. 1-3/8" hexagonal mesh), which was loosely secured to a row of abutted cinder blocks. Raccoons eventually broke several wire strands and began scavenging the body. In early February 2004, one or more opossums fed on the body consecutive nights after raccoon feeding began to decrease. As insects were scarce and few bodies were available for scavenging, an opossum diligently masticated on relatively fresh tissue for about two and-a-half hours (Figures 115-118). Only once did it remove tissue, but



Figure 115. An opossum tugging on the partially attached integument, firmly clamped between the upper and lower dentition. Video still captured on 8 February 2004 (ca. 8:45 PM).



Figure 116. An opossum gripping the partially attached integument between its anterior teeth. Video still captured on 4 February 2004.



Figure 117. An opossum directly biting down on soft tissue attached to the right torso. Video still captured on 4 February 2004.



Figure 118. An opossum gnawing on the previously broken rib ends using its posterior teeth. Video still captured on 4 February 2004.

only a small piece was consumed. The opossum repeatedly bit down on the tissue with alternating anterior and posterior teeth, and pulled and backing away from the body while the tissue was clamped in it's teeth. The tissue flap was repeatedly masticated on and rolled around in it's mouth (Figure 119). Additionally, opossums fed on decayed tissue overlying knees or elbows (Figure 120-122); and an opossum-gnawed on muscle tissue that was largely exposed by feeding brown rats (Figure 123).

On 11 January 2004, a nearly intact liver was discovered lying atop the torso of a body covered by an opened body bag and chicken wire. The autopsied body (with returned organs) had been placed at the facility one month prior, and raccoons began scavenging the corpse during the later part of December. The mis-shapen liver was absent both the day before, and the day after, the sighting. The liver was photographed with minor damage consistent with biting and chewing (likely by an opossum), but little-to-no tissue had been consumed. The chewed liver appeared similar to the skin flap that was heavily masticated on by an opossum.



Figure 119. Opossum-masticated tissue flap. Photograph taken on 2 February 2004.



Figure 120. Left elbow first scavenged by a raccoon (above), then scavenged by an opossum (below).



Figure 121. Left knee repeatedly chewed on by opossums.



Figure 122. Shredded tissue produced by an opossum drawing it's long canines through the decaying tissue. Photograph taken on 28 September 2003.

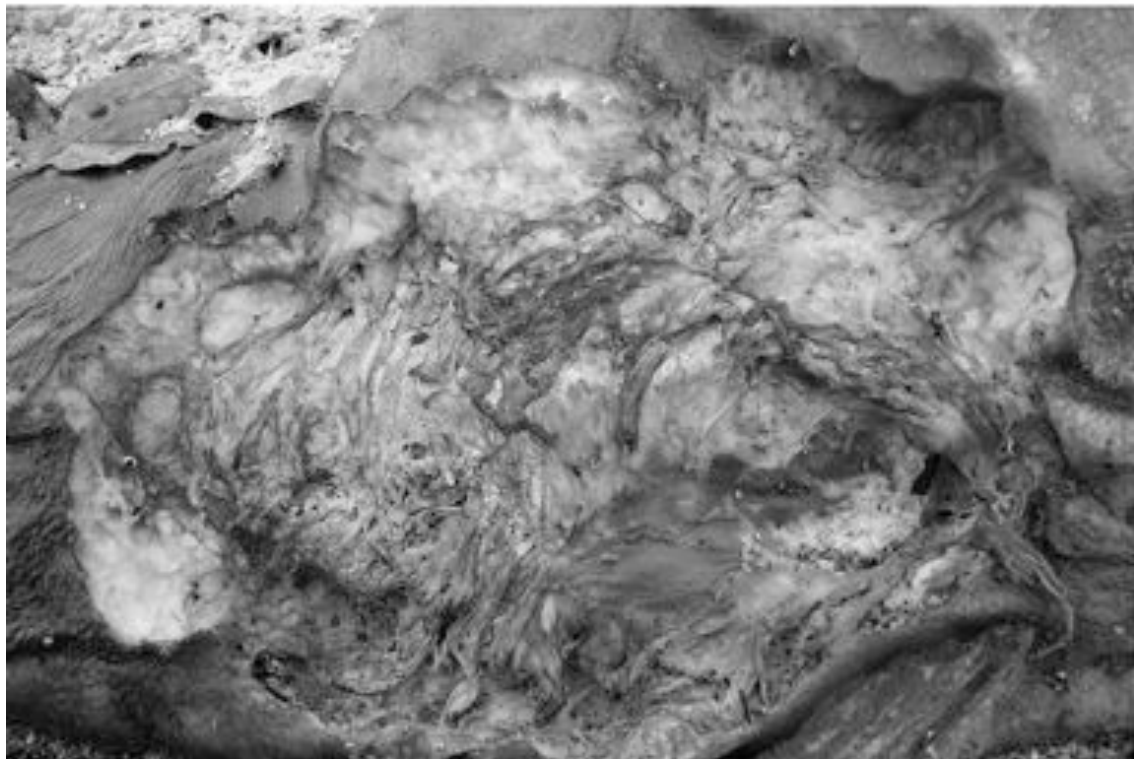


Figure 123. Opossum gnawing on muscle tissue of left hip (above); hip with opossum and brown rat scavenging (bottom).

Bone modification

In the present study, only a couple of instances of bone modification were attributed to an opossum. The first instance was repeated chewing of a big toe (Figure 124). The toe was completely flattened, dorsal-to-planter, yet no bone or soft tissue was actually removed. The chewing was believed to be by an opossum, which primarily used it's posterior teeth. The indentations in the soft tissue are consistent with the morphology of the opossum's posterior teeth. Because no tissue was removed from the toe, the raccoon is unlikely to have been the

A single instance of carnivore-like modification was attributed to opossum feeding. This event was not captured by nocturnal photography, but an opossum was the most likely scavenger. A body was placed at the facility on 9 December 2003. The fully autopsied body was nude, positioned prone and covered by both an open-faced body bag and sheet of black plastic. After two nights of exposure, characteristic raccoon soft tissue scavenging appeared on the left thigh and torso. A wildlife camera equipped with a 35 mm film camera with flash was



Figure 124. Chewed left first digit: plantar view (left) and anterior view (right). Photograph taken on 2 April 2004.

placed on location on 16 December. The exposed roll of film was removed the next day and one-to-three raccoons were photographed at or near the body. However, opossums were also regularly entering the facility in December and were captured on 35 mm film and video imagery at other scavenging locations. Three weeks later, post-Christmas Break, the body lay as an articulated skeleton bearing only skin, muscle strands, tendons and ligaments. Snow tracks and the appearance of the body implicated multiple scavengers, including raccoon, opossum and crow. Raccoons were the primary scavenger of this corpse, however, when the skeleton was examined in the William M. Bass Donated Collection, unusual bone modification was found on one of the clavicles.

The sternal end of the right clavicle is pictured in Figure 125. The sternal end received two cuts by a stryker saw. The first cut was incomplete, leaving the posterior shaft intact. The second cut bisected the posterior shaft and formed a protruding angle of compact bone. Three or four short shallow scores were present in the compact bone; and the once sharp, cut edge was smooth and had rounded-over edges, which were slightly polished.

The Virginia opossum is the inferred agent of the bone modification. This conclusion



Figure 125. The sternal end of the right clavicle. The posterior shaft shows three or four short, shallow scores in compact bone. The cut bone edge (left) appears polished and has rounded-over edges.

was based on the following reasons. Rounded-over edges and bone polishing occurs when an animal—typically, a carnivore—repeatedly mouthes, bites, sucks, and salivates on a bone, which is often moved to a secluded or safe location for gnawing. The polished margin is typical of canid gnawing, but nothing about the scavenged corpse suggested a canid had visited the scene. And in the case of the modified clavicle, the acromial end remained articulated to the damaged scapula. A canid would have disarticulated the clavicle with its carnassial teeth and removed the bone from the scene, prior to such prolonged gnawing. The northern raccoon was not inclined towards extended gnawing, especially of bone. Raccoons were persistent, and tissues that were not easily detached were attacked using multiple strategies and angles of attack—forepaws and both anterior and posterior dentition. However, they did not display the patient, persistent masticatory behavior displayed by the opossum when it was unable to do much damage.

In the case of the right clavicle, bone gnawing occurred in situ, and only the opossum displayed behavior consistent with such modification. During consecutive nights in February 2004, a Virginia opossum was recorded for lengthy intervals (one may have lasted nearly two hours) and was seen repeatedly chewing and rolling a flap of tissue around in its mouth. Such persistent masticatory behavior could have produced the polished bone seen in Figure 125. Polished bone was not seen on other of the examined skeletons from the facility. The few short, sharp-edged scores with crushed bone edges and lack of clear pits indicated a smaller animal, with sharp canine tips and no carnassial teeth, produced the bone modification.

Discussion

Virginia opossums at the facility largely foraged for maggots on human corpses and this was accomplished by licking body surfaces with their tongue. The opossum was not sensesearching for prepupae and pupae in the soil, but it did lick migrating maggots off a crushed rock surface. Dietary studies based on opossum stomach contents found diptera larvae without carrion residue (Hamilton 1951; Hopkins and Forbes 1980). Of the opossum's diet, Hamilton (1951:260) states, "Tipulid [crane fly] larvae and numerous fly maggots were present in several stomachs. Since maggots were present when no trace of carrion was evident, it is presumed that

the opossum may eat the maggots in preference to the carrion on which the fly larvae feed.” Similarly, Jurzenski and Hoback (2011) report that an opossum preferentially ate American burying beetles (*Nicrophorus americanus*) on a rat carcass and only fed on the carcass when all visible beetles had been consumed. Further, this behavior was repeated twice, as the opossum left the rat carcass for a few minutes to give the beetles time to recolonize the carcass.

The larvae of many carrion fly species have hooking mouthparts which, if ingested alive and they survive digestion, can be used to attach themselves to the lining of the gastrointestinal tract leading to inflammation. Because the opossum is a thorough masticator, the abundant fly larvae at the facility represented a nearly year round, protein-rich food source for these foragers.

Multiple opossums were not seen together inside the facility. Opossums are generally viewed as solitary creatures, but multiple individuals have been photographed at deer carcasses in Wisconsin (Nolden n.d.)—such instances are probably uncommon. At the facility, a solitary opossum and multiple raccoons were commonly seen co-feeding at bodies but offensive and defensive behaviors were displayed and the raccoon was clearly the dominant scavenger.

Opossums fed indiscriminately on soft tissue that was previously-scavenged or was moist and well-decayed. In the present study, opossums chewed on integument, musculoskeletal tissue, and an excised liver. Morton and Lord (2006) observed one or more opossums feeding on the internal tissues of domestic pigs, like viscera. In this study, opossums did not successfully feed on the flesh of human corpses until tissue was soft and putrescent or raccoon’s had first scavenged tissue. This suggested that the opossum’s dentition is ill-equipped to breach the integument of a fresh or uncompromised corpse. Yeager and Elder (1945) state opossums left conspicuous feeding sign as they mangled goose carcasses, and usually ate from them where found. Opossums are thorough masticators; and in the present study, they repeatedly chewed on pieces of attached tissue and rolled it around in their mouth.

Opossums rarely survive two years in the wild and they are somewhat nomadic moving about every six months to a new territory (Krause and Krause 2006). The opossums living near the facility may be atypical in these regards due to the increasing number of body donations placed at the facility which provides a relatively stable, year-round food source, be it insect, flesh, or small animal prey.

Female opossums with young outside the pouch were not seen at the facility, but subadult opossum teeth and bones were identified in a raptor pellet collected at the facility. Female opossums are casually maternalistic: they fiercely protect their pouch the first few weeks following birth, but young that either fall off their mother's back or those foraging on their own may be ignored for awhile or even left behind (review by Kimble 1997). Additionally, young can be easily predated on by raptors and other mammals, including raccoons and conspecifics. Female opossums with young that can leave the pouch are known to leave them in the nest while they forage to avoid their being predated on. During the present study, opossums did not nest in the facility and observed behaviors appeared directly related to foraging and feeding.

Opossums will capture small animal prey using their forepaws which have much extension and flexion in the digits. However, their converging grip prevents independent movement of the digits (Abdala, et al. 2006; Coues 1869). Thus, they did not use them to collect maggots—a very small and active prey. Rather, multiple maggots were collected together by repeatedly licking surfaces with their tongue. Unlike raccoons, opossums did not use their forearms to reach into body cavities: they probed with their rostrum. Anatomical studies demonstrate the opossum's claviculo-scapular strut is rigid: range-of-movement of the humerus is restricted to uniaxial, or near uniaxial, motion. However, a large range of motion is available in the wrist. Thus, opossums commonly used their forepaws to assist them in feeding by stabilizing their own torso or the food substrate.

