Postmortem interval (PMI) determination at three biogeoclimatic zones in southwest Colorado

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POSTMORTEM INTERVAL (PMI) DETERMINATION AT THREE BIOGEOCLIMATIC ZONES IN SOUTHWEST COLORADO

A Thesis

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College

in partial fulfillment of the requirements for the degree of Master of Arts

in

The Department of Geography and Anthropology

by
Maria T. Allaire
B.A., Fort Lewis College, 1997
December 2002
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ABSTRACT

Three pig (Sus scrofa L.) carcasses were exposed during the summer in three different biogeoclimatic zones ranging in elevations from 6,700 to 11,100 feet in order to determine the rates of carrion decomposition and arthropod succession patterns on carrion in southwest Colorado. The carcasses were exposed in three scenarios: sun-exposed, shaded, and sun-exposed/shaded. Of the total 63 taxa collected, thirty species overlapped between two biogeoclimatic zones. A strong elevational preference is indicated for the Sarcophagidae taxon. A previously undescribed Boettcheria species was collected at 11,100 feet. The rates of decomposition lengthened as elevation increased due to a prolongation of the bloat stage. Natural mummification occurred at the two highest elevational sites. The meteorological data recorded at the local NOAA stations did not reflect the weather conditions that occurred during the same time period in the three biogeoclimatic zones.

**Key Words:** arthropod succession, biogeoclimatic zones, carrion decomposition, forensic science, postmortem interval, southwest Colorado.
CHAPTER 1: INTRODUCTION

Determination of the postmortem interval (PMI) is a crucial and fundamental step in any death scene investigation when a death is not witnessed. Estimation of the postmortem interval is defined as the length of time between death and corpse discovery. At the onset of death, the medical parameters to establish the cause, manner, and time since death begin to degrade. With the progression of time and soft tissue decomposition, a PMI determination by a pathologist or medical examiner becomes more difficult and less accurate (Anderson and VanLaerhoven 1996). In death investigations, the discovery of a corpse is often delayed (i.e., days, weeks, months or years) because of intentional concealment by a suspect, death occurring in a remote area, and cases involving shut-ins, to name just a few. In such cases, the role of the entomological evidence associated with the corpse becomes critical for PMI determination. In death investigations when foul-play is suspected or the identification of the person is unknown, a PMI determination is essential for narrowing the fields of suspects or possible missing persons.

Estimation of PMI is based on a composite of taphonomic factors. Taphonomy refers to all the natural processes to which a corpse is subjected after death. The stages of morphological decomposition and arthropod colonization patterns are the most common taphonomic factors utilized for PMI estimation; however, the geographic region or biogeoclimatic zone impact these factors. Biogeoclimatic zones are defined by habitat, vegetation, soil type, and meteorological conditions. The arrival time, length of colonization and arthropod species present, in addition to the rate of morphological decomposition, can vary greatly between biogeoclimatic zones.
Currently, the American Board of Forensic Entomology recognizes the necessity for research within different geographic regions and biogeoclimatic zones, and the development of respective PMI determination databases. The reason behind this necessity is that even though an insect may be classified as Holarctic, Nearctic, urban or rural, arthropod succession on a corpse will be impacted by different biogeoclimatic zones within a region (Anderson 2001). Today, there exists a culmination of both generalized and specific information about the life-cycles, distribution ranges and habits of arthropods, and arthropod succession data for PMI determination. The benefits of this wealth of information are two-fold. First, it has established respective databases for specific geographic regions and biogeoclimatic zones. Second, it provides background information and guidelines for researchers who are conducting fieldwork on PMI determination in a geographic region or biogeoclimatic zone for the first time.

In southwest Colorado, the landscape is comprised of canyons, high plain savannahs, streams, high elevation lakes, mesas, mountains and valleys. Elevations range from 4,000 feet above sea level in canyons to over 12,000 feet in the mountains. The meteorological conditions within southwestern Colorado are as diverse as its landscape. Therefore, the southwestern Colorado geographic region is comprised of multiple biogeoclimatic zones.

