Forensic Science International 266 (2016) 576.e1–576.e6

Contents lists available at ScienceDirect

Forensic Science International

journal homepage: www.elsevier.com/locate/forsciint

Forensic Anthropology Population Data

Postmortem scavenging by the Virginia opossum (*Didelphis virginiana*): Impact on taphonomic assemblages and progression

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ARTICLE INFO

Article history:
Received 19 January 2016
Received in revised form 15 April 2016
Accepted 16 June 2016
Available online 24 June 2016

Keywords:
Forensic science
Forensic anthropology
Accumulated degree days
Bone modification
Post-deposition interval
Skeletal taphonomy

ABSTRACT

The Virginia opossum (*Didelphis virginiana*) is a highly active scavenger whose behavior has significant impacts on rates of decomposition and skeletonization, which have previously not been addressed. In this study, scavenging by the opossum led to the skeletonization of carcasses in half of the accumulated degree days (ADD) of a comparable non-scavenged control carcass. Opossums used body orifices, as well as natural tears caused by the decomposition process, to access internal tissues and consume them. This activity resulted in little movement of the carcass and the retained appearance of natural undisturbed decomposition. This concealed activity has the potential to cause drastically incorrect estimates of time since deposition and post-mortem interval. Scavenging by opossums was also found to leave distinct tooth mark and other defects on bone, which have not been previously distinguished in the literature. This research suggests, beyond effects on PMI, that scavenging by opossums has been historically overlooked and misattributed to canid scavengers.

1. Introduction

Scavenging by vertebrates is recognized as impacting forensically important factors such as rate of decomposition, dispersal of remains, recoverability of remains, the ability to properly identify remains, and the differential diagnosis of trauma on remains [1–5]. Many species of scavengers have been identified and their associated taphonomic impacts have been illustrated. For example, scavenging behaviors of domestic and wild canids, as well as rodent modification, have been described in some detail, particularly in the Pacific northwestern United States [1–3,6,7]. The Virginia opossum (*Didelphis virginiana*), although having been recognized as a scavenger of remains [3,4], has received very little taphonomic consideration. A recent study of scavenger guilds in north central Oklahoma suggests that the opossum partakes in frequent scavenging activity, which may have significant implications to forensic investigations, both in terms of estimations of post-deposition and post-mortem intervals, as well as the differential diagnosis of trauma, injury patterns, and artifacts from other scavengers.

The Virginia opossum is distributed in large numbers throughout the central and eastern United States, and the western coastal states of California, Oregon, and Washington [8]. Its range has slowly expanded into the other western states and it has recently been found in Arizona [9]. Adults are, on average, 2–3 kg in size [8]. The opossum is the only marsupial species in North America. Having an opposable hallux, as well as prehensile tail, renders it a highly adaptable forager [8]. Opossums have a diverse opportunistic diet, consisting of considerably high percentages of carrion and insects [8]. The opossum does exceedingly well in habitat that is encroached upon and fragmented by human activity. Under such conditions the opossum becomes a major suburban scavenger and carrion recycler [10]. An understanding of how opossums utilize remains, what impact they have on the condition of those remains, and what taphonomic artifacts they leave behind are significant to death investigations, particularly in metropolitan and semi-urban areas.

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http://dx.doi.org/10.1016/j.forsciint.2016.06.021
0379-0738/

2. Materials and methods

2.1. Site location

This study was conducted at the Oklahoma Department of Wildlife Conservation's, 226.6 ha Arcadia Conservation Education Area, in north central Oklahoma (35.625424 N, −97.381582 W). The preserve covers a mix of riverine habitat, mixed grassland prairie, and cross-timbers [11]. This diverse landscape provides habitat for a wide variety of mammalian species including large predators and mesopredators, as well as small omnivores, avian and reptile species [11]. Public access is allowed to the area for hiking and fishing year round. Hunting access is limited to a small number of archery deer permits annually and no other hunting or trapping is allowed. The preserve is surrounded by suburban residential housing, with the closest housing to the carcass drop location being 0.54 km to the southeast, and is in close proximity to the greater Oklahoma City metropolitan area.