The Virginia opossum's small-and-pointed cusp molariform cheek teeth are well-adapted for crushing and chewing insects, moderately-adapted for severing and chewing decaying soft tissues, but ill-adapted for bone destruction of medium and large-sized vertebrate carcasses. In this study, the opossum chewed toes, attempted to gnaw on a broken rib end, and gnawed on and modified the sternal end of a sawed clavicle. The Virginia opossum was not a significant modifier of human bones. Opossums have been photographed with bone portions from decaying carcasses in their mouth, on which they likely chewed (Morton and Lord 2006; Nolden n.d.). In a tooth mark study by Delaney-Rivera and coworkers (2009), an opossum was allowed to feed on a defleshed goat limb for 24 hours (Delaney-Rivera, et al. 2009). Examination of the recovered limb yielded two small measurable tooth marks on epiphyseal portions (0.85 x 1.09

mm, and 2.11 x 8.09 mm). Morton and Lord (2006) report that opossums fed on dessicated and mummified pig carcasses feeding directly on the remains at the same sites as the fox. Further, an opossum disarticulated a number of skeletal elements, and held and chewed the epiphyseal ends of rib bones. Mann et al. (1990) report that a female opossum and her litter nested alongside a body donation at the facility, but did not disturb the nearly skeletonized remains.

Opossums were not seen excavating dirt from the two filmed shallow graves at the facility, but this is not surprising as they are poor diggers and alternative feeding sites were available. However, Morton and Lord (2006) saw an opossum attempting to dig down to a shallowly buried pig carcass (<1 ft).

Summary

The Virginia opossum largely feeds on the fly larvae developing on a corpse. The opossum will feed on soft tissue, but it has difficulty removing flesh from relatively fresh human remains. Opossums tried to detach soft tissue flaps by gripping a mouthful of tissue in their teeth and jerking backwards away from the corpse. They directly fed on tissue by biting down with their canines and incisors or by using their cheek teeth.

Significance

The Virginia opossum is a beneficial scavenger at the Anthropology Research Facility because its feeding reduces the abundant carrion insect population. Further, their soft tissue feeding rarely produced macroscopic bone damage. The opossum does, however, collect maggots on its tongue by licking body surfaces and crevices. This behavior may disrupt studies aimed at estimating the postmortem interval from skin microbial speciation and succession. Opossum feeding may also disrupt entomological studies by the removal of diptera species or life stages which could result in erratic presence or absence data. Given the large number of corpses available at any one time in The Facility's recent past, this is unlikely to be a problem for entomological sampling; but opossum feeding may be disruptive in a less carrion-enriched environment and in postmortem interval estimates for human remains recovered in an outdoor forensic setting.

PART 4. RODENTS

Abstract

Three species of rodents were studied at the Anthropology Research Facility: the brown rat, (*Rattus norvegicus*), the eastern gray squirrel (*Sciurus carolinensis*), and the white-footed mouse (*Peromyscus leucopus*).

The brown rat and white-footed mouse nested, and took shelter in, decayed human remains, but they did not co-occur. Both species gnawed on fleshed human remains throughout soft tissue decay, feeding on skin, fat pockets, and muscle. Further, they scraped and removed tissue, including cartilage, muscle, and periosteum, from bone surfaces. The brown rat consumed grease-laden spongy bone. Increasingly weathered bone reduced of nutrients was sometimes gnawed, but in small amounts and without pattern. Such gnawing is attributed to factors like habitual gnawing and exploratory behaviors; and possibly, to obtain minerals or sharpen incisors.

The gray squirrel navigated around decaying human bodies, but gnawed only on dry skeletal remains. Gray squirrels at the facility gnawed only on exposed bone and did not clear away debris—even dropped leaves—to uncover bony projections for gnawing. However, their movements over a dry skeleton combined with those of a larger species, like the raccoon or opossum, could disperse and re-expose bone which elicited gnawing.

Introduction

The rodent dentition is equipped with opposable pairs of chisel-like, continuously-growing incisors which are separated from the cheek teeth by diastemas—gaps which replace the canines. The rodent incisor is hypsodont, i.e. open-rooted, which enables a lifetime of constant growth to counteract excessive wear due to continual gnawing. The upper incisors are more sharply curved than the lower; and in profile, the growing root forms a tighter helix. The growth rate of the upper incisor is less than that of the lower; so the longer, and faster growing, lower incisor removes the bulk of gnawed material.

The smaller, wild rodents are incredibly active and agile. They have the ability to contort, and rotate, their bodies and heads into unusual positions. Rodent forepaws may be used for support, grasping, or reaching.

Brown rat

Brown rats (*Rattus norvegicus*), also referred to as Norway rats, house rats, sewer rats, and wharf rats, are commensal rodents unintentionally introduced into the New World during the late eighteenth century. The aggressive brown rat thrives in interior urban centers of North America and can be found in and around human habitations from subtropical Florida to the more frigid portions of Alaska. While most likely to inhabit the ground where they constructs vast networks of tunnels, they are also adept climbers. Brown rats are predominately nocturnal with two main periods of feeding; one just after dark and another just before dawn.

Commensals have long histories of association with humans in the Old World. Tchernov has suggested that one of the more interesting consequences of initial long-term human sedentism that took place approximately 10,000 years ago in the Near East, "...is the abrupt appearance of commensals around human habitations".

By the time brown rats reached the New World they had developed a heavy dependence on man. In northern regions of the United States, for example, they are unable to survive without the protection and food provided by humans. As rodents, they feed on cereal grains cultivated and stored by humans, but they have also developed a taste for nearly anything consumed by humans, including meat and fat. Indeed, although classified as rodents, brown rats seems to "prefer protein and fatty foods" to vegetables and fruits and have been characterized as the most omnivorous of all mammals.

The brown rat has poor vision, but their eyes are highly sensitive to variations of light intensity. This allows them to detect movement in extremely low lit conditions. To compensate for their poor vision, the vibrissae or whiskers serve as touch receptors that when aligned with an elongated object, enables the rat to travel rapidly and confidently (Pisano and Storer 1948).

Brown rats are habitual ground burrowers. Their dug tunnels are about two-to-two and a-half inches in diameter, generally three feet or less in total length, and most are twelve inches or less below the surface. Each burrow is accessible by multiple entrances and contains on average, one or two dens. (Pisano and Storer 1948).

Foraging and feeding

The first body donation filmed at the facility was for a two week period beginning the last week of September and into October 2003. When filming began, the body had been exposed at the facility for 23 days. Raccoons had previously scavenged the soft tissues of the left arm and both calves and the rest of the body remained covered with a body bag. The appearance of the legs suggested the body had moved into the dry stage (Rodriguez and Bass 1983) and although a large maggot mass was present beneath the bag, at least one wave of migration had occurred.

Nocturnal video showed brown rats were active throughout the night both traveling by the body and foraging around it, and sometimes probing beneath the exposed legs or edge of the body bag. Up to two rats would actively forage around the body for short intervals throughout the night. The rats spent much of their time near the body probing and moving small amounts of dirt, but only occasionally were their paws drawn to their mouth to ingest food.. In short, the rats appeared to be searching for preferred food(s). Identification of the ingested food was impossible, but it was assumed that they were selecting amongst the carrion insect fauna. This foraging behavior, i.e., probing sites with their nose and object retrieval with their paws was also frequently filmed at a second raccoon-scavenged body placed in mid-October and filmed in late November and early December. Maggot masses were never present on this body; but some flies and maggots were photographed.

In July 2006, two entrances to rat burrow were found in the side of a bank. One hole was active and one was not. The inactive hole was partially filled with what appeared to be debris like dirt clumps, twigs etc. Also visible were a small piece of broken human rib and a partial soldier fly puparium. The holes were about 12 inches apart and both may have been unused at the time.

A number of brown rat fecal pellets were collected at the facility. From this, a sample of 16 pellets from 4-16 November 2003 and 13 pellets from 7 June 2004 were examined under a dissecting microscope with 10-30X magnification. The pellets were inspected whole and only the outer surface was visible. Maggot skin cuticles were present in seven pellets from November—43.8% of the sample (Figure 126), and one pellet from June—7.7% of the sample.



Figure 126. Rat pellets with maggots collected at the facility on 4 November 2003.

Further, November pellets generally contained meaty animal matter and June pellets generally contained highly fragmented insect exoskeletal parts and seeds.

At the facility, brown rats vanished when a larger animal like a raccoon approached but reappeared upon its departure. This avoidance behavior enabled both species to modify the same corpse. As raccoon visitations decreased, the intensity of rodent gnawing increased so that brown rats sometimes erased small carnivore feeding traces during the removal and resculpturing of remaining soft tissue.

Brown rats constructed tunnels beneath many bodies. One or more burrow holes was dug next to a corpse and often near enough, that they remained hidden beneath the plastic sheeting or body bag. These tunnels did not always appear to be for nesting. Rather, some tunnels may have been constructed only to excavate carrion insects from the soil as they were sometimes very shallow and over time, sections would partly cave-in.

Dessicated torsos sometimes served as eating areas as indicated by the accumulation of gnawed and fragmented nuts and broken snail shells. Pisano and Storer (1948) referred to such

locations as shucking stations: secluded spots near runways or burrows where a brown rat would bring gathered food for consumption in greater security. Such sites were marked by a food midden and could sometimes be found below ground (Pisano and Storer 1948). More often at the facility, hollow torsos served as latrine sites that accumulated numerous rat droppings.

Rodents can alter the appearance of soft tissue decomposition by their movements about a corpse. This is seen in Figure 127, where claw marks are seen along with multiple, round-shaped areas of dried skin. These dried areas were produced by brown rats as they crossed over the abdomen, dragging their belly. The corpse's torso lay between their runway along a wooden fence to a rat feeding area on the right arm (positioned away from the fence) (Figure 128).

Soft tissue gnawing

Soft tissue brown rat-feeding of a nude corpse can be found nearly anywhere. Soft tissue, including skin, fat, and muscle, was removed in layers. A ring of epidermal drying often outlines circumscribed areas of removed tissue (Figure 129). This is from the upper incisors being placed



Figure 127. Drying integument caused by brown rats dragging their belly over skin. Note the claw marks near the bottom of the photo made by the four forepaw digits. Photograph taken on 27 March 2004.

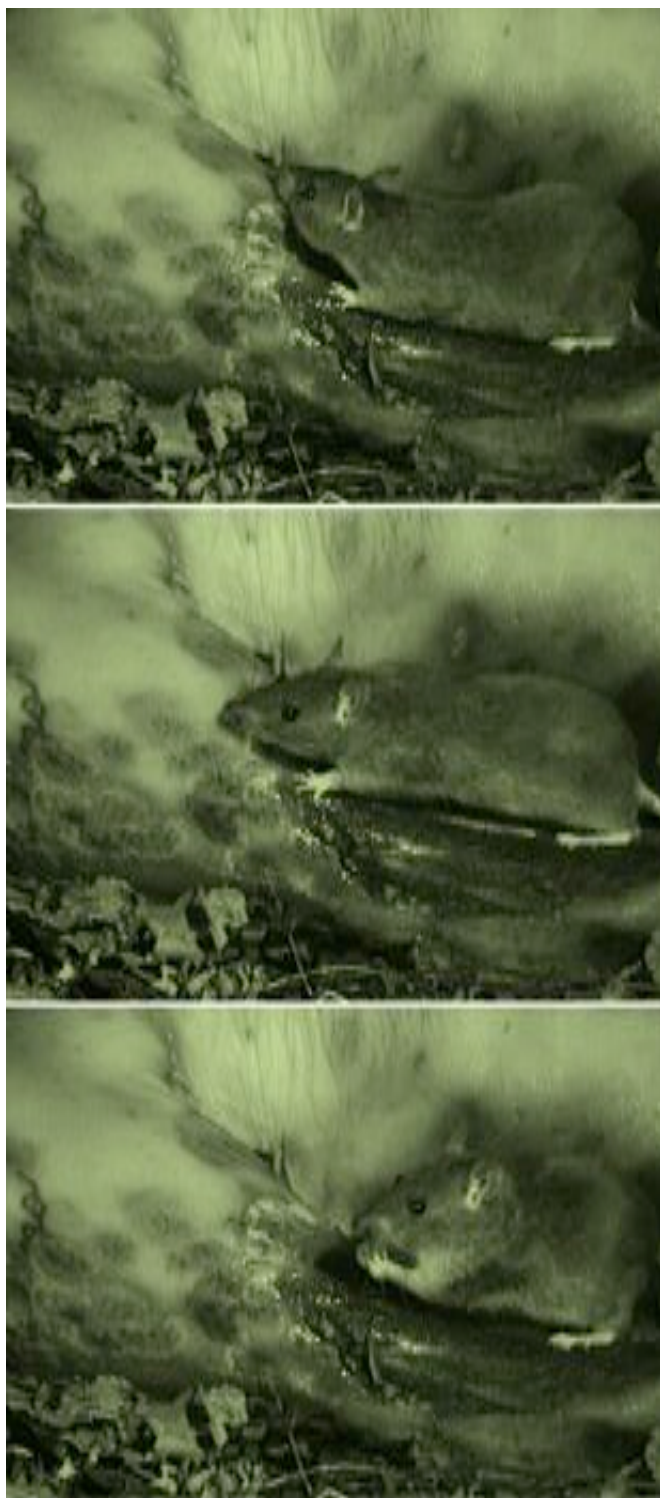


Figure 128. Brown rat feeding on soft tissue of the right anterior arm. Video stills captured on 2 March 2004.

