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Analysis and Observation of Decomposition of Immature Pigs in the Minnesota Winter/Early Spring

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ANALYSIS AND OBSERVATION OF DECOMPOSITION OF IMMATURE PIGS IN THE MINNESOTA WINTER/EARLY SPRING.

BY

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ABSTRACT

This study analyzes the multiple factors affecting the decomposition of pigs in the Minnesota Winter/Early Spring within the first twelve weeks postmortem. The winters in the Minnesota River Valley can vary in regard to weather patterns and temperature changes. Adding the variable of location and accessibility to the study creates a mix of important research conducted in a less populated area. Pig carcasses were used in lieu of human remains to allow the data to be as close to a real scenario as possible. One pig was placed next to a farm site and the other about a half of a mile away next to a river. The second pig was scavenged by animals two weeks into the 60 days and therefore was replaced a few days later with a larger pig. This experiment was conducted from late January to early April. Quantifying the taphonomic effects and changes that occurred was one of the main methods used to analyze the data. The decomposition results show a correlation between the presence of precipitation, dips in humidity, and temperature to a slower rate of decomposition. A significant feature of this thesis is the result that the pig placed in a less populated area next to a river exhibited more advanced decomposition due to animal scavenging. Another noteworthy feature is that insects did not make an appearance until the twelfth week of data collection in early April. According to these results, the freeze thaw cycle has an observable effect on the rate of decomposition; the level of accessibility for animals also figured significantly in the rate of decomposition seen in this study.

Introduction

Research on the human body is a critical aspect of more than just the medical community. The use of animal models in place of human remains for the benefit of research, and to gain knowledge of multiple different topics, has been practiced for decades. Due to ethical and legal reasons human remains are both restricted and regulated for medical research, so animal remains are often used in their place. Animal models are used for a wide range of scientific experiments and endeavors due to the ease of accessibility, and their affordability. Matuszweski writes, "In a similar way, our current understanding of animal decomposition is largely derived from experiments with non-human cadavers, with pig carcasses contributing overwhelmingly to this knowledge" (2019). In earlier studies, pigs have closely resembled human remains in terms of timescales in decomposition over seasons. The first use of pigs involved the role of arthropods in decomposition and much of the later research using pig samples and models also leans in that direction.

A study conducted by Geissenberger (2021) found that it is difficult to experiment on human cadavers, which in turn leads to difficulties in standardizing methods; animals are therefore often the preferred option. Pigs have proven to be “the best choice for human proxies in forensic research purposes, not only due to easy access to these animals, but also due to their similarity to humans regarding size, body composition, skin coverage with hair, gut microbiota, and more" (Geissenberger 2021). Pigs are easily accessible and are widely popular in forensic research, however, the recent creation of forensic and taphonomic facilities utilizing human cadavers remains the preferred method

in most cases. Comparative studies, however, have found that insect fauna utilization is largely similar in both pig and human cadavers. It should be noted, however, that pigs and humans are not the same so there may be differences which may lead to misinterpretations. It is also important to include that there are some nutrient differences and biogeochemical responses that are dependent on the location and samples used. My main research question will, however, focus on the freeze thaw cycle, weather data, accessibility, and the impact these factors have on decomposition specifically in Minnesota.

Literature Review

Cold Weather

Decomposition occurs over time and can be altered by multiple different variables. Temperature, times, accessibility, location, scavenging, and insects all have an opportunity to change the outcome of decomposition. Many different professions rely on the study of taphonomy or decomposition to determine things like the PMI (Postmortem Interval), or time of death. Some of these changes occur microscopically through the breakdown of cells, causing gases to be released and the decomposition process to commence. Bemelmans, and colleagues (2022) found that when the advanced stages of decomposition occur the abdominal wall will rupture, and the abdomen will cave in, allowing these compounds to be released. This observation will add to the stages of decomposition that will be observed by the naked eye for over 60 days.

The postmortem interval (PMI) “refers to the time between the death and discovery of a corpse” (Amendt et al., 2011). Multiple different factors affect PMI. A paper from Mata-Tutor (2021) notes that extreme temperatures can alter evidence. Extreme heat increases the rate of decomposition, however, extreme cold can alter evidence as well or extend the stages of decomposition well beyond the reported intervals. That is why it is essential to document the extent cold weather can affect decomposition of both flesh and bone.

Past research suggests that using pigs in place of human remains produces similar results. Nguyen (2012) mentions that porcine organs are approximately the same size as human organs and have similar internal structures. In the article it was found that porcine organs used in crash test simulations showed that thawing of the organs can significantly change some mechanical properties of certain tissues. In some instances, the freezing process can lead to possible autolysis after the thawing process. This finding supports the possibility that the decomposition process may speed up as the fetal pigs freeze and thaw over the Minnesota winter. Another aspect of this article states that "decomposition had a large impact on circumferential samples of porcine sigmoid and rectum, which becomes stiffer whereas the effect on longitudinal samples seems to be smaller” (Nguyễn et al., 201); this supports the idea that decomposition occurs differentially and at a faster rate in particular orifices and organs.

There is some conflicting research on the differences and impact that a frozen or thawed carcasses may express during decomposition. Micozzi (1986) found that when frozen the samples decomposed from the outside-in rather than inside-out. However,

more recent studies from Bugajski and Stokes (2008) show that being frozen makes no difference in the sample's decomposition. On the other hand, Roberts and Dabbs (2015) found that during the process the survival rate of bacteria in animal cells and the microorganisms living within and on the animal lessens when frozen. However, this does not mean that all bacteria are gone or completely frozen. Regarding this research project, the pig samples arrived frozen and traveled a distance in cold temperatures in the Midwest. Within the same study it was mentioned that "for example, accidental, natural, or intentional deaths occurring outdoors may result in individuals experiencing freeze-thaw cycles with circadian or seasonal temperature fluctuations" (Roberts, Dabbs, 2015). The pig samples were frozen on arrival and then experienced further freezing temperatures outdoors. This closely simulates real-life cases where human remains are found during below-freezing temperatures.

A case study conducted in Indiana by Bugajski in 2011 found that there was no major difference between refrigerated and frozen pig carcasses regarding the arrival time and presence of flies and beetles. The pig sample being frozen for two months did not change or alter the life events of blow flies or beetles that attended it. Therefore there is little to no difference in starting a project with a frozen or refrigerated sample before thawing. However, as previously stated and referenced by Micozzi (1986), there is a slight difference between thawed and frozen samples when beginning research before the initial thaw.

Weather and temperature can play a major role in the decomposition of fetal pigs. Wind and rain can change the attractiveness that decomposition may have for flies.

Chemicals in the air can be dispersed so flies may not have a chance to discover a body right away. The pigs are placed out in the natural environment and will be exposed to all temperature changes and weather patterns. Hwang and Turner (2005) mention how "temperature is an important factor in determining the catches of flies, especially in winter. Low temperatures not only reduce the flying activity but also the release of stimuli". Even when habitats are in different areas and accessibility differs, insect activity is less than what would occur in the summer months.