2.2. Specimens

Domestic pig (*Sus scrofa*) carcasses were used as analogs to human remains, as has been established in previous forensic scavenging and taphonomy studies [4,5,12,14]. Three pig carcasses were used for each of the experiments. The specimens were obtained from the University of Oklahoma, College of Medicine, the Oklahoma State University, Swine Research Center, and from donations by a local farmer. Carcasses obtained from the University of Oklahoma were used previously for endoscopic surgical curricula at the college, and were euthanized by anesthesia. Carcasses obtained from the Oklahoma State University Swine Research Center were natural deaths. The donated carcasses were euthanized by .22 caliber rifle shot to the crania due to illness. The project was conducted under the University of Central Oklahoma IACUC authorization #7008, #7009.

2.3. Experiments

Three experimental series were conducted from October 2012 through March 2014. Three carcasses were placed for each of the experiments. Each carcass was individually numbered for experimental reference. Carcasses were kept on ice during transport and temporary storage, and were placed at field sites within 24 h of being obtained. In each experiment, a carcass was placed within an animal proof wire cage (1.5 m × 1 m × 0.5 m), which consisted of a metal frame covered with a thin wire mesh [5,13], to serve as a control. For each experiment, a second carcass was placed undisturbed directly on the ground and left exposed. A third carcass, was modified to allow for the implantation of radio transmitters (Wildlife Materials, Inc. SOPI) into medullary cavities of long bones in order to find their location if moved from the deposition site.

2.4. Data collection and analysis

The study site was monitored continuously throughout the experiment period by both electronic surveillance and regular site visits. Carcasses were monitored with battery powered motion triggered trail/game cameras (Moultrie GameSpy I-85) with infrared flashes [5,12,15], and a Digital Video Recorder (DVR) system with cameras that captured video 24 h a day [4,12,13]. All of the cameras were moved as needed to ensure that carcasses remained in view and that quality video and photo data was collected.

The site was visited every other day at the beginning of each experiment, with the frequency tapering off to weekly visits as the movement and usage of the carcass diminished or stopped completely. At each visit the carcasses were photographed and any changes in the condition of the carcasses were noted. Changes in orientation and movement of elements from the previous visit were also recorded.

Activity tables were created, based on video data of scavenger visit times for all experiments, which charted species, visit time, and sunrise and sunset. Skeletal elements were examined for taphonomic indicators of scavenger activity. Temperature and humidity data were collected using Tinytag© Plus 2 data loggers. The data loggers recorded temperature and relative humidity measurements at 15 min intervals throughout a 24 h period. Average daily temperature was calculated from the interval temperature data and used to calculate accumulated degree days (ADD) for all experiments [16]. ADD measures the amount of heat loading on the carcass during the decomposition process by using the sum of average daily temperatures from the time of death until discovery. This allows for standardization and cross comparability between regional and seasonal studies. Total body score (TBS) was also calculated using the scoring system established by Megyesi et al. [16]. TBS is a standardized measure of taphonomic progression that is assessed by scoring the body in three regions: the limbs, trunk, and head and neck. Each region is assigned a number on a scale of fresh to dry bone, and then each score is combined for a total score ranging from 3 (completely fresh) to 35 (dry skeletonization).

Collected data was used to evaluate temporal distinctions and patterns in scavenging behavior. These included discernable patterns in carrion visit time, carcass usage, and subsequent remains' displacement. Actions such as grooming in proximity to the carcass after feeding were included in total visit duration. Patterns were evaluated for their ecological significance and usefulness in informing forensic death investigations and searches for remains.