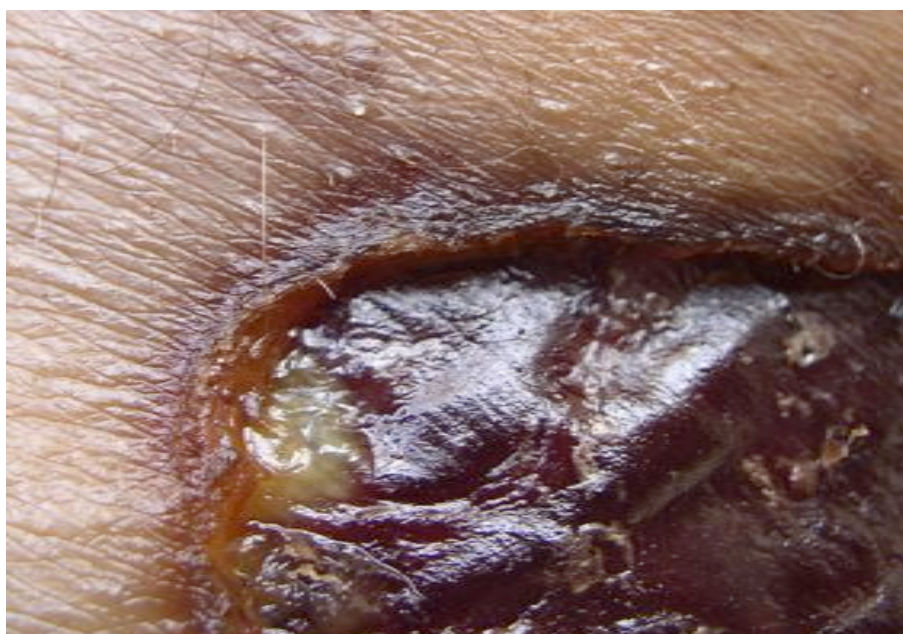


Figure 129. Rat-gnawed soft tissue margin with a ring of dried epidermis due to upper incisor placement. Photograph taken on 24 March 2004.

gently against the skin. Short, linear impressions, or cuts, occur when the upper incisors are more heavily placed against the skin (Figure 130). On one corpse, skin was not consumed. Rather, it was gnawed off in lunate-shaped strips and discarded onsite (Figure 131). Skin margins were scalloped (Figure 132), because the rat positioned its torso at a feeding spot, then gnawed as it turned its head from side-to-side. It then advanced either forward or sideways to gnaw again. Subcutaneous fat was pocketed out; and when muscle was fed upon, muscle strands appeared snipped (Figure 133).

Rat gnawing on soft tissue occurred throughout decomposition on fresh remains as well as those decayed or mummifying. Dessicating soft tissue appeared shredded, frayed, or ragged due to the tearing and pulling action of the rat's head and incisors (Figure 134).

Brown rats also gnawed on the soft tissues of embalmed bodies. Extensive rodent gnawing occurred over lengthy intervals on two donations, in particular, one of which was also scavenged by raccoons. Extensive rodent soft tissue gnawing and undermining of skin was present on the legs, torso and right hand on one of these bodies. The persistence of brown rats'

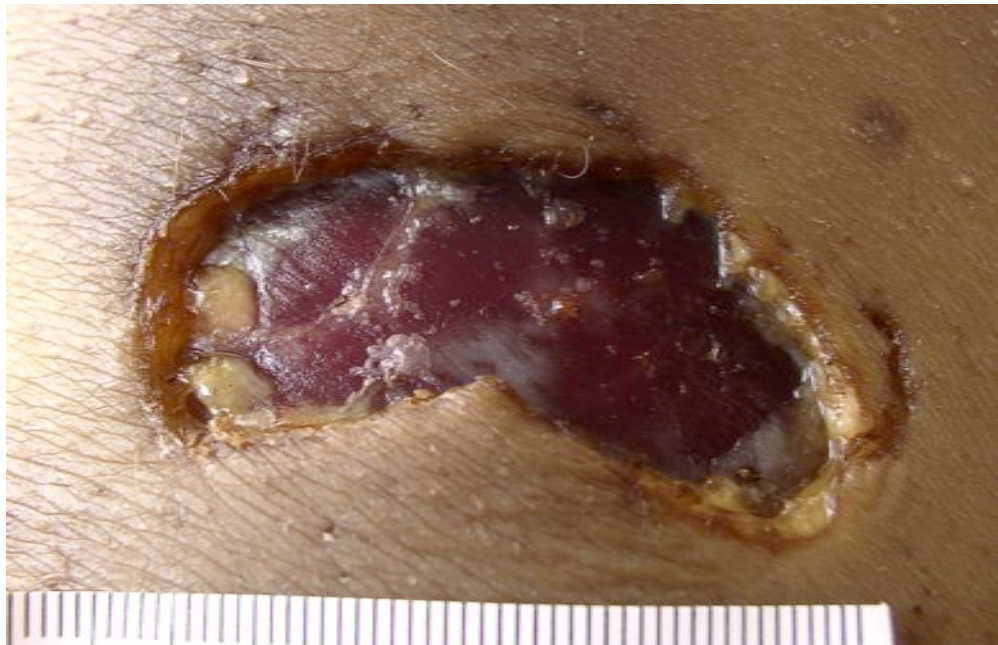


Figure 130. Brown rat removal of fat layer and skin incisions produced by the upper incisors. A millimeter scale is shown. Photograph taken on 21 March 2004.



Figure 131. Gnawed and discarded pieces of skin. Photograph taken on 18 March 2004.



Figure 132. Brown rat scalloping of soft tissue margins. Photograph taken on 17 July 2006.



Figure 133. Brown rat incisal snipping of muscle fibers and undermining of fat. Photograph taken on 27 March 2004.



Figure 134. Left thigh showing tissue layers with fringed edges. Photograph taken on 21 September 2003.

feeding upon the embalmed body is demonstrated by the following field note account:

In an attempt to prevent the extensive rodent soft tissue consumption from progressing to bone destruction, the plastic sheeting covering the body was removed so that it lay fully exposed beneath the tree clearing overhead. The plastic served to protect the rats from overhead predators, specifically, from great-horned owls attracted to the facility by the rats' presence. Knowledge that these owls were actively hunting at the facility at this time was based upon the near daily sighting of great-horned owl molt feathers lying on the ground. A progress check just a few days later produced both sharp laughter and a gleam of admiration as the rats, in the meanwhile, had excavated a shallow tunnel up to the body—through the compact, clay soil—and had constructed a shallow, wide trench beneath the torso so they could continue feeding with overhead protection. In light of their demonstrated saviness, no further harassment ensued.

Bone modification

Brown rats gnawed on greasy bone rich in cancellous tissue and covered by thin cortical (Figures 135-136). Greasy cancellous bone was excavated into and their incisors sometimes left squared-off ends. This may be caused by scraping of the upper incisors. Most bone is removed by the lower incisors, which for the brown rat, are more rounded in cross-section and grooves are often not so shovel-shaped as those that appear in Figure 136. Subchondral bone was often left intact so that bone ends appeared to be pedestaled (Figure 137). Brown rats pedestaled three distal femora in May and June of 2004. Extensive destruction occurred on the bones of the hands and feet and sometimes they were completely consumed.

When rats burrowed beneath bodies or habitually used either the plastic or the mummifying tissue itself as overhead protection, rodent tooth marks were sometimes found along the ribs, vertebrae and pelvic bones, as well as other accessible locations. Dessicating tissue and progressively dry bone was nibbled at, and gnawed upon, by the brown rat (Figure 138). Feeding experiments with captive wild rats indicated that when dry, old bone was given to rats, gnawing appeared to be exploratory as only a little amount of bone was removed.



Figure 135. Brown rats removing fatty cancellous tissue from the right knee joint. Photograph taken in June 2004.



Figure 136. Distal femur with two distinct furrows in cancellous bone. Photograph taken in June 2004.



Figure 137. Brown rat pedestaling of long bones. Photograph taken on 3 July 2006.



Figure 138. Brown rat gnawing of the increasingly weathered right femoral head (PMI=2.5 yr). Photograph taken on 31 May 2006.

White-footed mouse

White-footed mice were rarely photographed or filmed at the Anthropology Research Facility for various reasons, but they were common at the facility. Their presence and activities were most visible when few or no brown rats were nesting there, or in areas outside of brown rat territories. White-footed mice are extremely quick, easily frightened, and they rarely paused when out in the open.

White-footed mice are notorious for their shredding behavior. Materials like twigs, leaves, paper, cloth, etc. are shredded apart between the incisors and fashioned into fluffy, ovaloid nests. They constructed their nests in the outdoor shed and plastic storage bins; and in the absence of nesting brown rats, in the dessicating torsos of human remains. A nest removed from an outdoor shed in mid-October 2004 was teased apart and along with mouse, contained a number of hairs from multiple humans and other mammals, like the raccoon. Nests built in

skeletonized torsos covered with mummified skin were largely constructed of fallen leaves and decayed leaf netting, bits of paper, and man-made fibers, like discarded string and cloth.

White-footed mice used defleshed and relatively dry crania for shelter and secluded feeding spots. On two occasions, human crania with a faint path leading up to the foramen magnum were picked-up and nutshell fragments and pupal casings dropped out of the foramen magnum. In June 2005, the author witnessed someone lift a cranium off the ground and a startled mouse leaped out from it and disappeared into a nearby mummified torso.

Species account

Members of the genus *Peromyscus* are collectively referred to as white-footed mice or as read more recently, deer mice (Burt and Grossenheider 1980; Reid 2006). Approximately sixteen species varying in color-markings and size are distributed throughout the United States and Canada. The deer mouse (*Peromyscus maniculatus*) and white-footed mouse (*Peromyscus leucopus*) are together the most common and widespread genera species. The white-footed mouse inhabits the eastern half of the United States—excluding Florida—and its range extends west into Montana and southwest into New Mexico and areas of Arizona (Reid 2006).

The white-footed mouse has a head and body length of 3.5 inches and weighs 0.75 ounces. It is similar in size to the commensal house mouse (*Mus musculus*), but has large eyes and ears, a distinct white underbelly and feet, and has a haired tail that is bi-colored (Murie 1974). Deer mice have good vision and are less dependent upon their vibrissae for guidance than the brown rat and house mouse; so their movements are often independent of objects. And while they do not establish conspicuous surface runways, they may use those established by other species. The white-footed mouse often travels by great leaps and bounds on its lengthened hind limbs. If alarmed, the mouse will nervously drum its hind feet.

The white-footed mouse prefers wooded and brushy areas—especially edge areas—and typically avoids open, grassy habitats, although it will cross such areas to reach a treeline beyond. The mouse is both terrestrial and semi-arboreal, and will construct fluffy, spherical nests in abandoned birds' nests, hollow logs, underbrush, outbuildings, and previously excavated underground burrows (Murie 1974).

Peromyscus species are highly omnivorous, opportunistic feeders. They eat a variety of nuts, berries, wild seeds, insects and their larvae, plants, and fungi (Jameson 1952; Reid 2006; Whitaker 1966). They collect and cache food items, mostly seeds, that can be carried in an internal cheek pouch to either a feeding station or a winter storage site.

This mouse is strictly nocturnal and remains active year-round (Reid 2006). It falls prey to nearly any meat eater that hunts at night, including the northern raccoon, the Virginia opossum, the red fox, domestic cat, the American mink, shrews, and the great horned owl and eastern screech owl—these species being highlighted because they frequent the facility.

White-footed mouse predation on immature diptera

Abstract

A feeding experiment was conducted with live-trapped white-footed mice (*Peromyscus leucopus*) and carrion-frequenting fly larvae and pupae to learn if this mouse species readily consumed immature flies, as suggested by observations made at the Anthropology Research Facility. Captive mice ate some larvae and many pupae; and mouse-predated puparia were distinct from fly-emerged, insect-predated, and parasitized, puparia. This short report documents white-footed mouse consumption of carrion-frequenting fly pupae; it describes mouse feeding sign left on pupal casings and remnants, and calls attention to rodent predation on the entomological evidence at outdoor human remains scenes.