One possible outcome of this study is the possibility that no insect activity will occur. A study conducted by Reibe and Madea (2010) in Cologne, Germany found that remains associated with low temperatures presented little to no signs of decay from insect activity, noting that "In December no fly activity was recorded. Hence, the temperature does matter when it comes to the general question of insect activity due to low temperatures". They found that even if there is a short amount of sunlight in colder temperatures it does not affect the total number of eggs laid. This finding suggests that the variable of insects may not have as great of an impact on decomposition during the Minnesota winter.

Dix and Graham (1999) laid out a timeline of decomposition through which the body proceeds. As rigor passes, a green discoloration comes to the skin and is normally seen within 24-36 hours after death. However, this thesis found the coloration to appear weeks later. Bloating was also noted weeks later, likely due to the colder weather. Skin slippage is another step within the same reference, however, the pigs in this experiment skipped that step entirely and were eaten by scavengers before this occurred.

A study conducted in Canada by Cockle (2015) found a consistently underestimated PMI for cases exposed to cold or freezing temperatures. The study compared an older PMI formula to a variety of cases, including ones in extreme temperatures. They also found a delay in decomposition underground versus on top of the ground. The original formula that provided an estimated PMI was, on average, half of the actual length of time, suggesting that the older formula was grossly underestimating the impact colder weather has on the extension of PMI.

Scavenging

Scavenging is another major factor that must be taken into consideration when discussing decomposition, especially in above ground cases. A case study conducted in South Africa by Spies (2018) shows that vertebrate scavenging affected the decomposition process greatly. The act of human decomposition was recreated using domestic pig carcasses and studied over 93 days. Scavenging from a mongoose was observed by Day 14 and this animal proved to be the primary scavenger, leading to advanced decomposition at an accelerated rate. Analyzing and quantifying the patterns of scavenging can be key in determining the PMI of a case. A study done by Spies, and colleagues (2018) found the first activities by a mongoose will attempt to scratch through the skin near the anal area, then quickly exposing the tibiae and fibulae. This was similar to that seen in this thesis as the raccoons were first to scratch near the pubis and lower belly area, then moved to the hind limbs. Also within this study, it was seen that scavenging was high at the beginning stages of decomposition before skeletonization occurred. It is also important to analyze the ecosystem and the behaviors that animals will

show as scavengers. Within the same study, "the degree of scatter was comparable to that caused by the Virginia opossum in Oklahoma, USA, with most porcine skeletal elements found within 5 m of the original deposition site" (Spies et al. 2018). The opossum or raccoon is a much more likely candidate to be seen in Minnesota due to its specific geographical location and conditions. In the study by Spies and colleagues, phalanges were the most likely bone to be dragged off and scattered. However, in this study the live trap cages the pig samples are placed in should prohibit such things. Spies and colleagues (2018) also analyzed the presence of clothes on human or pig carcasses and the decrease in scavenging it caused. Given that the study was conducted in South Africa, the rate and tempo of scavenging is unlikely to be similar in my study. However, it is important to note that a majority of scavenging research is conducted in warmer climates and more needs to be done in colder ones.

Learning about what animals may scavenge off of the fetal pigs is extremely important for understanding the decomposition process. One of the main families of species that may visit pigs is blowflies. This species is common and can be one of the first animals to visit a dead body. Amendt (2011) mentions forensic entomology's "main application is in the determination of the minimum time since death in cases of a suspicious death, either by estimating the age of the oldest necrophagous insects that developed on the corpse or by analyzing the insect species composition on the corpse". Analysis of larvae can also aid in forensic cases with the correct professional collecting the evidence. For this paper, there will be a basic presence or absence noted, utilizing

basic principles of forensic entomology. These techniques are also used in the estimation of time since death or PMI.

A study conducted in Romania by Iancu and colleagues in 2015 over the winter season identified the common insects and bacteria from swine samples found to be most useful in the estimation of PMI. The temperature during the study was highly important as it affected the rate of decomposition, “mainly due to its influence on the decomposers community (insects and microorganisms). For instance, the appearance of necrophagous insects is influenced primarily by temperature and the ability to reach the corpse"(Iancu et al. 2015). The fact that this research was conducted during winter (as not many projects are) supports the role cold weather plays between specific geographical locations and seasons, and the impact of fly activity.

Not only are flies and other insects known to be present during decomposition, but a wide range of mammals are suspected to show as well. A study conducted by Pokines and Pollock (2018) found "these scavenging species often include birds and small mammals in the size range of raccoons, red fox, bobcats, fisher, and rodents, and the role of these small species in the scavenging of large vertebrate remains in terrestrial environments is an under-researched aspect of forensic taphonomy". Even though the pig samples are in a cage it is important to expose them to any possible attempts at scavenging that may occur. These attempts of possible scavenging will be documented by the trail cameras. Pokines and Pollock (2018) also describe how the opossum can feed upon the maggots, rats, and mice that are attracted to soft tissue, and that many other

animals such as domesticated dogs, fox, cat, and bird species may also participate in scavenging.

Many of the studies noted here have all been conducted at secure facilities with a high fence enclosing the perimeter. The study from Cape Town (Spies et al. 2018) mentions how the surrounding areas have a large number of domesticated cats and dogs and that the pigs were secured with fencing. This fencing is also a deterrent for domesticated animals. However, this thesis allowed for those animals to be a variable within the study while still providing some protection for the pig carcasses.

Fungi or mold may also be present during decomposition. In an examination by Ishii (2006) they found that since “fungi also appeared on the surface of the animal and human cadavers, its possibility of acting as an index for postmortem interval has been discussed". There have been several different fungi reported to grow on human remains and animal cadavers, but there are even more that have not been reported or studied. This thesis will note the presence, color, and appearance of any fungi that may appear in the pig carcasses during the decomposition process. The fungi discussed within the literature mainly focused on a mold that is white in color. However, the results of this experiment found possible fungi that were orange in color; this will be discussed later in the weekly results timeline section.

Accessibility

Accessibility is another factor that can determine the rate of decomposition. One case conducted in Yorkshire, UK found “that soil conditions at these three burial sites has

a marked effect on the condition of the buried body but even within a single site variation can occur" (Wilson et al., 2006). The three burial sites where the bodies were placed included moorland, woodland, and pastureland. This variety of accessibility and location allows for different results to be retrieved. It is key to have more than one location for a forensic case study as it allows the researcher to also address the impact of different environmental conditions. Climate has a tremendous impact on decomposition due to temperature and humidity; however, microclimates may be just as important when comparing decomposition rates in different cases.

One major role that plays in the speed and degree of decomposition is accessibility to the remains. Byers (2017) notes that "accessibility of the remains to scavenging is the last factor noted as affecting the activity of biological organisms. Since animals of all sizes are the main agents of decomposition, any circumstances that make it easier for these creatures to access remains should speed this process". Jeong (2016) mentions that raccoons are present in both rural and urban environments and are well known for being omnivores and scavengers by nature. Therefore, if human remains are placed outside and are relatively accessible there will be raccoon scavenging, particularly in Minnesota. In a warm climate at the University of Tennessee Body Farm, there were 23 days in January before the first initial scavenging, none in February, 17 days in March, and 12 days until the first sight of scavenging in April. The average trend is for less presence of raccoons in the colder months and more scavenging during warmer months (Jeong, 2016).