3. Results

Virginia opossums were the most common scavenger seen visiting the carcasses with 188 distinct events captured on digital video or photograph, which is 70% of the total mammalian scavenger visits. Visits were defined by an animal coming into view of the camera, partaking in a scavenging related activity at the carcass, such as feeding or cleaning, and then leaving the view of the cameras. The overwhelming frequency of opossum visits stands in stark contrast to the visit frequency of other mammalian scavengers observed throughout the experiment period. Bobcats (*Lynx rufus*) were observed on digital video or photograph feeding at carcasses only 31 times (11% of total visits) and coyotes (*Canis latrans*) 51 times (19% of total visits). Opossums were observed scavenging at 6 of the available carcasses, coyotes at 7, and bobcats at only 2. The two carcasses which were not scavenged by opossums were removed from the area by coyotes within a few days of placement and were available the least amount of time.

Average opossum visit duration was highest in the first experiment with 15.34 min per feeding event. It was lowest in the third experiment at 4.6 min per visit, where average daily temperature was highest. While this implied some relationship between activity and temperature, it was not of statistical significance.

Opossums scavenged at predictable times of the day and were almost exclusively nocturnal except for a single visit that was recorded at sunrise. This pattern persisted over the course of all seasons. Opossums were observed scavenging during all seasons of the experiment, and showed no distinct seasonal preference (Fig. 1).