Introduction

Small mammal predation is the primary biological mechanism of population control of a number of insects; and insect-eating deer mice (*Peromyscus* spp.) can destroy appreciable numbers of live arthropods and their larvae (Buckner 1954; Holling 1959; Jameson 1952; Parmenter and MacMahon 1988; Smith and Lautenschlager 1978). Deer mice are attracted to carrion and will scavenge on animal flesh (e.g., DeVault 2004; Jennelle, et al. 2009; Komar 1999), but Jameson (1952) suggests they will engorge themselves on carrion fly larvae.

Remotely-captured photography and videography of scavengers and their feeding was used to document the animal modifiers of human remains at the University of Tennessee's Anthropology Research Facility. At the time of this study, no less than between 30 and 45

donated human corpses decayed outdoors at the secured, 1.3-acre wooded research facility; and up to 25 bodies lay in shallow graves. The data collected over a three-year period, suggested white-footed mice regularly consumed immature carrion diptera at the outdoor human decomposition facility.

In August 2004, a prone body was deposited in a shallow grave freshly excavated in a small grassy clearing along the northernmost, west fenceline. By October 1, two small areas of the corpse—the right waistline and right upper leg—were exposed by raccoons which had enlarged cracks in the overlying 2” of soil. By the month’s end, soft tissue was being removed from the inferior pelvis. On December 30, numerous mouse feces were discovered lying on the packed soil below the exposed inferior pelvis and scattered inside the by then hollow pelvic cavity. Mice were presumed to be regularly entering the lower torso to feed on soft tissue and on maggots that continued to develop in warm tissue recesses. Mice nesting was ruled out due to the damp environment and because, by then, opossums regularly frequented the grave site.

On January 1, 2005, white-footed mouse activity was documented at an obese body that arrived in early August 2004. The surface-deposited, prone body lay along the south fenceline. It was loosely wrapped in by then mouse-shredded hospital linens; and partly tucked inside, and completely covered by, two extra-large body bags in which the double-bagged body had been transported. When the combined coverings were drawn aside, the right neck and upper torso region were revealed. Further, abundant mouse feces and diptera puparia, and fragments thereof, lay scattered alongside the otherwise undisturbed torso. Mouse predation of fly puparia appeared likely, but no puparia were collected at the time for microscopic examination.

Mice often built their fluffy nests in the torsos of nearly skeletalized remains with mummified skin tags—these remains were typically protected from the elements by minimally, 6-mil plastic sheeting. However, a startled mouse was uncovered a few times at dessicated bodies even in the absence of a nest or conspicuous rodent gnawing. And crania that lacked soft tissue sometimes contained nut shell fragments and fly pupal casings. While fly puparia of a late colonizer can accumulate inside a cranium during larval migration, the mast fragments were certainly deposited there. One day, a cranium was picked up and a startled mouse leaped out of the foramen magnum, dropped to the ground, and disappeared into the corresponding

mummified torso. Every day, one can visually trace the many linear disturbances of leaves or soil that disappear into uncovered, largely skeletalized bodies or beneath body coverings. The high degree of small mammal activity around decaying bodies is attributed to white-footed mice and shrews, as both have been discovered at human remains. Further, they are both thought to be primarily after the insects that are attracted to the decaying bodies.

To learn if white-footed mice fed on the immature flies that developed on and around decomposing human remains, mice were live-trapped at the facility, placed in indoor terrariums, and subjected to feedings of collected fly larvae and pupae.

Methods

Two Havahart® live traps (Model #1020, Woodstream Corporation, Lititz, PA) were baited with peanut butter and rolled oats and stationed along varying rodent-sized surface trails at the facility. Intermittant trapping was carried out over a period of eight weeks (January–March, 2005). Deployed traps were checked once or twice daily and sprung traps nearly always contained a white-footed mouse. By the end of the trapping period, six mice were retained for study.

Mice were housed indoors in two large aquariums covered with wire mesh screen (12” x 12” x 24” and 14” x 14” x 20”). Each terrarium contained three individuals: an adult male, an adult female, and a juvenile; and was supplied with shredding and nesting materials and enrichment items used for hiding, climbing, etc. Captive mice were provided with fresh water daily and fed a mixture of rat and mouse variety chow, wild bird seed with freeze-dried mealworms, and striped sunflower and safflower seeds. Twice, 1-doz. small crickets were purchased from a pet store and released live into mouse habitats. This was further supplemented with green leaf lettuce; and wild seeds, nuts, berries, and invertebrates gathered at the facility.

After mice were established, multiple collections of diptera pupae and a single collection of sluggish prepuparia were taken from around decomposing bodies at the outdoor research facility and fed to captive white-footed mice. Four feedings were documented and are described here. Insect collections occurred in the late afternoon to early evening from late March to the middle of May. Collected diptera were placed in a shallow dish in mouse terrariums that same

evening. Puparial remnants and any uneaten pupae were collected after one or two nights of exposure.

For a sample of naturally emerged pupal casings, post-feeding diptera larvae and pupae were collected twice from the facility (late April, early June) and placed in a screen-lidded tub. The first collection of flies completed their pupation in dug facility soil, and the second, in purchased vermiculite. Emerged flies were nearly all blow flies—about 200—and after they were released outdoors, their pupal casings were carefully gathered and retained for study. This emerged sample was later extensively fed on by carpet beetles (Family Dermestidae). An uncompromised sample of emerged pupal casings was then collected from a battery box that once held a decomposing rat carcass. Pupal casings that were parasitized—had a small bore hole, or insect-predated—had a larger hole with finely serrated edges (Smith and Lautenschlager 1978), were removed from the sample as insect-modified comparative specimens.

Mouse-predated and emerged pupal casings were examined under a stereomicroscope using 10-30x magnification. Each sample of pupal casings were separated and grouped based on gross appearance, i.e., similar modification. Predated casings were grouped into three categories: absent anterior end, absent posterior end, and absent both ends; and examined for white-footed mouse feeding sign.

Observations of mouse feeding behavior were carried out between 6 p.m. and 12 a.m. under very dim lighting (an outside street lamp) as mice only emerged from their nest in the early evening when the room was dark and quiet. Even then, the mice were easily frightened by movement or unexpected sounds, so for the fourth feeding a Sony Handycam digital camcorder (Model DCR-TRV350, Sony Electronics Inc., Oradell, NJ) in Nightshot mode (Lux 0) was used to record nearly 10 minutes of video footage of mice feeding on puparia.

Results

The circumstances surrounding each of the four feedings are described along with some behavioral observations and results.

Feeding #1

On March 25, several dark brown, hardened puparia were collected near a corpse and placed in one terrarium as a trial feeding. A mouse emerged from the nest, snatched up a puparium, and bit off one end. After feeding for a few seconds, the mouse discarded an empty pupal casing in the food dish. The dish was removed the following day; most puparia had been eaten overnight.

Feeding #2

On April 4, inactive larvae and puparia were carefully removed from the ground litter and soil about equidistant between two bodies placed nearly 13 weeks and 24 weeks prior. The immature diptera were roughly divided between two high-rimmed dishes and each placed in a terrarium. Sluggish maggots became active in the food dishes and many, if not all, escaped into the absorbent floor litter and perished. The dish was removed the following day; all prepuparia, i.e. contracting larvae, and healthy puparia were eaten overnight.

Feeding #3

On May 7, a hurried collection of dark brown puparia were brushed from the inner folds of plastic that covered a strongly odoriferous corpse. The puparia were placed on a 1-mm mesh screen and gently rinsed under a stream of tepid tapwater to loosen adhered debris. , but they retained a pungent ammoniacal odor. All Most puparia were immediately discarded, except 32 which were placed in one terrarium. After two nights of exposure, the still odiferous puparia remained uneaten and were removed from the terrarium and placed in a ventilated container with vermiculite at room temperature. No flies emerged, but dead puparia (n=18), parasitized puparia (n=14), and several emerged parasitoids were recovered.

Feeding #4

On May 14, puparia were gently brushed from a trash bag that lay on the bottom of a car trunk beside an overweight body that had decomposed since late-February 2005. The puparia measured 7.0 - 8.5 mm in total length. They were roughly divided and placed in both terrariums.

A camcorder was positioned about two feet away from one terrarium and captured nearly 10 minutes of video footage after one mouse began feeding. The recorded footage showed one adult male mouse ate six puparia within six minutes. The mouse fed in short feeding bouts, eating two puparia while at the dish and then bounding away for a time.

When the mouse selected a puparium to eat, it grasped it in its mouth with the long axis held cross-ways so an end protruded out each side—the near ends appeared to be tucked in the diastemas. It then sat on its haunches, grasped the puparium with the long axis held length-wise between the forepaws, and nibbled or bit off one end of the puparium (Figure 139). Pupa within darker puparia appeared to be pulled out of their casings (Figure 140).

The food dishes were removed from the terrariums after two nights of exposure. Recovered puparia are listed in Table 13. White-footed mice ate 150 (96.2%) of the 156 fly puparia placed in the two aquariums.



Figure 139. A white-footed mouse holding a puparium after it nibbled off one end.



Figure 140. A white-footed mouse extracting a pupa from its puparium.

Table 13. Puparia recovered from Feeding #4.

Puparia¹	Count
<i>Modified</i>	<i>(150)</i>
Removed anterior	118
Removed posterior	30
Removed both ends	9
<i>Unmodified</i>	<i>(6)</i>
Dead	6
Parasitized	0
Total	156

¹puparia measured ca. 7.0-8.5 mm in length

Discussion

Mice did not indiscriminately feed on puparia. Rather, they brought their nose near or against several puparia, before they selected one to eat. Pupae were not always completely extracted from the puparium when one end was removed as some casings had both ends removed or were torn apart. Typically, 50-75% of the total puparial length remained (Figure 141). Several puparia lacked conspicuous mouse feeding traces as the anterior end was broken off along the transverse cleavage line—a line of weakness that nearly encircles the “fifth segment” (or abdominal tergite 1). White and lightly tanned puparia in early sclerotization were repeatedly nibbled on until they were completely consumed. No adult flies were discovered in the aquariums. One pupal casing contained a partly eaten, imago (adult) fly which was missing its abdomen and at least one leg. Some segments, or tergites, were split longitudinally, which was a clear sign of predation.

Buckner (1954) illustrates mouse feeding traces on a larch sawfly cocoon (*Pristiphora erichsonii*) with a removed end which he describes as having a scalloped edge. Smith and



Figure 141. Examples of mouse-predated puparia.

Lautenschlager (1978) describe captive white-footed mouse feeding on gypsy moth (*Lymantria dispar*) pupae as mice usually opening one end and eating the contents, but many times they will simply tear apart pupae and eat them. Mice do not store pupae as other foods. Hastings and coworkers (2001:669) state “Small mammals either consume or remove the entire [gypsy moth] pupa or leave large pupal fragments with ragged edges caused by their incisors.”

The forensic entomologist may be interested in the feeding signs left by species that consume the developing larvae found on a decomposing human corpse. Inclusion of mouse-predated puparia can erroneously lengthen the estimated minimum postmortem interval (see Catts & Haskell 1990:125-6). Predation on maggots may introduce error into estimates of the maximum PMI.

Deer mice commonly frequent carrion (DeVault 2004; Jennelle, et al. 2009; Komar 1999). Jameson (1952) dissected two deer mice (*P. maniculatus*) stomachs that were filled with small muscoid maggots, which he suggests were obtained from a deer carcass decaying near his study site. Further, he suggests that deer mice can destroy appreciable numbers of arthropods and their larvae. Newly dropped bot-fly larvae may be predated upon by their rodent host (Catts 1982; Stewart 2011).

Insect-eating small mammals are important biological control agents and if their populations are decimated (e.g., poisoned), decomposition studies may not reflect early decay studies and those outside the facility due to voluminous numbers of carrion insects accelerating decay at insect-friendly temperatures. Campbell and Sloan (1976, 1977) have shown that when insect-eating birds and small mammals are removed from an area, insect population could increase tenfold in one year.

White-footed mice are active year-round and predate on both recent and overwintering insect pupae. White-footed mice efficiently forage for overwintering weevil pupae at a soil depth up to 3 cm (Semel and Andersen 1988). At the facility, white-footed mice may reduce insect numbers and their feeding may or may not affect arthropod species composition. What is not well understood is how insect-feeding affects human remains scenes and forensic entomological estimates of the postmortem interval. It is assumed, and perhaps rightly so, that

insect-feeding species may initially affect the carrion fauna, but fly colonization eventually overwhelms predators due to their vast numbers.

White-footed mice forage within individual, circular home ranges about 1/5-acre in size, but are generally tolerant of their neighbors. The exceptions being during breeding season and year-round for some aggressive males. In winter, home ranges are reduced and mice may even become communal as they concentrate around food resources (Schwartz and Schwartz 1981).