In this study, the pigs were placed in two different locations on the property to document the effects of accessibility and location on the rate of decomposition. Pig 1 was placed at a location close to the working farm site and barns. Pig 2 was placed farther away from the farm site near a river bottom. The first location has closer accessibility to the farm cats and other smaller animals, while the second location is likely to be more accessible to larger animals such as raccoons, foxes, coyotes, and other wild animals.

An experiment conducted at AFTER (Australian Facility for Taphonomy Experimental Research) (Knobel et al. 2019) analyzed the decomposition rate of pigs and human remains in both the summer and winter. The main method used was thermal measurements along with entomological activity if present. During the winter portion of the study, the length of analysis had to be lengthened compared to the summer portion due to a slower rate of decomposition. The pig samples were placed on the ground in a cage in semi-shaded areas in the vicinity of rural housing. Both the human remains and pigs in the winter study had half the amount of fly and beetle species present compared to their summer counterparts. Also within this study, differences between pig decomposition and human decomposition are noted. During the winter portion of the study, the pig samples experienced a higher rate of decomposition and fly presence than the human remains sample. Even though pig and human samples are comparable in many scenarios it is an important reminder that they are not the same and may show different results. However, the main variability within the Australian study was the difference in body mass between the human and pig samples.

A study conducted in Argentina (Cordoba and Buenos Aires) (Horenstein et al. 2010) during the winter months discovered that pig carcasses placed in sunlit places had longer occurring decomposition stages compared to the carcasses that were placed in shaded areas. However, the stages occurred in such similar and closely related timelines that they did not show differences large enough to definitively say whether shaded or sunlit places in winter led to accelerated decomposition rates. These stages of decomposition are based on carrion collection. However, in a much dryer area of (Mendoza), different results were found in 2012 by Aballay and colleagues. They found the length of the decomposition process was about half the time in the sun than in the shade, except for during the fresh stage where it was longer when placed in the shade. Winters in Minnesota tend to be variable with some years being dry with less snowfall and other winters trending towards having more extremes such as lower lows and higher highs. Bigalke (2020) mentions, “Minnesota, a state known for its extreme winter climate, is undergoing rapid changes to what may be its most iconic season”. A sample placed in the sun may have a shorter decomposition time frame compared to a sample in the shade. However, shade may provide cover for scavengers to gather and feel protected rather than being out in the open. It is important to understand that temperatures during Minnesota winter vary and can change rapidly. This further affects the PMI.

During the wintertime, it is more difficult for law enforcement to find human remains in forested areas. A paper by Pokines (2019) mentions how "human and non-human cases showed clear seasonal patterns of discovery that relate in part to human activity levels, with low rates during the winter months, a peak in late spring, and

generally high levels through the summer before decreasing in the fall". Given this fact, the effects of winter weather on remains should be a priority in taphonomic studies.

Ethics

The land on which this research was conducted is located in Le Sueur County MN, within Kilkenny Township. Permission was granted by the landowners to conduct this study on their land. Updates were provided to the landowners when the project was started and when the 60 days or extended 12 weeks were over. They were also briefed on the background and importance behind this project and why this research was being conducted.

Methods and Materials

The fetal pigs used in this study were approximately 14 inches in length and were ordered from Nebraska Scientific, a website that provides scientific materials to students and teachers. When the third pig was acquired from a local farmer about one mile down the road from the original family farm site, it was approximately 30 inches in length.

The fetal pigs did not have any injections or vaccines, nor were they treated with any preservatives to keep them from decomposing. The pigs arrived packaged well and still frozen on ice. The third pig, acquired later on, was fresh and died one day before being placed outside in the same spot as Pig 2. Pig 3 did not have any preservatives. However, there is a possibility it had received one or more vaccines.

To record the weather in the area a local weather station (KMNWATER24) between Kilkenny and Waterville was utilized. This weather station is connected to a website titled Weather Underground. This is a website where data is retrieved and added to a site for the use in recording information such as temperature, precipitation, humidity, and wind speeds. During the study, snow and ice were left in place, with no attempt to remove it. This will allow for the natural process of decomposition in a cold winter climate to occur. When temperatures rise the snow will melt and when temperatures fall the water will freeze and turn into ice surrounding the pigs. This is reflected in the data recorded in some of the weeks. Freeze and thaw are among the larger factors affecting the decomposition process in this study. The physical environment of the pigs, including snow or ice cover, played a key role in the rate of decomposition, along with the degree of animal scavenging.

All photos were taken on a Samsung Galaxy S21, with the exception of stills from trail cameras set up to record animal presence. Trail cameras were used to take photos and track different animal scavengers that were present during the entirety of the experiment. The trail cameras used are a Moultrie A300 All Purpose Series and a Garde Pro A3. These cameras allowed for documentation of animal scavengers during both day and night.

Methods used such as observation and record keeping allow for a rounded documentation to be produced both digital and physical. Even though decomposition occurs at different rates in different places of the body, since the fetal pigs are relatively small in stature each pig will be scored as one whole. However, there will be notes taken

if significant change happens in a particular area or animal scavenging occurs. The decomposition table is created by taking input from Megyesi, Nawrocki, and Haskell (2005) along with a combination of other information regarding the specific geographical location and temperature predictions. The table is as follows.

Decomposition table

0. No change/Frozen appearance.
1. Thawed, fresh pink with some color, the start of some discoloration.
2. Early decay, some marbling, moist, presence of insects or scavengers.
3. Active decay initial bloating.
4. Decay some exposure of muscles or bone.
5. Late decay exposure of many bones.
6. Early skeletonization, wet bone.
7. Late skeletonization, dry bone.

1 Map of Pig Locations

The pigs were placed in live trap cages that were secured by wire that wrapped around a nearby tree. The ends of the cages where the doors are located were also wired shut. The live trap cages made it possible for some animal scavenging to occur, without having the pig carcasses being dragged off and lost. The cages also make the pigs accessible for insect scavenging. The pigs are not wrapped in any material therefore insects will have full access to the remains. The trail cameras were then set up to the desired setting and strapped to a nearby tree to capture any activity.

The pig carcasses were placed in similar areas regarding sun and shade coverage. However, as this research takes place during the winter/spring, there are no leaves on the trees under which the pigs were placed. Both cages were placed underneath at the foot of trees with some sun and shade provided during different times of the day depending on the sun's position. The trees also provided a cover or possible escape route for scavengers making the space more attractive to the animals.