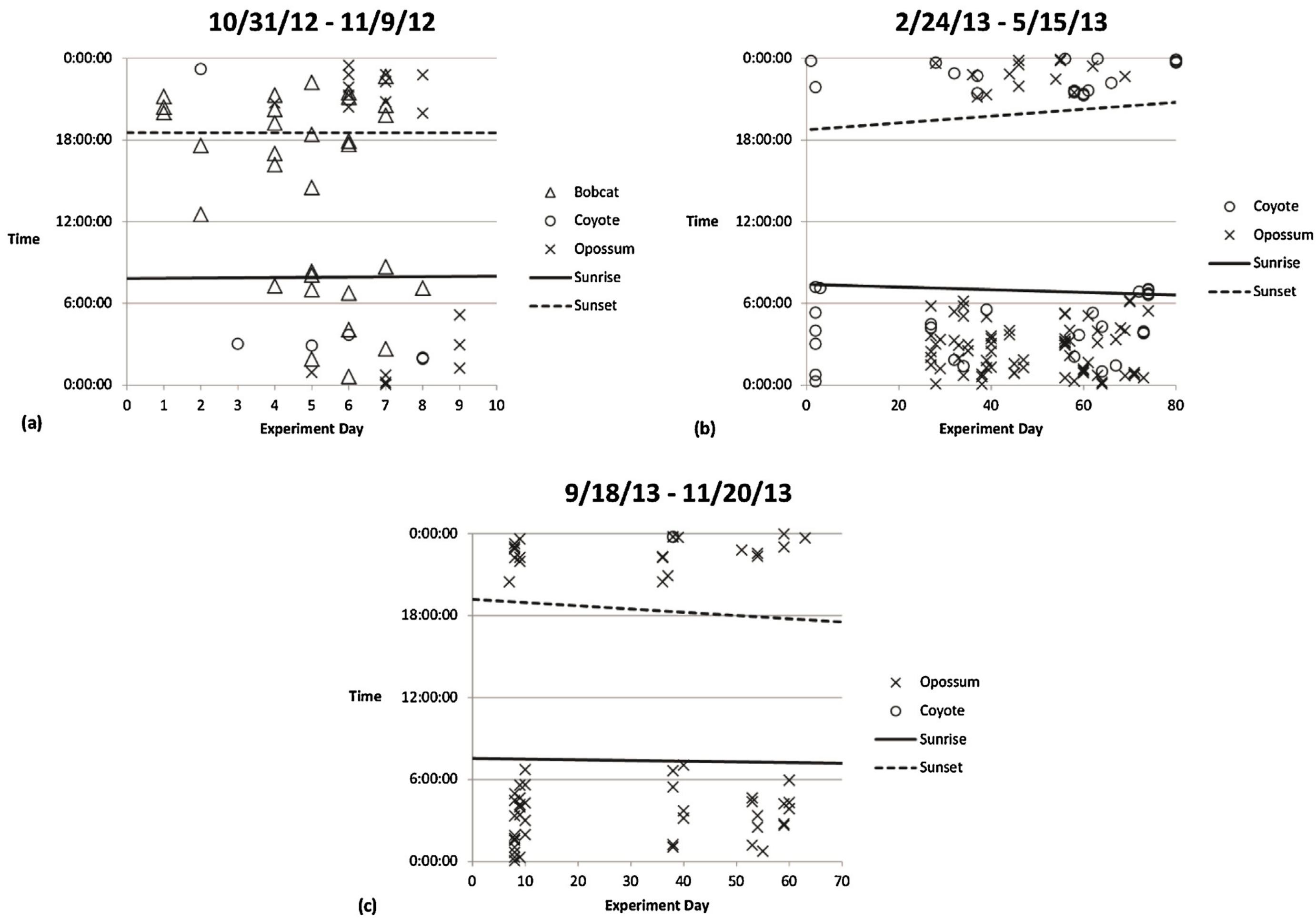

Fig. 1. Scavenger visits for all experiments by species, experiment day and time. (a) Fall, (b) winter, & (c) summer, with sunrise and sunset lines derived from the Oklahoma Department of Wildlife's sunrise/sunset data table www.wildlifedepartment.com.

Opossums fed mostly on fresh carcass viscera. They accessed internal tissues through natural orifices, such as the anus and tears in the abdomen caused by decomposition. They did not make their own entry locations or primary wounds. This is in contrast to other scavenger guild members (coyotes and bobcats), who facilitated tissue access by integumentary cutting and tearing. The utilization of these natural orifices disrupted carrion fly activity and larva production via spatial competition for the same locations of entry that the insects utilize to lay eggs. Preference for these sites for oviposition have been described elsewhere [17]. Additionally, opossum scavenging activities at these sites disrupted and dislodged existing masses of insect eggs. It is well documented that insect activity highly influences the rate of decomposition [18]. This disturbance of insect activity contributed to longer fresh stage duration, and subsequently promoted scavenging by other vertebrate species. However, opossum activity did not completely prevent insect colonization.

Opossum activity decreased when carcasses were heavily infested by insect larvae. Scavenging by the opossum resumed when carcasses were in advanced decay with minimal insect activity. In these later phases, opossums fed primarily on skin and bone. They were highly destructive to small bones, feeding readily on elements of the hands and feet, ribs, and edges of flat bones, such as the pelvis, scapula, and ramus of the mandible. Opossums were noted to cache small elements (vertebrae, ribs, and parts of the pelvis) under a tree in a hollowed out portion of the trunk about a meter directly south of carcass 3–1.

Carcasses scavenged solely by opossums were minimally scattered (Fig. 2). Many skeletal elements were left in position at the primary deposition site, similar to a pattern of undisturbed decomposition. Scattered recoverable elements were within 10 m of the original deposition site, as compared to elements scattered by coyote scavenging, which were moved as far as a 0.5 km away.

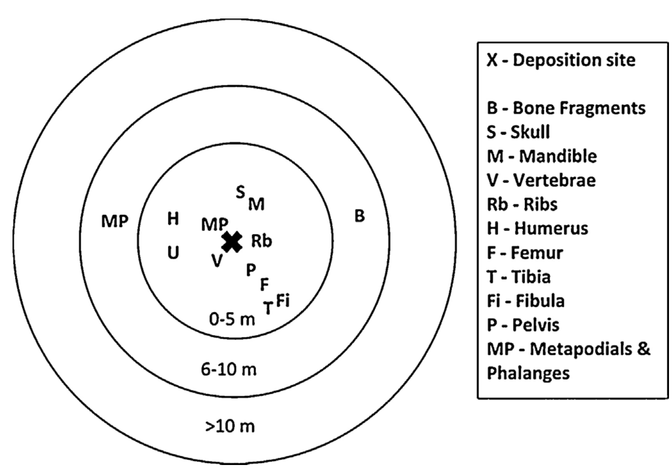

Fig. 2. Radial distribution diagram of skeletal elements at final collection for carcass 3–1, scavenged only by *D. virginiana*. Summer season.