Empty pupal casings at an outdoor homicide scene may be due to mouse predation, rather than fly emergence. While mouse feeding can't outcompete with fly colonization of a decomposing corpse, mouse-predated pupal casings could be incorporated into the scene sample to be examined by an entomologist. White-footed mouse predation is easily recognized when the posterior end of the puparium has been removed, but is less clear when the anterior end is absent. It is important to recognize mouse feeding sign in the latter case, particularly for corpses dead about a month; or any instance in which emerged puparia are calculated in a postmortem interval estimate.

Summary

White-footed mice were live-trapped at the University of Tennessee's Anthropology Research Facility, placed in terrariums, and fed late instar fly larvae, including prepupae, and pupae that were collected from decomposing corpses. White-footed mice avidly ate fly pupae: they completely consumed forming puparia and pupae, and they expertly extracted pupae from their hard puparia.

Soft tissue scavenging

To document white-footed mouse scavenging of human remains at the facility, a camcorder was positioned next to a trunk of an interior-stripped four-door sedan which contained a bloated corpse. The trunk lid was positioned partly open so the camera could film mice feeding on the lower limbs. The nude buttocks, legs, and feet were visible. White-footed mice gnawed on the feet and removed skin, fat, and muscle tissues (Figures 142-144). Their feeding occurred throughout the night by multiple nibblings lasting for only two or three seconds.



Figure 142. White-footed mouse nibbling on the left heel of a body placed in an open car trunk. Video still captured on 29 March 2005.



Figure 143. The left heel and insole of a body placed in an accessible car trunk, with soft tissue nibbling by white-footed mice. Photograph taken on 3 April 2005.



Figure 144. White-footed mouse gnawing of right sole and toes of a body placed in a car trunk. Bone modification is restricted to the distal phalanges. Photograph taken on 3 April 2005.



Figure 145. Extensive white-footed mouse gnawing on left heel, ankle, and lower calf. Photograph taken on 21 June 2006.



Figure 146. White-footed mouse gnawing of right heel and sole. At least two mouse pellets are adhered to the tissue. Photograph taken on 21 June 2006.

In general, soft tissue artifacts were circumscribed with scalloped margins (Figure 145), and shallow craters may be hollowed out of flesh (Figure 146).

Bone modification

Only one example of bone modification was attributed to white-footed mice at the facility. In the single known instance of bone gnawing, damage occurred secondary to soft tissue removal. The cortical surfaces of foot phalanges were repeatedly scraped as mice removed the fatty toe pads and adherent tissue (Figure 144). Feeding experiments in which greasy bones were provided to wild white-footed mice demonstrate they do gnaw on fresh bone, but more data is needed to determine if any pattern exist. White-footed mice are suspected to be the gnawers of an unprovienced greasy clavicle attached to a tree stump at the facility (Figure 147). No photographs were obtained of the gnawing event, but a white-footed mouse was once seen atop the log after dark.



Figure 147. Greasy clavicle gnawed by an unknown mammal—probably rodent. Very fine bone particles lay near the gnawed areas. Photograph taken on 24 May 2004.

Gray squirrel

Eastern gray squirrels are a regular presence at the the facility, where they are only known to gnaw on relatively dry bone. The eastern gray squirrel is among the most widely distributed native tree squirrels in eastern North America and has been successfully introduced into parts of the North American West Coast as well as Europe. Unlike some members of the sciurid family, the gray squirrels does not hibernate but is active year-round. Its greatest activity periods are shortly after sunrise and in the late afternoon. It is unlikely to be active during heavy rains, high winds, or unusually cold weather. The arboreal gray squirrel spends much time on the ground. Its diet is generally restricted to nuts, tree buds, and field corn when available; it also eat flowers, bark, fungi, birds' eggs, insects, and sometimes animal matter (Bowers, et al. 2004; Edwards, et al. 2003; Kilham 1953; Schwartz and Schwartz 1981). Food consumption is greatest in the spring and fall, and peaks in September and October when increased foraging and scatter-hoarding activity occurs in preparation for winter (Edwards, et al. 2003).

The wildlife literature indicates gray squirrels often gnaw bones and antlers for their calcium and other mineral content (Bakken 1952; Barbour and Davis 1974; Bowers, et al. 2004; Carlson 1940; Kilham 1953; Madson 1964; Schwartz and Schwartz 1981). This activity is reported to be particularly prevalent among breeding females during spring (Carlson 1940; Madson 1964; Schwartz and Schwartz 1981).

Gray squirrels likely carried off some clavicles and they transported several human vertebrae. They may have even dragged around human radii and fibulae, but it must have been a difficult endeavor. A gray squirrel was seen batting around a human scapula, which weighed about 45 grams—they scapula was moved several feet (Figure 148). All the forementioned bones were discovered with fresh gray squirrel gnawing and they lacked carnivore toothmarks. A squirrel-gnawed subadult, domestic pig sacrum appeared and disappeared multiple times during the present study. The bone always appeared along the same section of wooden fenceline and adjacent trees, where squirrels commonly traveled along the top of the fence. Aside from being horizontally-displaced, the sacrum was likely vertically-displaced multiple times in its



Figure 148. Eastern gray squirrel (far right) snatching a right scapula out of the camera's view. Video still captured on 13 May 2006.

taphonomic history as the bone appeared to have been dropped while moving along the fence.

A body in advanced decomposition was placed in a partially shaded location at the end of August 2003. Raccoons scavenged the calves and feet and rats later burrowed beneath the upper torso. The body was picked up one year after placement. Nearly two weeks later, a calotte was found back in the underbrush roughly 25 feet away from where the body had decomposed. Photographs were taken of the calotte in situ and two weeks later when it was collected, fresh rodent gnawing consistent with gray squirrel was present on the autopsy-sawed margin. A small amount of periosteum adhered to the calotte. Rodent gnawing occurred after nearly 13 months of exposure.

Rodent gnawmarks consistent with gray squirrel was noted on two separate occasions on a second calotte in February 2007. The body, a victim of a house fire, was placed 6 July 2006 and had decomposed at the facility for 7 months, but it was exposed to direct sunlight for much of the day. A digital camera and motion detector were positioned over the skeleton for four weeks following the original gnawing episodes. The camera captured chipmunks and an eastern cottontail traveling on the narrow trail that coursed by the skull; and although a gray squirrel was photographed next to the skeleton, no new gnawing occurred.

Three body donations decomposed and lay exposed at the facility for lengthy decay intervals. Both skeletons became weathered, but one more so than the other which received less sunlight and remained covered in more leaf litter throughout the year. Any bones that became covered in leaf litter, even if previously exposed to become bleached and at least partly degreased, were ignored by gray squirrels until they were uncovered by events like wind gusts or human interference. Gray squirrels bury, and later uncover, winter food caches so why squirrels at the facility appear reluctant to uncover bone for gnawing is unknown. These behavioral observations may be misconceived or the amount of weathered bone available at the facility due to previously uncollected, then rodent cached bones was more than ample and there was no motive for uncovering bone.

On 6 January 2003 a body was deposited in an inconspicuous, out-of-the-way spot on the steeply-inclined northwest-facing slope. The body decayed in relative isolation on the shaded hillside until the skeleton was collected on 11 October 2004. The author regularly trekked the

hillside in search of newly deposited raccoon scat; and prior to one such foray on 9 June 2006 (the most recent search was two weeks prior to that date), a human clavicle appeared lying atop the leaf litter at the base of a tree roughly 20-30 ft away from where the skeleton once lay. No other bodies had decayed in the immediate area aside from this particular set of remains. The clavicle was later re-associated with the processed and curated skeletal remains.

Rodent gnawing was present on a few small areas of the clavicle, which was recovered 20.5 months after the rest of the skeleton for a combined postmortem interval of 41 months. The tooth marks appeared to be recent and either the clavicle had been moved to an unknown location and then moved again to its found location, or it was overlooked during skeletal retrieval and recently moved to the recovery site at the base of the tree. The latter is plausible as the skeleton was covered by nearly two seasons of decaying leaf fall and woody debris.

Two unprovienced human clavicles were secured to a fallen tree trunk at the facility in January 2004 and monitored over an 18 month period for bone gnawing by the eastern gray squirrel as reported by Klippel and Synstelien (2007). It was discovered that during about a two week period from March into April, newly formed bone shavings from a dry human clavicle were present on multiple days (Figures 149-150). Why removed bone was not entirely consumed by squirrels during this period was unknown. Similar occurences of bone chips being found lying on or near a bone have been noted for a whitetail deer rib placed at the facility and for a domestic cattle scapula placed in the author's backyard in Blount County, Tennessee. Seasonal comparisons between these three experiments have not yet been made.

Gray squirrel toothmarks are very distinctive. Their manner of gnawing is often obscure, because they frequently move about the bone while gnawing. However, Figures 151-152 clearly demonstrate that the uppper incisors are anchored on a ledge, and the lower incisors scrape away bone. The continual gnawing motion of the lower incisors often makes the individual incisor grooves indistinguishable. The body size of the rodent, rather the length of the lower incisor from the tip to the gum, is related to the length of the grooves as well as the hardness of the gnawed substance—in this case, bone. Rodents generally consumed all gnawed bone, but chips sometimes remained littered on or about the bone (Figure 150).



Figure 149. Eastern gray squirrel gnawing on dry bone. Photograph taken on 18 February 2005.



Figure 150. Gray squirrel-gnawed dry clavicle. Photograph taken 31 March 2004.



Figure 151. Typical gray squirrel gnaw marks. Note the multiple series of fan-shaped gnaw marks along the anterior ascending ramus. Photograph taken on 12 September 2006.



Figure 152. Rodent gnaw marks along the anterior ascending ramus: upper incisor anchor marks (left) and lower incisor scraping marks (right). Photograph taken on 12 September 2006.

Summary

Rodent species differ in whether or not they consume soft tissue and whether they prefer to gnaw on dry or greasy bone. Because of the rodent's dentition and their manner of gnawing, rodent gnawing can be readily distinguished from that by carnivores. The brown rat and white-footed mouse gnawed on human soft tissue and greasy bone. The gray squirrel only gnawed on exposed, dry bone.

PART 5. ANNOTATIONS

Abstract

These annotations describe the activities of several animals at the Anthropology Research Facility, which have yet to be mentioned. These species ate insects and/or preyed on very small animals, like white-footed mice. Some species are known scavengers, but they were not seen directly feeding on a corpse. In some instances, this suggested that scavenging was not the species' preferred means of obtaining food.

Introduction

The latin names for the species mentioned in this section are listed in Table 2. Some species are known scavengers, but they were rarely seen at the facility. Other species do not typically scavenge the hard and soft tissues of larger carrion. However, they may be found in association with the remains while foraging for food or when seeking a temporary or permanent shelter. This is especially true of insect-eating mammals and birds. Very small mammals outside of their nests and burrows habitually seek out paths of travel that best afford protection from terrestrial and avian predators. Human corpses that decayed at the facility in small clearings without ground shrubbery often provided some protection for these species. Very small animal runways typically coursed alongside corpses at the body-ground interface or traveled between skeletal elements and under mummified skin. The small bones of the hands and feet and dropped teeth were found scattered along these runways. Even cervical vertebrae were sometimes displaced. In most instances, small bones became scattered due to the animal's movements. However, some bones must have been carried because of the lengthy displacement distance.

Rodents and rabbits

At least one woodchuck denned inside the facility. It was twice seen during the day and it was viewed on video several times as a camcorder was once stationed near its den. The woodchuck did not disturb human remains, but it sometimes grazed on nearby plants. The highly herbivorous woodchuck feeds on grasses and plant matter (Reid 2006). Multiple eastern chipmunks lived at the facility. They did not scavenge or gnaw on human remains. Chipmunks

foraged in the ground litter—sometimes even around skeletal remains—in search of insects and mast. One individual was filmed intermittantly at a partly exposed shallow burial over a three and-a-half hour interval. The chipmunk busily foraged in the loose soil around and atop the burial. A wave of maggots had recently migrated from the corpse, and the chipmunk appeared to be collecting prepupae and storing them in its cheek pouches. The eastern chipmunk feeds on a variety of edibles like insects, fungi, bird eggs, mast, and sometimes very small animals (Reid 2006).

Multiple eastern cottontails either reside within, or often enter, the facility. Piles of fecal pellets are abundant and several nocturnal photographs of cottontails near human skeletal remains or dry animal bones have been captured. However, there is no evidence which suggests the eastern cottontail modifies bone. This species is a strict herbivore feeding on green plants, bark, and twigs (Reid 2006); and the cottontail rarely suffers from mineral insufficiencies as their gut physiology has adapted for mineral conservation (Chapman and Litvaitis 2003).

Carnivores

Canids were sometimes seen inside, and just outside, of the facility's fenceline. In mid-November 2003, the author startled a great dane with a red collar just after it chomped on a foot. Care was taken to photograph and note fresh bone damage throughout the facility so as to not confuse canid modification with that of the raccoon. On four separate occasions a red fox was photographed. On two nights in May 2005, a red fox was photographed walking atop a fallen log where a rodent bone gnawing experiment was being monitored. One year later, a red fox was filmed at mid-morning as it paused near a skeleton before it proceeded uphill (Figure 153). There is other evidence that suggested canids sometimes entered the facility, like indistinct canid prints, grave digging that sometimes seemed atypical of the raccoon, and an occasional human limb that was carried a distance. In general, canids did not appear to have entered the facility all that often.