Results

Timeline Week by Week

The order of two 14-inch fresh frozen fetal pigs from Nebraska Scientific was placed on January 17th, 2023, and the pigs arrived at the family farm on January 25th, 2023. The pigs arrived within two days of being shipped from Omaha. The length of time the fetal pigs were deceased before purchase is unknown. The total cost for the two fetal pigs was $80. The pigs were placed in their designated spots on the same day as their

arrival, meaning both pigs were placed into their separate live trap cages on January 25th, 2023, which will be considered Day 1 of 60 or the extended 12-week periods.

The pigs arrived in a cooler in separate bags on ice and were still slightly frozen from the shipping process. Once the pigs were secured in the live trap cages, Pig 1 was placed in a location closer to the farm site and Pig 2 was placed further away from the farm site by the river, as seen in Figure 1. The cages were secured to a nearby tree using fencing wire to help in keeping the cages in an upright position in case of large scavengers attempting to roll the cages. The trail cameras were also placed in view of the cages to catch the presence of any possible animal scavengers. One the first day the pigs were placed outside they were still slightly frozen from the shipping process. This is important to know as it may have a slight effect on the decomposition rate. However, if the pigs did not come frozen, they would have frozen overnight as the temperature the first week they were exposed to the elements dropped below freezing. Quantitatively I gave both pigs a score of 0 using the decomposition table measurement tool previously laid out in this thesis. Both pigs scored a zero as they were still frozen and showed no sign of thaw or fresh pink color.

2 Pig 1 Week 1

3 Pig 2 Week 1

The second week of February 1st showed no change in decomposition. The qualitative data seen was that the pigs changed ever so slightly in color, however, not enough to make a large difference in decomposition. There was also a little bit of snow coverage in the cages, and it was difficult to analyze the remains while not disturbing the snow on top. For the second week the pigs were scored a 0 again. The remains did show a slight color change, as the hairs on the carcass were more visible.

4 Pig 1 Week 2

5 Pig 2 Week 2

During the third week of February 8th the project changed due to the loss of Pig 2, which was completely carried away by raccoons. Pig 1 was scored as a 0 again as it showed signs of still being frozen with a slight pinkish color being present on the nose of the pig.

6 Pig 1 Week 3

6 Pig 2 Week 3 Missing

Pig 2 was lost as raccoons were able to find a weak spot and bend the live trap cage and pull out the pig little by little. I was unable to determine a quantitative score for the third week for Pig 2 as there was no carcass to score. When it was determined that there was nothing salvageable from Pig 2 another pig was acquired from a local farmer. This pig (designated Pig 3) had died a few days before it was put out in the same location as Pig two. A larger cage was built out of wood and chain link fence to protect the new

and much larger pig. When placed, Pig 3 had some fluid leaking out of its nose and a small-sized lividity spot on the underside of the carcass where it had been laying. The pig was also stiff due to rigor mortis which disappeared after 48 hours as the pig was stored at an average ambient temperature of 50°F until it was placed outside to replace Pig 2.

During the fourth week of February 15th the pigs showed little change. Pig 1 exhibited no sign of change except for a small amount of discoloration around the mouth. This discoloration was orange in color and could be either mold or bodily fluids escaping from the orifices during autolysis. A second live trap was also placed around Pig 1to add protection from raccoons. Given the noted changes Pig 1 was scored as a .5. Pig 3 showed few signs of decomposition and appeared similar to the previous week. Pig 3 was scored a 1, the same as the previous week.

8 Pig 1 Week 4

9 Pig 3 Week 4

Week Five on February 20th showed little advancement in decomposition as there was a large snowstorm that occurred. Pig 1 was still in a somewhat frozen state and partially covered in snow. There was also an unidentifiable frozen liquid coming out of its mouth area. As there were no other areas of decomposition the score was the same as the week before at .5. The spots of lividity on Pig 3 were darker in color and the nose was much pinker in coloration, meaning the carcass was thawed through from the previous week's snow and ice storms. There were also dark circles around the eye orbits and black veins were present in the stomach area. The pig carcass also showed signs of bloating.

The combination of observations led me to score the pig at a 1.5.

10 Pig 1 Week 5

11 Pig 3 Week 5

In Week Six on February 28th another snowstorm had passed; this time even more snow cover was noticeable. Pig 1 scored a 0 due to the snow cover. Both pig carcasses were covered in snow, however, Pig 3 in particular exhibited small holes in the snow near the anus and feet. The leakage around the nose from the week before was not visible due to the snow coverage. Due to these factors the pig was scored a 1 given it was partially covered by snow.

12Pig 1 Week 6

13 Pig 3 Week 6

During Week Seven on March 7th there was still snow covering Pig 1. This could be due to the ice lodged inside of the smaller cage. There was, however, a small hole in the ice and snow on the side of the cage where a raccoon was scavenging the pig. Some flesh was missing; however, the damage could not be fully assessed due to the snow cover. Due to these observations Pig 1 was scored a .5 due to advancements of decomposition from animal scavenging. Pig 3, however, showed a greater advance in decomposition. The lower belly/pubic area had opened, or perhaps exploded, and stomach contents or unidentified fluid had spilled out to the snow below. The color of the inside of the carcass was fresh pink as though it might have just happened. It is also important to note that there was no presence of insects of any kind. There was also still some ice on top of Pig 3. The previous lividity spots on the bottom side of the pig, as well as the anus and eye orbits all exhibited signs of deterioration, as well as mold growth. The abdomen was still round, but marbling was present in the belly region. These advancements in decomposition allowed a score of 2.

14 Pig 1 Week 7

15 Pig 3 Week 7

During Week 8 on March 14th extra protection was placed around Pig 1. Fence posts were placed around the cage to hopefully deter raccoons from eating the pig carcass in its entirety, similar to what happened during the second week concerning Pig 2. Pig 1 was still covered in snow and therefore scoring the decomposition of the pig was difficult, resulting in a score of 0. Pig 3, however, did show signs of decay as the stomach and lower belly where a hole was previously noted had enlarged in comparison to the previous week. The rib cage was also deflated and less round. The color of the inside of the carcass was a duller brownish pink color in comparison to the previous bright reds and pinks of the previous week. There was no sign of insects. It is important to point out that in relation to animal scavenging there was a track-like circle surrounding the cage pressed into the snow. This was due to the high traffic and the popularity that the pig carcasses received by different scavengers. Pig 3 was then updated to a score of 3 due to the progress of decomposition accelerated by the animal scavenging.

16 Pig 1 Week 8

17 Pig 3 Week 8

During Week 9 on March 21st Pig 1 was still covered in some ice as it had not fully melted. However, there was a hole in the ice where scavenging had occurred from raccoons. Through this opening you could see stomach contents and the rear end of the pig. There were no insects present during Week 9; the pig was then scored as a .5. Pig 3 showed little development from the previous week. There was evidence of raccoon scavenging on the feet and hind limb, exposing flesh. The size of the spots of lividity, or soft areas, have not grown since week 5. The river was previously frozen over, however during Week 9 the river opened and started to flow. Due to these factors the score of Pig 3 was 3.5 due primarily to the exposure of the lower limb bones.