Two of the carcasses in the experiment were scavenged solely by opossums prior to skeletonization. Carcass 1–1, which was intended to be the first control specimen and was contained in a wire mesh cage, was infiltrated 13 days after initial placement. However, the cage prevented entry by larger vertebrate scavengers, allowing for comparison of opossum only scavenging to that of the other species observed. This carcass, as well as carcass 3–1 (which was available to other scavengers but only visited by an opossum prior to skeletonization) showed a large difference in ADD to skeletonization when compared to that of the undisturbed control. These two carcasses reached a total body score (TBS) of 29 (which indicates overall skeletonization with still greasy bones and some mummified tissue, on a scale that terminates with completely dry bones and a score of 35) in less than half of the ADD of the non-scavenged control (Fig. 3).

Scavenging by the opossum produced identifiable taphonomic indicators and observable markings on skeletal remains. Ribs of carcass 1–1, displayed a pattern of splintered and fractured ends (Fig. 4). The right scapula had gnaw-marks and punctures along the medial border (Fig. 5), as well as punctures on the acromion and spine. The right mandibular condyle was also chewed and missing.

4. Discussion

The high frequency of scavenging by Virginia opossums on the carcasses in all seasons indicates that these mammals are prolific scavengers in semi-urban cross-timbers environments. The existing biological and ecological literature supports these findings and suggests that the opossum is a highly active scavenger in many habitats. However, the opossum has not historically been observed in these frequencies in forensic scavenging studies. The likely explanation for the discontinuity lies in the specific traits inherent in opossum carrion feeding. The opossum likely scavenged remains in previous forensic studies, but went undetected due to unique patterns in carrion tissue access, limited remains disturbance and movement, and the similarity of their feeding artifacts to that of canids, as well as limitations on their detection by motion triggered cameras. Game cameras in this study often failed to capture activity of animals close to the ground, especially after dark. They were also triggered less often by small bodied animals. Even medium sized bobcats were able to move in the area of the game cameras without triggering their action. These cameras are designed to capture larger game, like deer and the IR sensors may not be sensitive enough to be triggered by smaller animals. Mice (*Mus sp.*) in the vicinity of the carcasses were seen on the DVR but not on the game cameras. The use of the DVR allowed for better capture of these animals' activities, without a reliance on a motion triggered mechanism to activate recording. The other study that captured extensive opossum scavenging also utilized video recording in conjunction with still cameras [4].

The opossum has been observed previously to cause limited disarticulation of skeletal elements [4]. During this study, the opossum was observed multiple times dismembering feet. These were also the most common elements that were subsequently dispersed by the opossum or completely consumed. These elements tended to be consumed late in the decay cycle during the second phase of scavenging. This is an important factor when estimating time since deposition. Missing skeletal elements, such as the hands and feet, in situations devoid of canid scavenging, can indicate lengthy post deposition intervals. Dismemberment due to canid activity tends to occur soon after deposition. The timing of carcass acquisition by the opossum mimics the canid pattern, but occurs much later.

The opossum fed on carrion from the inside out removing organs and viscera, then tissue and skeletal muscle, followed by integument and finally bone. The opossum, in contrast to the other mammalian scavengers, rarely gained access to internal soft tissue by creating wounds in the outer skin. This mimicked natural decomposition sequences of skin tearing and deflation following carcass bloating. Similarities in the carcasses' condition between scavenging by opossums and naturally occurring late stage decomposition holds significance to forensic investigations. Without careful examination, the presence of opossum scavenging may go undetected and contribute to overly lengthy post-mortem interval estimations.