Figure 153. A red fox passing by human skeletal remains. Video still captured on 2 June 2006.

A feral cat was once filmed inside the facility and three years later, a different cat was seen just outside the main gate lying on the roof of a storage building. In November 2003, when brown rats were abundant, an orange tabby cat was video-taped on the property attempting to catch a rat racing towards its burrow (Figure 154). It was unsuccessful and left after a few minutes. Both feral and domestic cats are probably common in the area, but they rarely entered the facility.

Shrews and moles

The true shrews and moles (Order Soricimorpha) are insect-eating specialists (Reid 2006). The diet of these voracious insectivores is largely comprised of invertebrates including insects and their larvae, sowbugs, snails, centipedes, and earthworms (Hartman, et al. 2000; Reid 2006).

Shrews are common, and quite active, at the facility. The single box-trapped shrew was identified as a northern short-tailed shrew, but other species are found in east Tennessee and may



Figure 154. A calico cat spotting (top) and awaiting (middle) an oncoming brown rat. After a failed pounce, the cat watches for further rat movements. Video stills captured on 26 November 2003.

be present at the facility (Reid 2006). Shrews are most active at dusk, but they are sometimes active during the daylight. One could hear their high pitched chattering squeals and both see and hear their movements beneath the leaf fall. Sometimes they were seen making quick dashes between patches of ground cover. One afternoon I heard dry leaves rustling and stopped to observe fallen leaves moving near a body. After the leaves stilled, a shrew darted into the open and then quickly vanished beneath a body bag covering a corpse. The author thrice watched a foraging shrew disappear beneath a body bag. Shrews were sometimes discovered beneath body bags covering remains in advanced decay. While the bodies can provide shelter for shrews, they are believed to be feeding on insects around the corpse. Shrews were not captured on video feeding at bodies, but only one motion sensor was used and the body itself prevented it from picking up the movements of very small animals when they remained on the far side of the corpse.

The short-tailed shrew eats snails, earthworms, mice and voles, beetles and their grubs—like the American burying beetle, sowbugs, and other insects and pupae (Jurzenski and Hoback 2011; Shull 1907). Diptera larvae represented a mere 1.4% by mean volume in the diet of the southern short-tailed shrew, but dietary studies of other shrew species have found as much as 12.3% (review in McCay 2001). Jackson (1961:32) reports, “maggots can be made the main food of [short-tailed shrews], and they do well on it”. Schlüter (1980) states two European shrews (forest shrew, *Sorex*; and water shrew, *Neomys*) prefer to feed on invertebrate carrion visitors, but during winter, they are the primary scavengers of mouse carcasses. Shrews consume small animal carrion (e.g., Haberl 2002), they eat beef (Brack 2006; Shull 1907), and have been documented at whitetail deer carcasses (Jennelle, et al. 2009). However, there was no evidence which indicated that shrews at the facility scavenged on the human remains. Carrion consumption is likely unnecessary due to insect abundance.

The northern short-tailed shrew will prey on weevil pupae at depths up to 15 cm (Semel and Andersen 1988). Short-tailed shrews are known to build up winter caches of gypsy moth pupae (*Lymantria dispar*) (Smith and Lautenschlager 1978).

A large study of the eastern mole's diet in South Carolina found scarab beetle larvae, ants, and centipedes were the three most important food items. Significantly, beetles in all life stages represented 42.4% of the diet by mean volume (Hartman, et al. 2000).

The eastern mole creates conspicuous soil ridges on the ground surface during construction of their shallow feeding tunnels. These tunnels are generally temporary and are built after rains in search of new food sources. Moles are active both day and night. Peak activity occurs on damp and cloudy days during the spring and fall. Moles do not hibernate, but they are rarely seen during cold weather as they remain in deeper permanent tunnels which connect to a nesting chamber. Moles are solitary and each will construct its own system of permanent subterranean tunnels (Schwartz and Schwartz 1981).

Fresh mole ridges were noted in late August 2004, following three out-of-four days of precipitation. The ridges appeared on the hillside in the southeast corner of the facility and encircled multiple bodies in either active or advanced decay. Five bodies decayed in close proximity. The most recent body arrived six and-a-half weeks prior. A new donation was placed closeby at the end of August. Moles remained active in the area through October. Five years later, a photograph of this same location showed an active, but less elaborate system of mole feeding tunnels.

The facility appeared to support large numbers of shrews and moles; and the numerous insects likely supplied a stable, year-round, food source for these ground dwelling insectivores who store up and/or continually forage on overwintering insects—carriion or otherwise. Shrews and moles are voracious feeders, but how this influences the carrion faunal community at the facility is unknown. Further research on shrew and mole foraging and feeding strategies in this insect-saturated environment is warranted.

Bats

Bats (Order Chiroptera) were spotted at the facility on multiple occasions. Most North American bats are insectivores and catch flying insects on wing, including beetles and moths (Barbour and Davis 1969; Reid 2006). On several late spring and summer evenings in 2006, up

to three bats circled above the clearing just inside the main gate. They frequently made low-diving passes, sweeping downwards, then skywards, after flying insects.

In May 2005, the author emerged from the woods near the main gate and moved towards the underbrush where a body was barely visible in the twilight. The small orange beam of the weakly-charged flashlight fell on a small, lightly-colored object with two glowing eyes that appeared to hover about four feet over the body. By the time a large flashlight was retrieved from the car, the object had vanished—it may have been a bat.

In July 2006, a camcorder captured a flying object alight atop the camera's housing and a dark triangular wing-tip passed twice in front of the camera lens. Four nights later, after the camcorder was moved a short distance away and the viewfinder overlooked a section of the electric fencing, a small, dark and fast-moving object hit the dual wire fencing with a force that caused the wires to rock wildly back-and-forth for several seconds—it must have been a bat.

Birds

At the beginning of this study, captured diurnal footage of birds was largely incidental and occurred at dawn. Later video was set to record 24 hours, but this was sometimes problematic because of the number of daytime researchers and visitors at the facility. Birds photographed or seen at the facility are listed in Table 2, and include raptors, black vulture, perching birds, and incidental species, like wild turkey and mourning dove. Other species were sometimes seen on the property, but they were not identified.

Birds of prey

Evidence of owls and one or more red-tailed hawks was discovered on the property. Large raptors did not nest inside the fenceline, but a nest was located in the woods just southeast of the facility. The red-tailed hawk, a diurnal predator, sometimes circled overhead the facility. One afternoon in August 2006, a red-tailed hawk was seen at the facility perched on a tree limb high in the canopy. After about thirty minutes, it flew overhead and dropped quickly to the ground where it captured what may have been a vole, given the animal's body size and apparent lack of tail. With the animal dangling in it's beak, the hawk flew a short distance away to a very large tree and consumed it's prey. When brown rat sign was being closely monitored in summer

2006, several great horned owl molt feathers were found lying on the ground over a two week period. A few large raptor pellets were also collected at this time (see below).

Neither hawks nor owls were seen near a corpse, with one exception. An eastern screech owl was captured on video in spring 2004 while perched on a large horizontal hanging vine just beyond, and above, a body undergoing active decay. The owl may have been startled by the noise of the camcorder as it immediately flew off. At least one screech owl pellet was collected—it contained the remains of a small frog. The screech owl feeds on a great many insects, particularly beetles, and also preys on very small animals (e.g., Artuso 2010).

About eight large raptor pellets were collected from the facility at various times between November 2003 and August 2006. At least one young-of-year opossum was identified in one pellet. Another pellet contained what appeared to be maggot skins along with the remains of a very small rodent. The large raptor pellets that were collected at the facility contained the remains of small and very small animals. Together, the pellets and personal observations suggested large predatory birds were after rodents at the facility as well as small passerine birds. Large raptors will feed on vertebrate carrion, particularly in the winter; but this is unlikely to occur at the facility given the Tennessee Valley's mild winters. However, more data is needed.

Perching birds

Perching birds (Order Passeriformes) include numerous species of primarily small birds, many having a melodious song (Peterson 1980). The six passerines identified at the facility—the northern mockingbird, American crow, European starling, American robin, Carolina wren and hermit thrush—are common and present year round in East Tennessee. All are omnivorous ground foragers that eat a number of insects and invertebrates and a wide variety of fruits and berries. The northern mocking bird was not seen feeding at the facility—it was photographed on the ground near a skeletonized body. The American crow was seldom seen at the facility. A crow was once seen perched on a tree limb; and in January 2004, multiple crow tracks were identified in the snow (Elbroch and Marks 2001) next to a raccoon-scavenged body. Corvids are known scavengers that will feed on both insects and soft tissue (e.g., Asamura, et al. 2004; Komar and Beattie 1998; O'Brien 2010). Crows may have slightly modified two corpses in January 2004, but this remains uncertain.

Both Mann and colleagues (1990) and Bass (1997) report that small birds at the Anthropology Research Facility were often seen around bodies feeding on insects, but never on soft tissue. The digital video and still imagery captured in this study largely supports their observations. The small passerines at the facility did not consume soft tissue, but they sometimes plucked at loose tissue.

The Carolina wren was a small, but very active bird around the facility. It's foraging was captured on video. One or more Carolina wrens were seen flying in-and-out of a car trunk (with raised lid) that contained a body in active decay. A wren repeatedly alighted on the trunk floor or atop the corpse, plucked up a maggot in its bill, and then flew off with it still secured between the mandibles. A Carolina wren and a hermit thrush took turns plucking maggots from a body with brown rat soft tissue scavenging (Figure 155). In the process, the Carolina wren twice plucked at a strand of exposed subcutaneous fat and the hermit thrush thrice pulled on a skin flap. Had the wren successfully severed the fat, it probably would have flown off with it. The thrush, however, may have only been trying to disturb any underlying maggots. Bass (1997)



Figure 155. A Carolina wren collecting a maggot off a brown rat-scavenged body. Video still captured on 1 April 2004.

reports that birds may incorporate human head hair into their nests. A Carolina wren's nest was built in the camera housing while the camera was removed for a few days. The fully formed nest was lined with numerous strands of hair from multiple mammals, including more than one human.

American robins were commonly seen at the facility where they foraged for prepupae. They plucked migrating maggots off the ground and pulled them from rock crannies. Robins were photographed with multiple squirming maggots clamped between their mandibles. They foraged alone or in small groups of up to about six birds. Robins never alighted on, or climbed atop, bodies.

In contrast to the American robin, European starlings flocked to bodies. Twenty-four hour video was captured for six weeks and 18 weeks at two bodies placed in the spring and summer, respectively. Starlings flocked to the bodies several times throughout the day; and they returned daily as long as maggot masses were present or larvae were migrating. Starlings are loud, aggressive birds that can mob lawns etc. in large, noisy flocks. The flocks at the facility were small, perhaps three or four dozen in number. Starlings plucked maggots from body crevices or surfaces and off the ground. Their bills caused minimal tissue damage and unraveled previously damaged fabric threads on a clothed body. Their claws sometimes left hairline, superficial scratches and pinpoint pricks in the skin. Further, skin and fabric openings were sometimes slightly enlarged and edges were pushed in by the bill as it probed for maggots just within. Starlings released a great number of white droppings onsite—both on the ground and atop bodies.

In July 2006, a bird was startled out from beneath the black plastic sheeting that covered a body in active decay, having died nine days prior. The bird flew out of site, but was presumed to have been after the late instar maggots feeding on the corpse.

Reptiles and amphibians

Little attention was paid to the reptiles and amphibians at the Anthropology Research Facility. Neither were seen in direct association with human remains. Identified taxa are listed in Table 2, but many species likely went unnoticed. Amphibians feed upon a variety of insects

and many reptiles will eat small animals, as well as insects. The abundant carrion insect fauna at the facility should attract insect-eating species.

Five-lined skinks are diurnal and were abundant at the facility, but they were never seen in direct contact with human remains. Five-lined skinks are essentially terrestrial and eat arthropods, like spiders, crickets and the larvae of beetles and flies (Conant 1975). Skinks in South Africa were sometimes found hiding under drying animal carcasses where they were seen feeding on beetles and occasionally flies (Kelly 2006). More data is needed on their feeding at the facility.

An eastern box turtle was once photographed hiding inside its shell near several bodies, but it vanished a short while later. Box turtles eat both plant and animal matter including a variety of insects. Reed (1958) documents the presence of snapping turtles (*Chelydra serpentina*) and Carolina box turtles (*Terrapene carolina*) at dog carcasses decaying outdoors in East Tennessee. When he examined the stomach contents of one adult box turtle, several adult and larval forms of beetles—clown, rove, carrion, and hide—were found. Other ingested items were a few newly-emerged blowflies, several dog hairs, a distal phalanx, and other undigested matter.