18 Pig 1 Week 9

19 Pig 3 Week 9

20 Pig 3 Week 9

On March 28th the pigs were checked for decomposition scores. For Week 10 Pig 1 showed no signs of advancements of decomposition. However, there was less ice and snow in the cage and therefore the pig was visible enough to score as a .5. Pig 3, however, did show further signs of decomposition as visitation by raccoons increased due to the warmer weather. Approximately the lower half of the belly area of the pig was completely gone with only the top half above the ribs remaining. The lower leg bones and vertebra were detached but still inside the cage as they were too large to fit through the holes of the cage; Pig 3 therefore scored at a 4.

21 Pig 1 Week 10

22 Pig 3 Week 10

23 Pig 3 Week 10

Week 11 of decomposition was recorded on 4/5. Pig 1 showed signs of more decomposition than the previous week. All of the snow and ice from the previous weeks melted and revealed the decomposing pig. There was no sign of bloat as the pig was already concave towards the pubic and lower stomach area. Pig 1 was wet in appearance and exhibited tiny specks that were identified as debris from the farm field. There was no sign of insects or animal scavenging during Week 11. Therefore, Pig 1 scored a 2 with the absence of insects, but with the presence of discoloration. Pig 3 also experienced a more advanced stage of decomposition; however, this was due to animal scavenging. As opposed to the previous week only the head, vertebra, a few ribs, and two legs remained. Pig 3 scored a 4.5 due to the loss of bone and the acceleration of decomposition from animal scavenging.

24 Pig 1 Week 11

25 Pig 3 Week 11

26 Pig 3 Week 11

The last data was recorded on April 11th during Week 12. This was the last day of the 60 day period for recording data for this thesis. During this week there were summer-like temperatures (70 °F) which accelerated the decomposition and brought flies to both carcasses. Pig 1 is scored as a 3 due to the advancement of leakage underneath the pig and the presence of insects. Pig 3 scored a 5 due to the exposure of some of the dry bones that were cleaned due to animal scavenging, as well as the darkened area surrounding the orifices in the face and the presence of insects.