This is especially true if using an ADD/body score model for assessing decomposition rates and stages. For example, using data derived from this study, employing an observed TBS of 29 and utilizing the equation derived by Megyesi et al. [16] ($ADD = 10^{(.002*TBS*TBS+1.81)} \pm 388.16$) the estimated ADD would be derived at 3104.5 ± 388.16 degree days. In actuality, the TBS of 29 was achieved at 575 and 656 degree days respectively. This vast discrepancy has major implications for forensic investigations, and as such careful consideration of the impact of opossum scavenging in

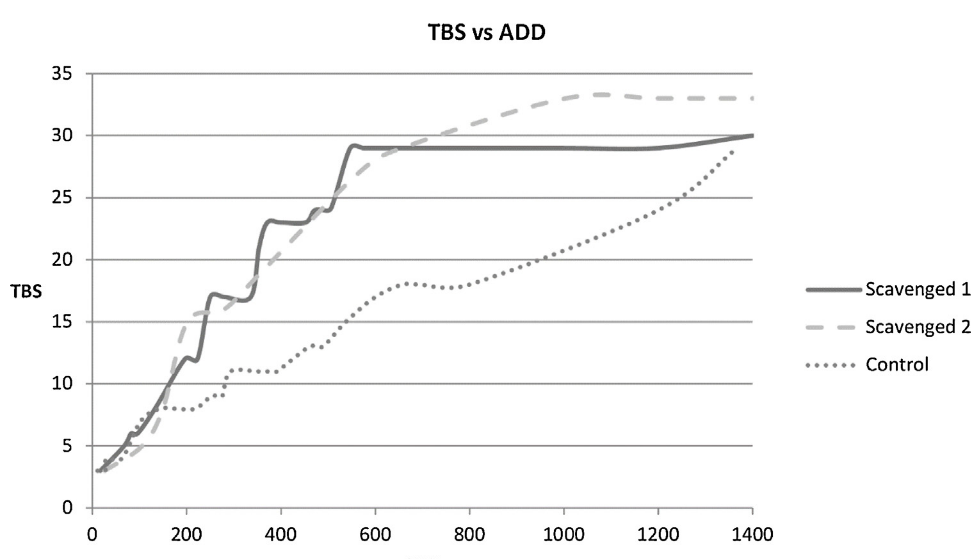

Fig. 3. TBS vs ADD for two of the experiment carcasses scavenged by opossums only compared to a single non-scavenged control carcass.

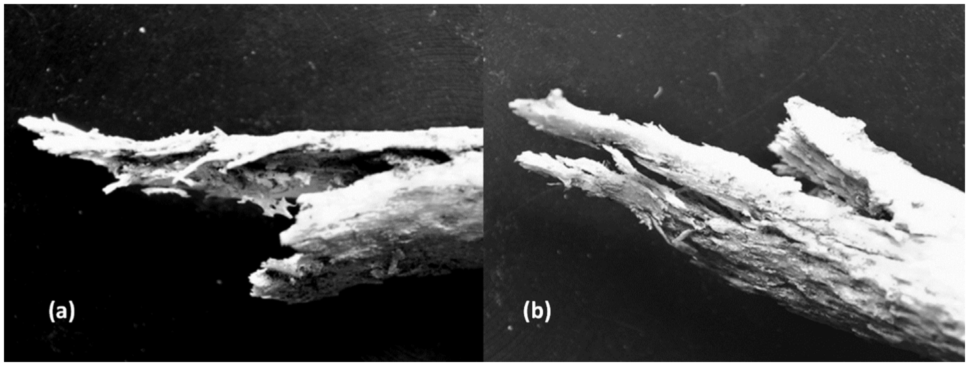

Fig. 4. Costal rib end from carcass 1–1, with extensive splintering from opossum scavenging, (a) anterior view, (b) posterior view, enhanced under 400 nm UV light.

taphonomic ADD calculations is warranted. Similar issues were found with using ADD and body scoring in aquatic environments due to the formation of adipocere and animal activity [21].