Rat snakes, Genus *Elaphe*, can be spotted inside the facility during the warmer months. These species eat mice, young rats, and small birds: young snakes will also eat lizards and frogs, especially treefrogs (Conant 1975). Garter snakes, Genus *Thamnophis*, eat amphibians, fish, and earthworms; and occasionally, leeches and alive or dead small animals (Conant 1975). Snakes were attracted to the very small animals at the facility. They were never seen on or near human remains.

CONCLUSIONS

This study is the first to use unattended photography at the Anthropology Research Facility. In conjunction with heat-and-motion sensors, primarily nocturnal video and still imagery was obtained of scavengers that modified human remains that decayed at the outdoor research facility. Because of this and diurnal field documentation, much of the bone and soft tissue modifications were attributed to specific scavengers.

Captured imagery showed the northern raccoon was the primary modifier of human remains that decomposed on-site. This little-mentioned scavenger demonstrated feeding behaviors and traces unlike those reported of canids. The following can be said about the northern raccoon:

- The raccoon commonly chewed on human fingers and toes and fed on soft tissue, mostly muscle.
- The raccoon is not attracted to blood; and soft tissue feeding seldom occurred at open wounds.
- The raccoon often fed with the aid of its forepaws.
- The raccoon used its teeth to bite and tear open skin at a particular spot and when it had eaten the immediate tissues, it placed a forelimb or head into the formed cavity to manipulate and detach the underlying soft tissues. Their repeated probing formed an increasingly enlarged, subcircular aperture in the skin, which sometimes became greatly distorted or was obliterated in an extensively scavenged corpse or body region. Upon muscle removal, pulled tendons often lay splayed about joints.
- Indicators of raccoon soft tissue feeding, like canine punctures, were sometimes hidden along rolled under margins or were distorted by late instar maggot mass feeding.
- The raccoon did not disarticulate fleshed remains, but contributed to joint dislocation and skeletal scatter. It was not seen transporting human bone, but it may have moved some individual bones for relatively short distances before abandoning them.

- Raccoon-produced bone modification occurred secondary to soft tissue scavenging, which intensified during the cooler months. Chewed bones of human hands and feet were common. Ribs, vertebrae, and scapulae were sometimes damaged; and long bone ends and shafts were occasionally toothmarked.
- Excluding chewed hands and feet, bone modification—however minor—occurred in roughly 30% of instances of raccoon soft tissue feeding.
- Raccoon scats contained seeds, crustaceans, very small vertebrates, carrion matter, and insects, including fly larvae. Few scats contained probable human bone; and recovered bone fragments were consistent with human ribs and bones of the hands and feet.

Rodents that modified human remains at the facility, included the brown rat, eastern gray squirrel, and white-footed mouse. The following can be said about these rodents:

- The omnivorous brown rat consumed human fat deposits, like subcutaneous fat and yellow bone marrow; and fed on skin and musculoskeletal tissues.
- The brown rat fed on human remains throughout decay. Feeding ceased when soft tissue was absent and bone no longer retained grease. Dry bone was test gnawed.
- The brown rat foraged for insect larvae, including fly prepupae and/or pupae—even likely, soldier fly pupae.
- The largely granivorous gray squirrel gnawed on bone devoid of grease. Test gnawing, i.e., one or two isolated gnawing events, occurred on bone from human remains at the facility that were exposed for less than one year. In these cases, the bone was exposed shortly after death and lay subject to the elements. Persistent gnawing, i.e., multiple gnawing events, was not seen until 1.5 years after death in East Tennessee forensic cases.
- The gray squirrel gnawed only on exposed portions of bone—it did not gnaw on bone covered by leaf fall.
- The omnivorous white-footed mouse gnawed on soft tissue and fresh bone. Dry bone was test gnawed. Minimal bone gnawing was documented at the facility because of this animal's small size and manner of feeding, i.e., brief nibbling events.

- Feeding experiments with captive wild white-footed mice from the facility, showed they commonly consumed fly pupae.

The Virginia opossum is largely a solitary scavenger. Several individuals entered the facility, but no more than one was ever seen in a single frame. The following is true of the Virginia opossum:

- The opossum primarily licked maggots off corpse surfaces.
- The opossum was an ineffectual scavenger of soft tissue—it sometimes fed on soft tissue, but only putrid and decayed tissue was noticeably modified and consumed.
- Instances of opossum-modified soft tissue were only briefly described as feeding by other scavengers obscured a clear signature.
- Opossum scats were odiferous and contained many maggots.

The Anthropology Research Facility attracted vertebrate scavengers as well as insect-eaters. Insect predation by insect-eating small animals, like passerine birds, reptiles, amphibians, shrews, moles, and omnivorous rodents, and the larger opossum and raccoon, helped reduce the carrion-frequenting fly and beetle populations at the thriving outdoor decomposition facility.

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APPENDIX

This appendix provides environmental data including climatological, hydrological and astronomical charts for the years 2003 to 2006. Climatological data was downloaded from the National Climatic Data Center (NCDC) and collected by the National Weather Service station at Knoxville's McGhee-Tyson Airport about 18.1 km (12.25 mi) south of the Anthropology Research Facility. Plotted normal data represents the 30-year interval from 1971 to 2000.

The abbreviations that appear in the following temperature and precipitation charts are defined as follows:

NMAX	normal maximum temperature
NMIN	normal minimum temperature
MMAX	monthly maximum temperature
MMIN	monthly minimum temperature
NPCP	normal precipitation
TPCP	total precipitation (rainfall)
TSNW	total snow (hail, sleet, snow)

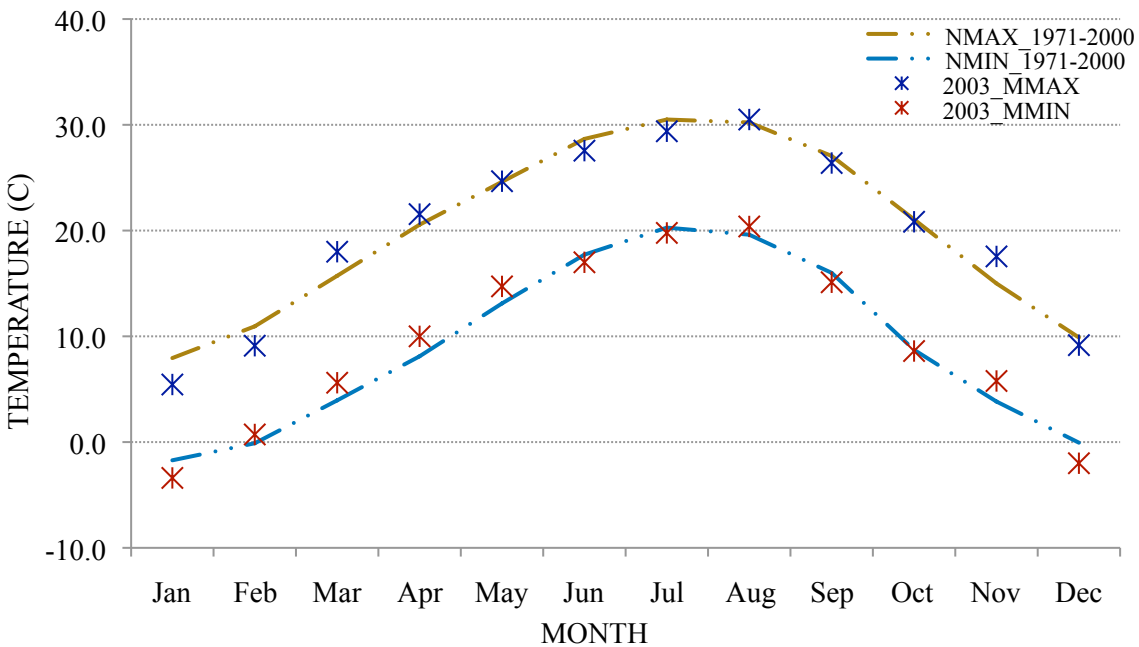


Figure 156. Ambient air temperature by month for the year 2003.

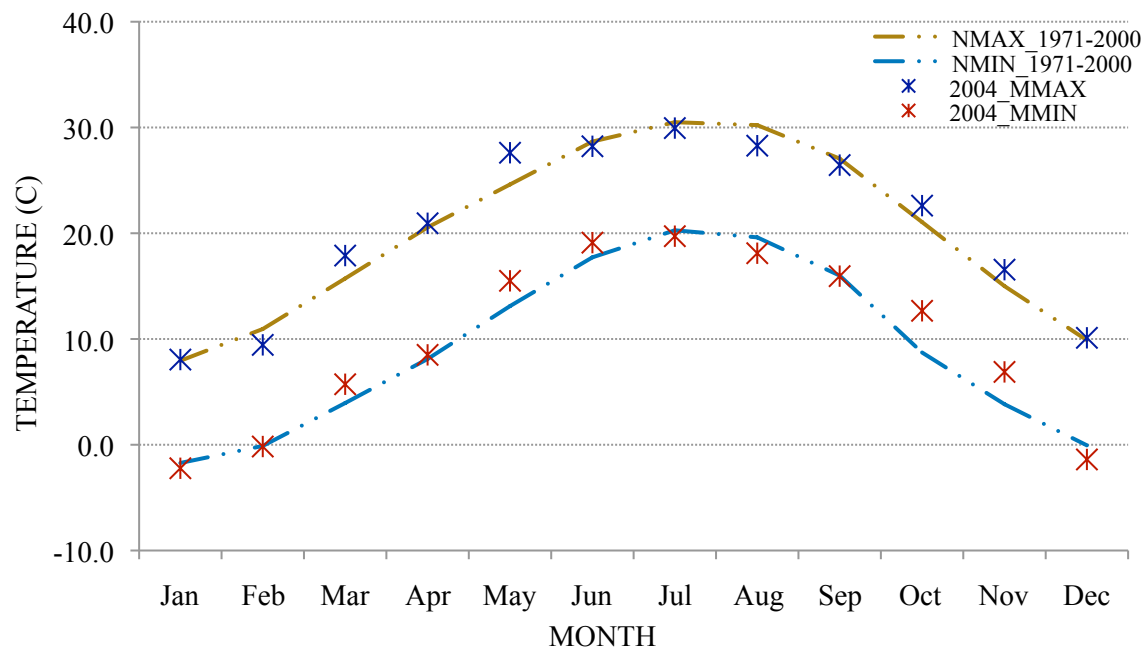


Figure 157. Ambient air temperature by month for the year 2004.

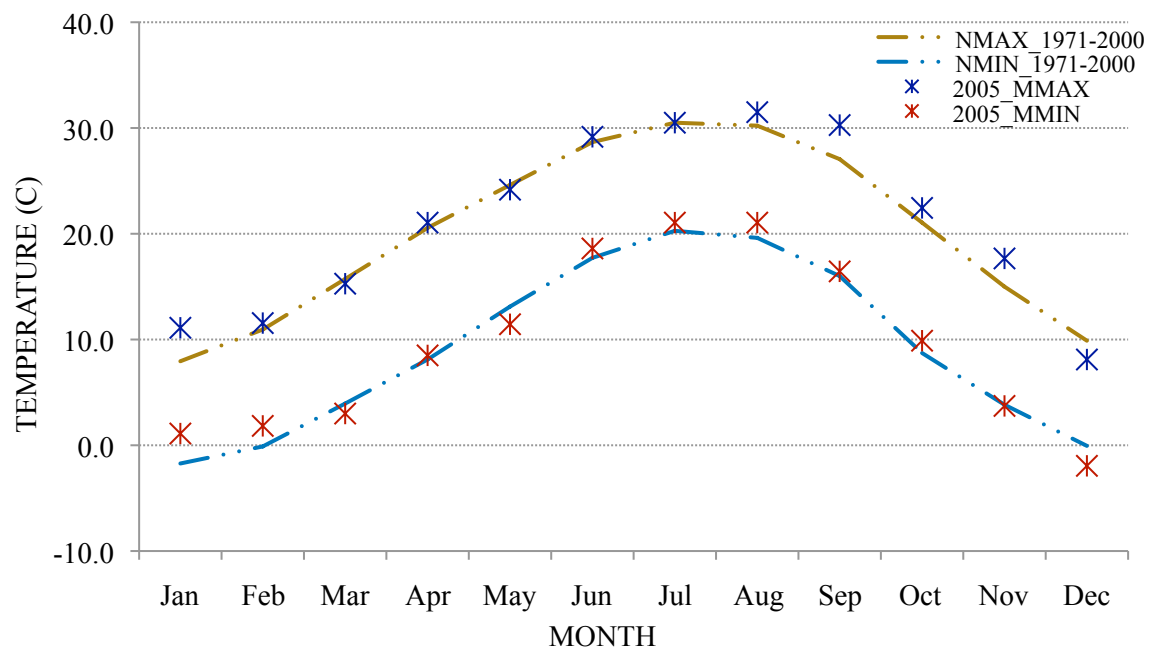


Figure 158. Ambient air temperature by month for the year 2005.