27 Pig 1 Week 12

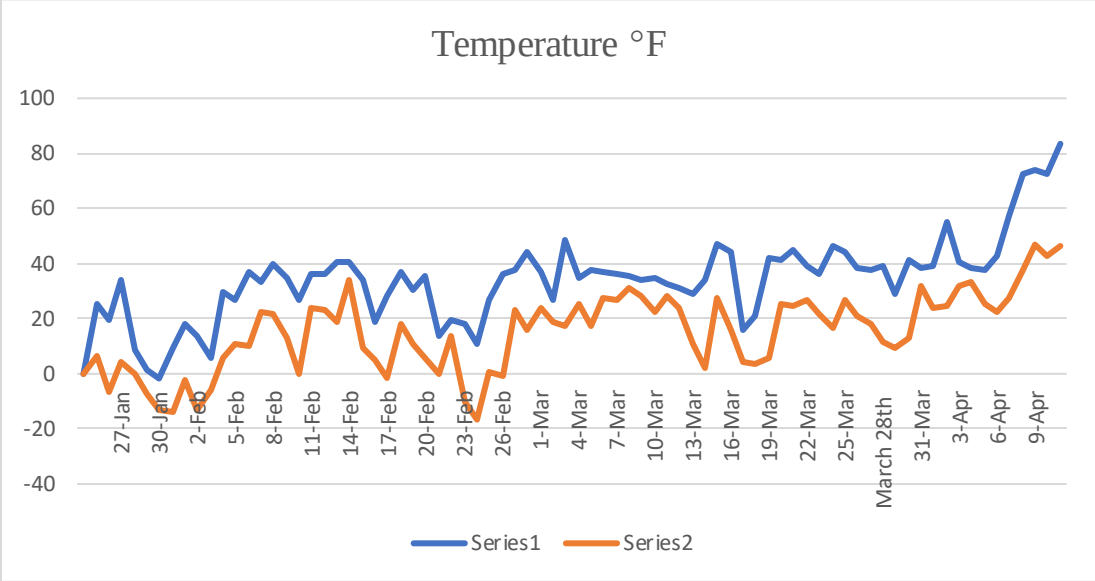
28 Pig 3 Week 12

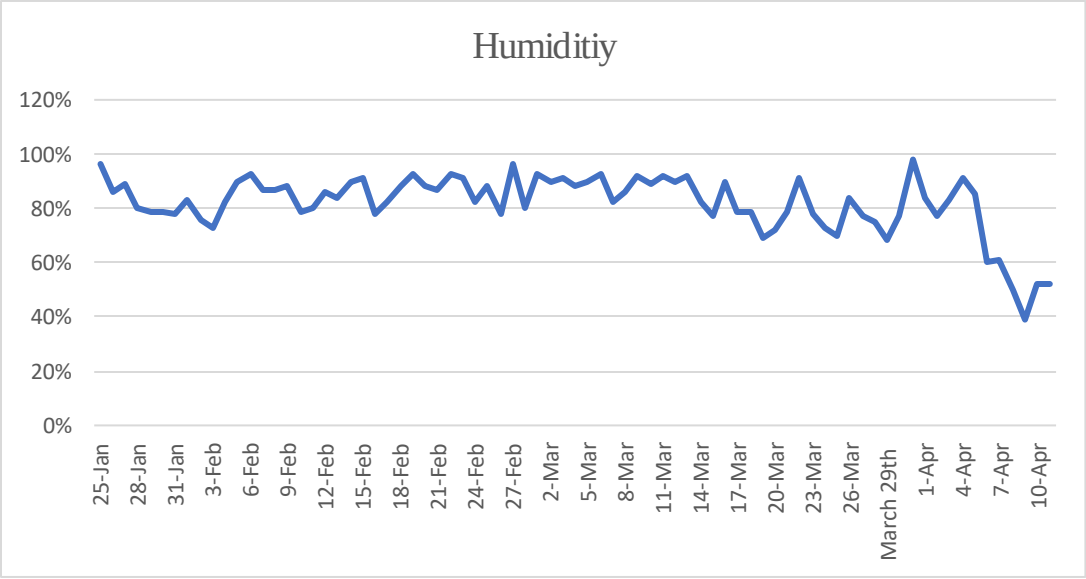
***29** Blowflies Pig 1 and 3 Week 12*

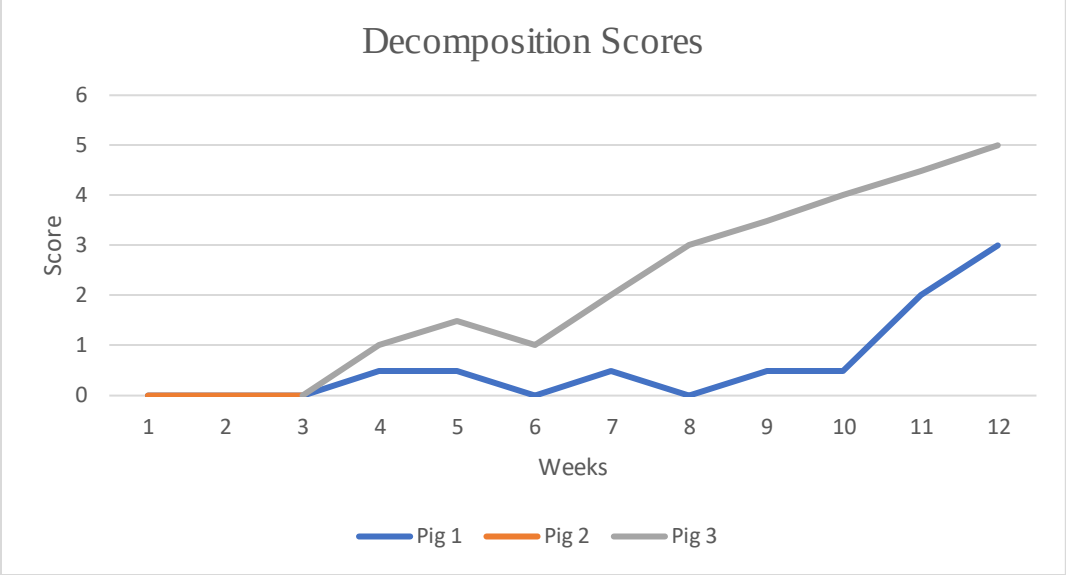
Figure 29 shows the common Calliphoridae, otherwise known as blow flies. These types of flies were present at both Pig 1 and Pig 3 during Week 12. These flies, as discussed previously in this paper, are common ones that show up when decomposing

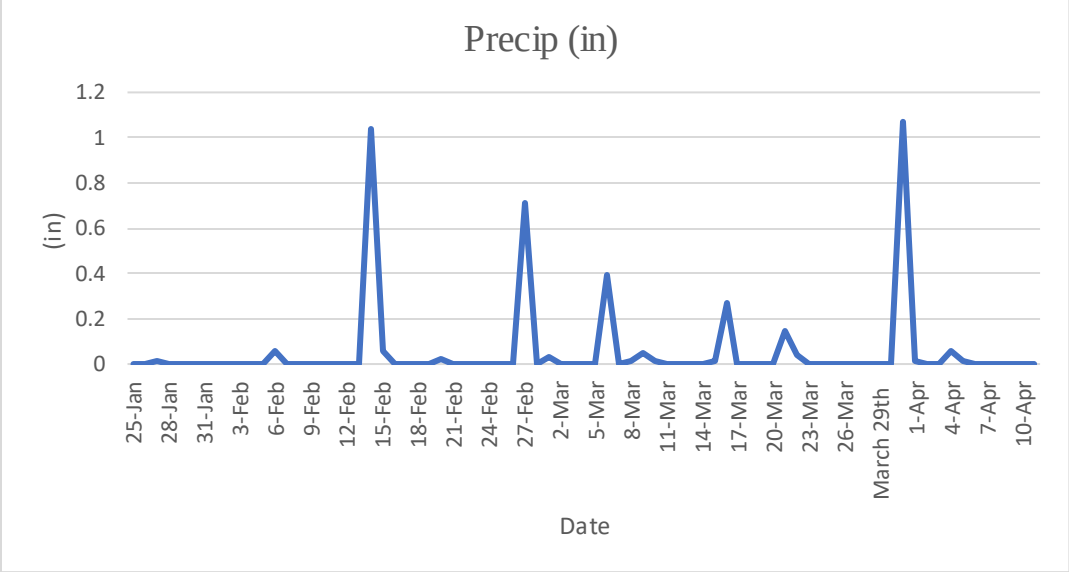
flesh is present. There were no signs of larva present at either pig carcass location. The flies also were small in number and did not gather in hordes around any orifices.