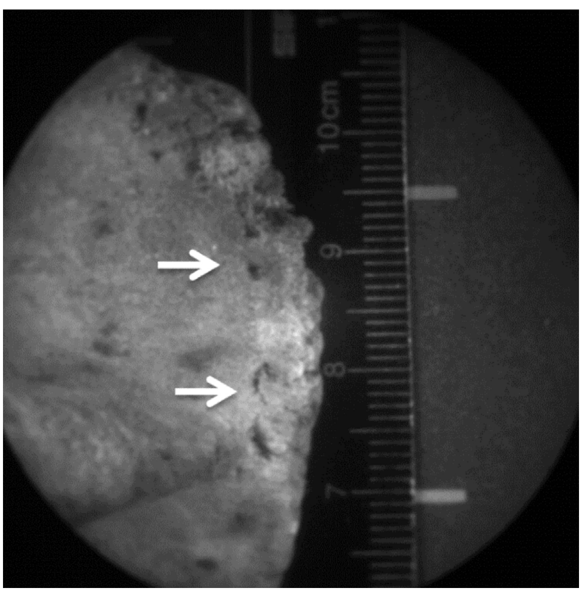

Fig. 5. Punctures and tooth mark defects on scapula of 1–1 from opossum chewing, enhanced under 400 nm UV light.

Seasonal variation may have additionally contributed to this difference. It has been noted that seasonal differences contribute to overall ADD, and that this method does not completely standardize the measurement of decomposition [19]. These findings additionally contrast with other research which showed no difference in decomposition rate between disturbed and undisturbed remains [20]. However, in this case the remains are not only being disturbed, but consumed. It is difficult to separate tissue loss from decomposition with tissue loss from consumption, we can only observe the end result. Future research may be able to isolate and account for the degree to which each of these factors contribute to the overall rate of decomposition.

Opossum scavenging, like that of other species, leaves unique tooth mark defects on skeletal elements which may be confused with that of another contemporaneous scavenger: the coyote. Distinguishing between the two is important when considering time since deposition as they access the carcass in different ways at different times. One distinct difference in the morphology of bite mark defects caused by opossum scavenging as opposed to coyote scavenging is the pattern of breakage seen in rib end fractures. In the case of opossum scavenging, rib ends are frayed and splintered. The ends splay outward and are split along the length of the rib. Whereas with coyote scavenging there is crushing of the rib ends and the breaks are more perpendicular to the bone (Fig. 6). There are also more rectangular shaped crushing type breaks. In some instances, as in the rib shown, the edges of ribs are completely sheared off.

This difference may originate from the way that the opossum is able to hold ribs with its opposable hallux. In both this study, and

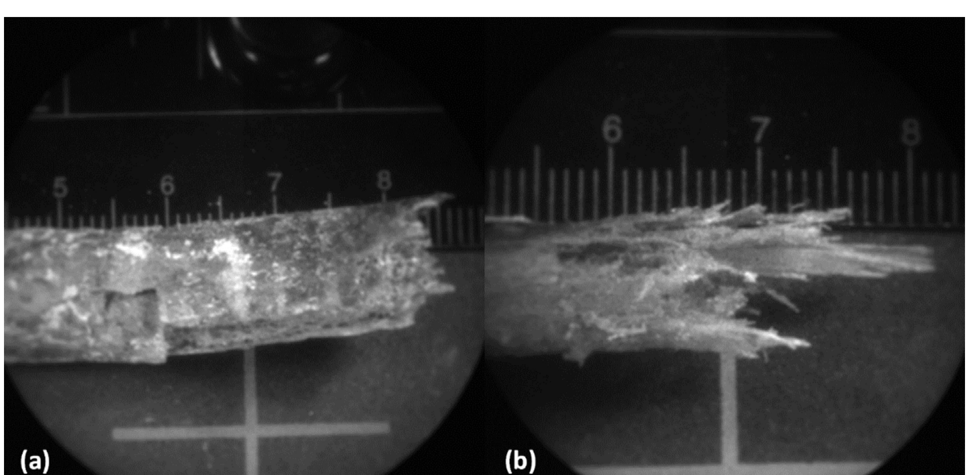

Fig. 6. Comparison of rib ends chewed by coyote (a) and opossum (b); enhanced under 400 nm UV light.