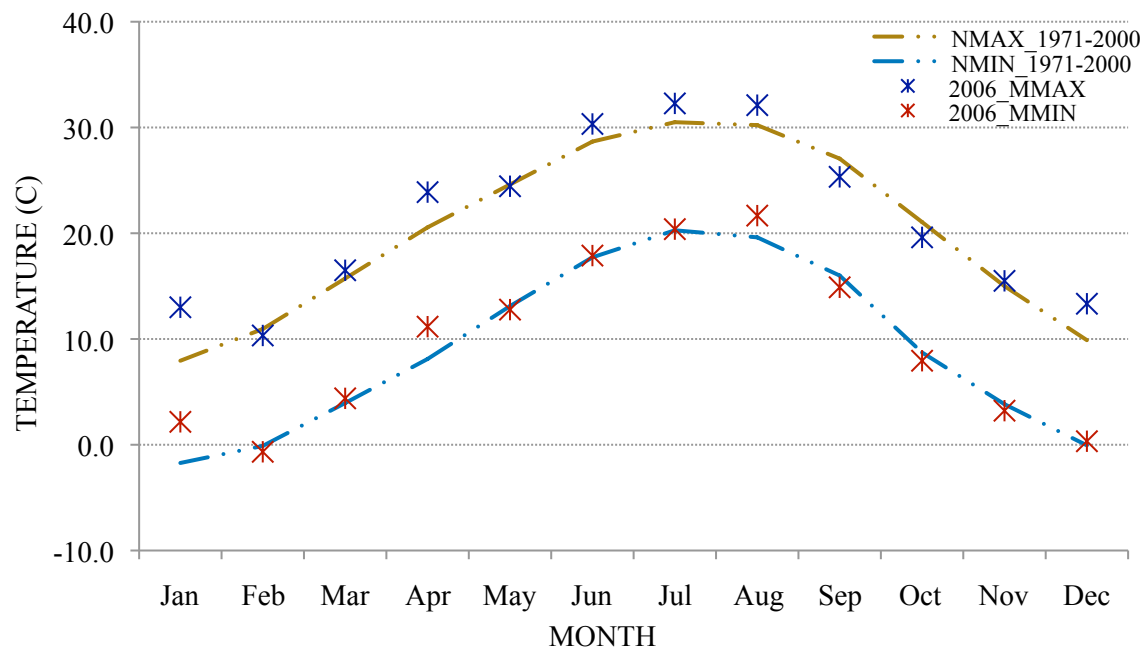


Figure 159. Ambient air temperature by month for the year 2006.

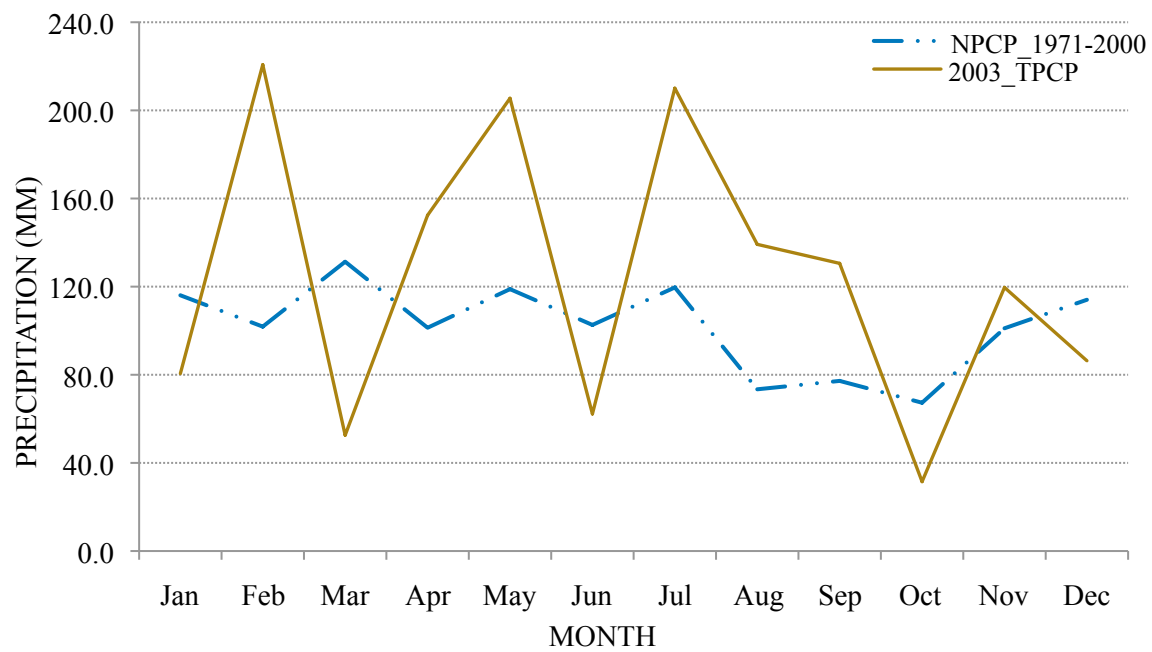


Figure 160. Total precipitation for the year 2003 (snowfall is unavailable).

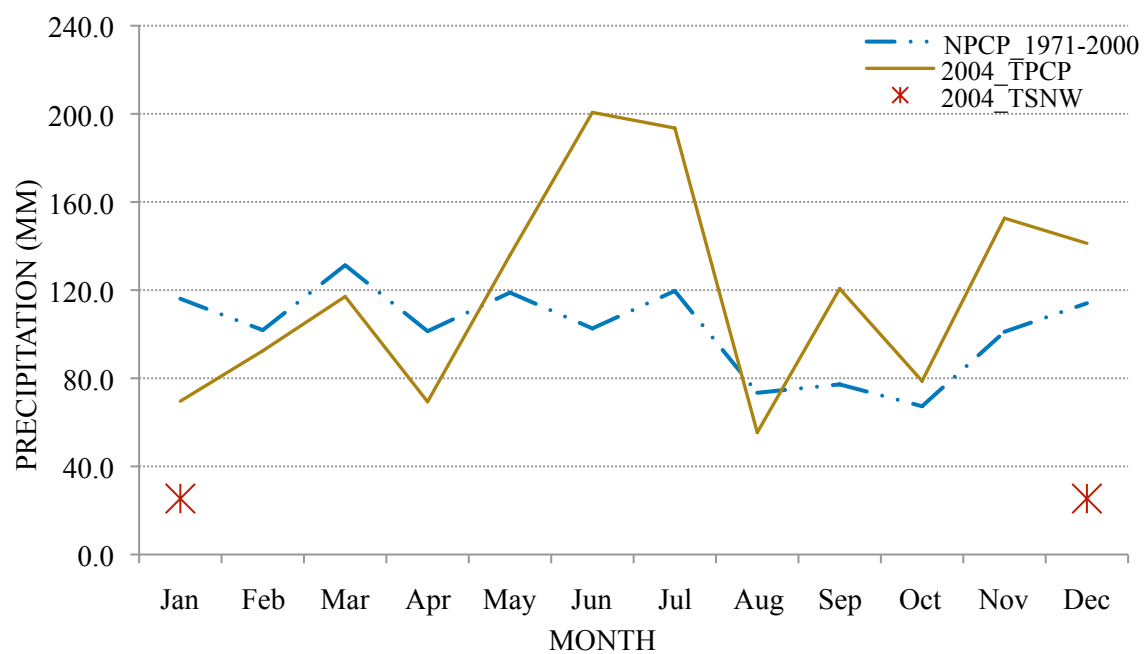


Figure 161. Total precipitation and snowfall for the year 2004.

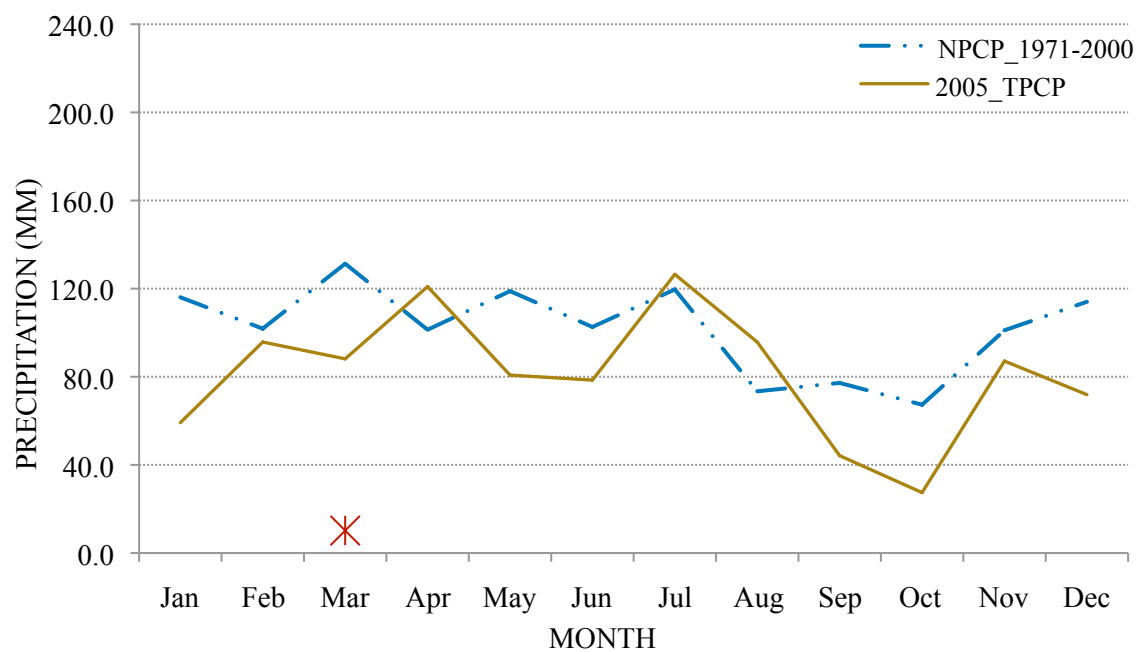


Figure 162. Total precipitation and snowfall for the year 2005.

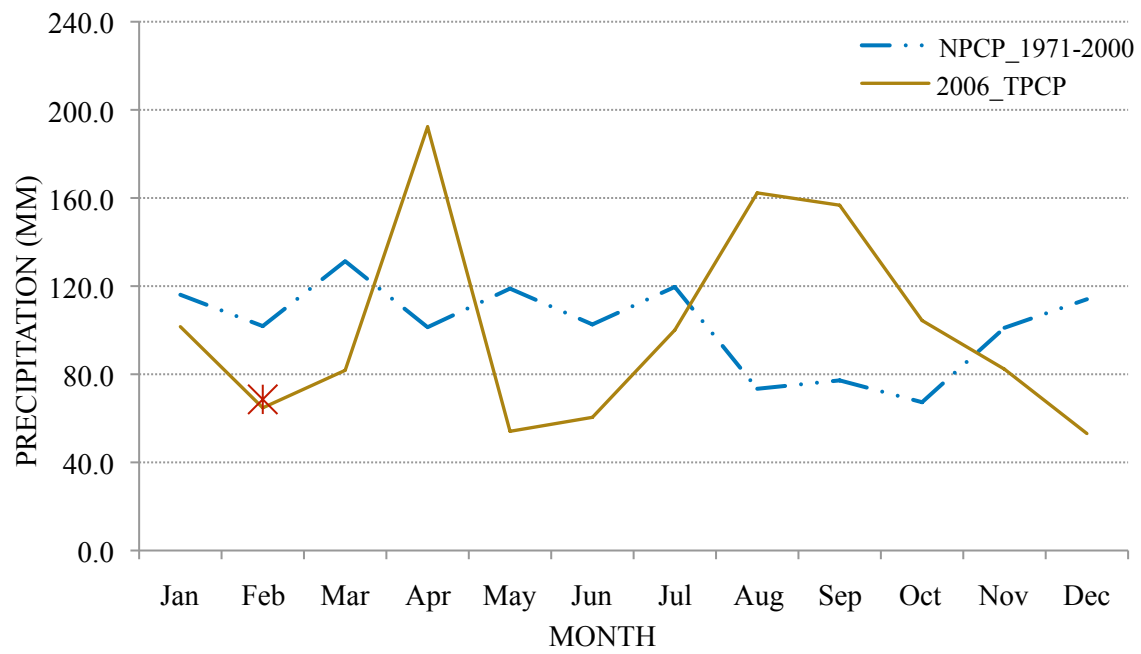


Figure 163. Total precipitation and snowfall for the year 2006.

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