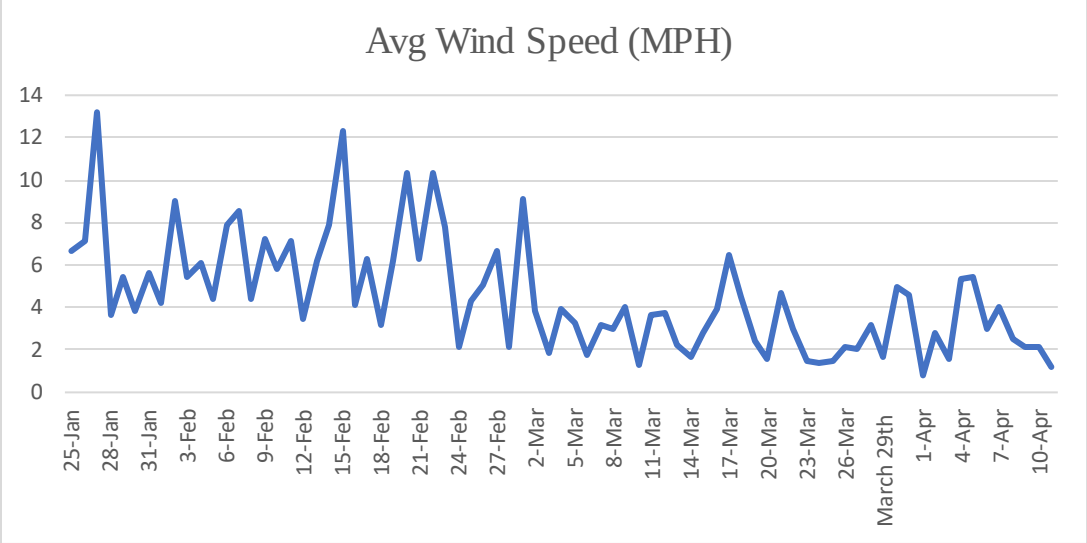
Graphs and Quantitative Data

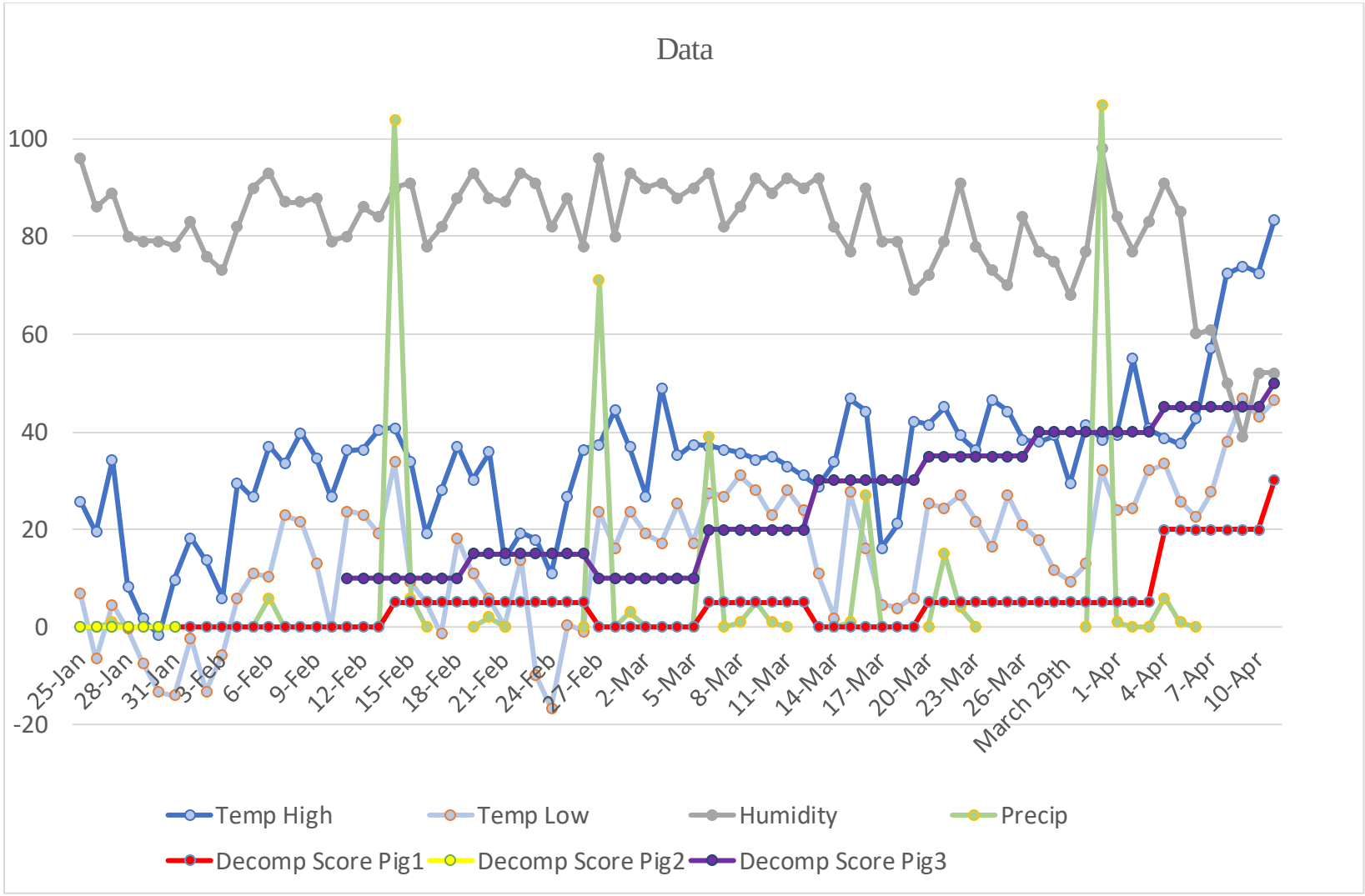





Decomposition Scores
Score
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
12
Weeks
Pig 1
Pig 2
Pig 3


Precip (in)
(in)
1.2
1
0.8
0.6
0.4
0.2
0
25-Jan
28-Jan
31-Jan
3-Feb
6-Feb
9-Feb
12-Feb
15-Feb
18-Feb
21-Feb
24-Feb
27-Feb
2-Mar
5-Mar
8-Mar
11-Mar
14-Mar
17-Mar
20-Mar
23-Mar
26-Mar
March 29th
1-Apr
4-Apr
7-Apr
10-Apr
Date


Avg Wind Speed (MPH)
14
12
10
8
6
4
2
0
25-Jan
28-Jan
31-Jan
3-Feb
6-Feb
9-Feb
12-Feb
15-Feb
18-Feb
21-Feb
24-Feb
27-Feb
2-Mar
5-Mar
8-Mar
11-Mar
14-Mar
17-Mar
20-Mar
23-Mar
26-Mar
March 29th
1-Apr
4-Apr
7-Apr
10-Apr


Data
100
80
60
40
20
0
-20
25-Jan
28-Jan
31-Jan
3-Feb
6-Feb
9-Feb
12-Feb
15-Feb
18-Feb
21-Feb
24-Feb
27-Feb
2-Mar
5-Mar
8-Mar
11-Mar
14-Mar
17-Mar
20-Mar
23-Mar
26-Mar
March 29th
1-Apr
4-Apr
7-Apr
10-Apr
Temp High
Temp Low
Humidity
Precip
Decomp Score Pig1
Decomp Score Pig2
Decomp Score Pig3

The table above combines all of the previous graphs' data with some alterations, such as moving the decimals of the precipitation and decomposition scores so that they will appear on the graph along with the temperature highs and lows. The humidity is shown as a percentage on the graph above. One main trend seen with both Pig 1 and 3 is the dip in decomposition scores around February 27th. This could be due to the days prior being below 0°F combined with a high amount of precipitation. However, on all the other occasions when there was a significant amount of precipitation the decomposition scores increased within a few days of that precipitation. Another noticeable trend is towards the end of the study in April, when the humidity decreased and the decomposition scores increased. Throughout this research humidity was shown to be one of the major factors in the rate of decomposition; however, this data indicates that as long as the temperature increases and wind decreases, decomposition scores will increase.

Discussion

One of the most interesting weeks in this study was Week 6, or the week of February 28th. During this week there was a significant amount of precipitation, with a dip in humidity and temperature. This is reflected in the decrease in decomposition scores. This can also be noted during Week 8, as while there was not as much precipitation, there was still a drop in temperature and humidity. Both of these weeks show a correlation between the decrease in temperature and a decrease in the rate of decomposition. However, during the warmer days in late March and April the precipitation did not have an impact on slowing down decomposition.

The greatest rate of decomposition occurred onwards from Week 10. This is probably due largely to the increase in temperature, especially with the temperature lows overnight being above 32° F or freezing for more than one consecutive night (otherwise known as the freeze thaw cycle). Average wind speeds were also recorded during the 12 weeks and there appears to be a correlation between the increase in decomposition and lower wind speeds. The lower wind speeds allow for more insect activity, such as flies being able to find the decomposing pig carcasses. The other major factor in decomposition that played a role in this research was the presence of animals and scavenging activities. Figure 30 shows a trail made by raccoons from the river to the location of the third pig. The high traffic can be seen within trail camera pictures that were taken almost every night as the raccoons returned to the carcass to feed.

It was approximately a month from February 8th-March 7th before the animals started scavenging on Pig 3. During this time there was also a major decrease in the rate of decomposition. As explored in the literature review, colder weather extends the estimated PMI. Therefore, this research suggests that it would take about a month during the winter months for a carcass to go through the stages of bloat, marbling, and perforation of the lower abdomen with no signs of insect activity and animal scavenging.

30 Week 9 Trail

The animal that visited Pig 1 the most was farm cats, with the cats returning 42 different times. Although they were the most likely to return, they only accounted for a minimal amount of the scavenging. The cats appeared mostly during the day. Raccoons and a mink accounted for the most severe damage from scavenging. These animals showed up at night. Raccoons showed up approximately 12 different times, and a mink and skunk appeared twice. Raccoons did not show up in January to Pig 1, but visited once in February, and eleven times in March. The farm cats visited during all of the months, while the mink and skunk showed up in March. This suggests that Pig 1 (the one closer to the farm) was less accessible by raccoons due to their wariness associated with human

presence, while the visitation of Pig 1 by farm cats during the daylight hours attests to their comfort and position as an accepted member of the farm.