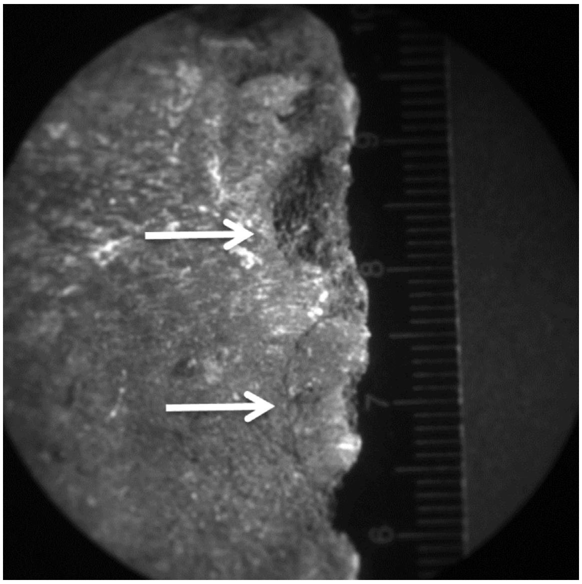

Fig. 7. Tooth mark defects on scapula of 2–2 from coyote scavenging; 400 nm UV light.

that of Morton and Lord [4] the opossum was observed holding ribs and chewing on rib ends. The opossum was observed twisting the rib while chewing on it as well as pulling it through its teeth. This biomechanical motion is very different than the manner in which a canid must leverage a bone in order to hold it steady and chew on it, resulting in a crushing downward force that leaves a different range of defects and more square fractures.

Similar puncture wounds were left by both species on the margins of the scapula and along the spine and acromion by their canines. These could be distinguished by their size. Punctures left by the opossum were 1–2 mm in diameter on average and were superficially deep. Those left by the coyote were larger than 2 mm and 1–2 mm deep. A survey of coyote and opossum dentition from the University of Central Oklahoma's skeletal collection showed a clear differentiation in the size of adult opossum and coyote canines, which corresponds to the difference in bite mark size.

Alongside the puncture wounds in both cases were depressed square-ish defects that likely correspond to premolar and/or molar cusps. Again these were smaller in size on the opossum scavenged scapula compared to those on the coyote scavenged scapula (Fig. 7). The defects caused by coyote molars and premolars are almost twice as large.

5. Conclusions

The opossum is an overlooked, forensically significant scavenger, which leaves taphonomically distinct indicators that are important and useful for forensic investigations. Scavenging by the opossum drastically increased the rate of decomposition and lowered time to skeletonization. Using current techniques, if signs of opossum scavenging are overlooked, post-deposition/post-mortem intervals may be significantly overestimated. More research is needed in order to create workable models to estimate time since deposition which can account for animal scavenging and the degree to which it contributes to accelerating the rate to skeletonization.

Due to its widespread distribution, and large population within the United States, it is essential that the necrophagus scavenging behavior of the opossum be considered in cases of exposed remains. The opossum was observed to feed heavily on remains without altering body position or location. Because feeding behaviors did not leave externally obvious markings such as bite or claw marks on soft tissue, their presence was often difficult to detect. Minute soft-tissue disturbances, which were only noticeable upon careful remains examination, were often present. Opossum scavenging leaves more distinct tell-tale taphonomic defects on skeletal elements, which can also inform forensic investigations. These defects are important to recognize in terms of differential diagnosis from various forms of trauma, and they also serve to help illuminate the timeline since deposition.

Acknowledgements

This project was funded by the University of Oklahoma, Office of Research and Grants, and the Forensic Science Foundation, Jan Bashinski Grant. We are grateful to the Oklahoma Department of Wildlife Conservation, especially Daniel Griffith and Damon Springer for providing access to the research site. We are also appreciative of Kimberly Watson and Amy Waters for aiding in searches and collections that were essential to this project.

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