Regarding Pig 2, whose location was close to the river, raccoons appeared 13 separate times, along with mink that appeared 6 different times. During these visitations the pig was completely eaten with no remains to be found. The second pig was visited by the raccoons at the end of January and early February. The mink visited during the same times as well.

Pig 3 experienced significant decomposition through scavenging as well. The raccoons appeared 54 different times, mostly during the night. Several minks, approximately 3, also appeared during the day. The pig was visited evenly throughout February, all of March and the first part of April. This differs greatly from Pig 1. One major difference between animal scavenging at Pig 3 was that even if there was

precipitation the raccoons still visited. For Pigs 1 and 2 there were no animal scavengers if it was raining.

Some other animals also appeared on the trail cameras such as deer, field mice, pheasants, blue jays, and black birds. However, none of these animals actively tried to eat or scavenge the pig carcasses. Another piece of qualitative data to note is the lack of scent. During this whole process there was never any noticeable scent coming from the pig carcasses.

Raccoons have played a much larger role in this thesis than first anticipated. Week 3 was the turning point of this thesis when Pig 2 was entirely eaten by raccoons. Pig 1 located closer to the farm site experienced some raccoon scavenging but that did not occur until early to mid-February. This shows how the accessibility of Pigs 2 and 3 is much greater than Pig 1. It can then be correlated to the idea that if human remains were located next to a river or body of water not near a farm site of human activity it would experience a much greater amount of animal scavenging and therefore decompose quicker. The raccoons were not prohibited by temperature as well and appeared to scavenge at any temperature.

Even though there was a variety of animals that were present to scavenge on Pig 2 and 3 there was still a lack of other common animals in the area such as coyotes or opossums. This could be due to the idea that raccoons are territorial, or they simply lived closer to the cage and had more direct access. Pig 1 also received a variety of visitors; however most were from farm cats as previously stated. Even though the pigs were

located less than a mile away from each other the differences in animal scavenging were great. This scavenging also greatly affects and reduces the accuracy of the PMI discovery.

Future Developments

The use of pig samples instead of human remains during research projects has gained a base of support among researchers and contributed significantly to our knowledge concerning decomposition. Wang (2017) mentions how research methods in succession studies have improved over time and that the standards for setting those replicates and controls allowed new generations to have more confident statistics in the future. Every experiment, no matter what the results, whether they support the given hypothesis or oppose it, is an addition to our knowledge on the subject. Even though there have been many experiments conducted utilizing pig samples they still provide a contribution towards the advancement of science. There are only a handful of researchers around the world that have access to a "body farm" and can employ human cadavers for research; Minnesota is not one of those places. Additionally, most "body farms" are located in warmer climates. That is why it is important to create research projects that assess decomposition using pig samples that address the effects of cold climates, winter weather and the freeze-thaw cycles.

This study supports earlier results that indicated there are differences between frozen pig samples and thawed ones in the rate of decomposition. There should be caution in place that this may possibly influence the final results. Research in the future

could be done with a larger sample size to account for the initial state of the remains. The PMI may be underestimated or incorrectly calculated in cases where temperatures are freezing from the outset.

The study of the freeze-thaw cycle of both pigs and human remains have connections to real cases. A study by Stokes, Forbes and Tibbett in 2008 analyzed the freezing of skeletal muscle prior to decomposition. They found that there was a connection between a criminal murder case where the victim was frozen for over two years. The body was discovered after it was dumped elsewhere. The skeletal muscle in a controlled setting has an impact on the soil that surrounds it. However, there is no variation between the frozen muscle and the refrigerated sample beside some small presence of ice crystals. The research reported on in this thesis both connects to and supports past research into the effect of cold temperatures and the freeze thaw cycle, but also provides more context concerning other factors that may come into play- specifically scavenging and accessibility.

As reviewed in the literature portion of this thesis there was exploration of the University of Tennessee "Body Farm" (Steadman, 2018) and the animal scavenging present there. Raccoons were the most present scavenger similar to this thesis; however, one major difference is the overabundance of raccoons that were present at the more remote location. A personal correspondence from Dr. Blue (a committee member for this thesis) informed me of past works done in the city of Mankato. A pig carcass was placed in town during the Minnesota winter months and received little animal scavenging, but many more types of insects were present. This study along with the findings of this thesis

creates a correlation between the higher amount of human presence with the lessened amount of animal scavenging. Pig 1 was not completely eaten compared to Pig 2 and was not as severely scavenged compared to Pig 3. Within the same article from Tennessee they found that the scavenging by raccoons was the most extensive in the winter months. Meaning, if this thesis was conducted in the summer rather than the winter the bacterial or internal decomposition would have been faster, but the scavenging from raccoons would have likely been the same due to the cage slowing down that process.

Conclusion

This study of decomposition rates in winter/early spring of Minnesota demonstrates the multiple variables that have an influence on decomposition. In particular, the variable of accessibility proved to be a key factor in the differences in decomposition between the two pigs. Their positioning at different locations, one closer to a farm site and the other adjacent to a river, proved that, despite being present on the same rural property, animal scavenging of the remains would be far greater at the site furthest from any human activity. The scavenging found clearly supports that the pig located by the river experienced more scavenging than the pig close to the farm site. Also of interest was the fact that raccoons were the primary scavengers encountered; mink, skunk and farm cats also made appearances, but these other scavengers did not contribute in any measurable manner to the overall rate of decomposition. Interestingly, coyotes, although ubiquitous in southern Minnesota, did not participate in any scavenging activities with either pig.

This thesis used a variety of cages and fences to protect the pig carcasses to some extent while still being able to observe the decomposition and exposing the pigs to the natural elements. Animal scavenging was one of those elements that affected the pig closest to the river and was more accessible by raccoons due to its location. The pig located closer to human activity received less scavenging although attempts were made when the weather was warmer.

Another aspect of this research was the question of the freeze thaw cycle and the changes it can have on decomposition. This research clearly shows a connection between the freeze thaw cycle and the lack of insects due to colder temperatures at night. Also at play in regards to insect activity may be wind speed and humidity. Spikes in precipitation and humidity correlated with the rise in decomposition scores. The lower wind speeds also allowed for the flies to find the decomposing carcasses in both locations. This research confirms previous findings on the subject, but it also adds new information concerning specific animal scavenging in the Minnesota River Valley, as well as documents and how weather patterns (freeze thaw, humidity and wind speed) impacted that scavenging. This, in addition to accessibility, led to very different rates of decomposition despite the pigs being located in the same general vicinity. Based on these results, this research will further help researchers understand the interplay between different taphonomic processes and factors and how they play a key part in decomposition in the winter/early spring in a cold climate region like Minnesota.

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