In southwest Colorado, no previous carrion decomposition and arthropod succession research has been conducted; therefore, no relevant PMI database exists that would assist in resolving the medico-criminal cases that occur throughout the region. To begin the process of establishing a relevant PMI database for southwest Colorado, the objective of this study was to identify and compare the arthropod taxa associated with
carrion, decomposition stage lengths, and arthropod succession patterns during the summer in three different biogeoclimatic zones.
CHAPTER 2: LITERATURE REVIEW

Each geographic region and biogeoclimatic zone is comprised of unique factors that affect carrion decomposition rates and arthropod succession patterns. The sequence of carrion decomposition has been well established by previously conducted studies; however, the rate of decomposition has been shown to be highly variable between regions, and from one biogeoclimatic zone to another. This in turn has a direct impact on arthropod succession patterns and PMI determination. The current research project is the first PMI study conducted in southwest Colorado; therefore, a review of previous PMI studies and associated literature will provide the current research project with carrion decomposition rates and arthropod succession patterns for comparison purposes, as well as research procedural guidelines.

Two of the earliest studies conducted by Evans and Deonier laid the foundation for future research in PMI determination and diptera life cycles. In 1935, Evans published his research findings regarding the effects of humidity on blowfly ovary development and oviposition. Using the blowfly *Lucilia sericata* Meigen, Evans found that high humidity was more favorable to ovary development than low humidity. Oviposition was also affected by humidity levels. Evans found that different humidity levels did not affect oviposition when temperatures were between 50º F and 95º F; however, when temperatures reached 104º F, female flies would not oviposit when humidity levels were low (p. 307).

Deonier (1940) studied winter decomposition rates in Southwest Texas and Southern Arizona. He documented both morphological decomposition stages and the seasonal effect on blowfly infestation. His findings demonstrated that wind levels as well
as cool temperatures conjoined with low humidity levels affected blowfly infestation patterns (p. 169). Evans’ and Deonier’s research showed how temperature and humidity levels affect blowfly activity and development.

David G. Hall’s book (1948), *The Blowflies of North America*, is a compilation of entomological information on the different blowfly species found in North America. The book contains in-depth information on each blowfly’s identification characteristics as adults and larvae, its distribution range (e.g., Holarctic, Nearctic, urban or rural), habitat and food source preferences, and a description of its life cycles. Dichotomous keys are provided for blowfly identification purposes. Even though few new blowfly species have been identified since the book’s publication date, it should be noted that the information on the blowflies’ distribution ranges is outdated. Today, Hall’s book (1948) is still considered a valuable reference for the accurate identification of adult blowflies and third instar larvae (Hall 1990).

Frank R. Cole’s book (1969), *The Flies of Western North America*, is a compilation of the entomological information of all the Diptera families inhabiting the western regions of North America. Dichotomous keys for identification to Diptera genera are provided as well as brief, identification characteristics to species. The major significance of this book is that the Diptera distribution ranges were defined according to habitation preferences. By illustrating the importance and interrelatedness of natural geological barriers, local flora, soil, altitude, rainfall, and climate to Diptera habitation preference, Cole set into motion the recognition for establishing respective PMI databases for geographic regions and biogeoclimatic zones.
The importance of entomological specimens in determining PMI for medico-legal cases was now shown to be correlated with the various stages of decomposition. In 1983, Lord and Burger outlined the protocol for the collection, preservation, and rearing of entomological evidence. Separate procedures were defined for flying, crawling, burrowing, immature, and soft-bodied insects. The protocol also included information about the labeling and shipment of specimens. The biogeoclimatic protocol set forth by Lord and Burger included the following categories of data that are essential to understand PMI: general habitat type (i.e., woods, pasture, swamp, roadway, etc.); terrain type (i.e., hillside, valley, and slope-facing direction); the vegetation present (i.e., types of trees, grasses, and shrubs); soil type (i.e., sand, gravel, mud, etc.); minimum and maximum temperature; and rainfall amounts (p. 942-943). Today, the protocol set forth by Lord and Burger is still taught and utilized (Haskell 1990; Haskell et al., 2001).

In 1965, Payne documented the interrelatedness of decomposition stages and arthropod succession patterns. In a hardwood-pine forest, Payne conducted his research over two summers in South Carolina using baby pigs *Sus scrofa* Linnaeus. Payne identified and defined six decomposition stages as fresh, bloated, active decay, advanced decay, dry, and remains. Payne noted that each stage of decomposition, identified as an ecological niche, was characterized by a particular group of arthropods (p. 601). Payne found that arthropods visiting the *Sus scrofa* L. carcasses fell into five types: necrophagous, omnivorous, predators and parasites, seekers of shelter, or accidentals. The two summer projects showed a direct relationship between morphological decomposition and arthropod activity, and that each was influenced by temperature and moisture.
Rodriquez and Bass (1983) reported on the first seasonal study of arthropod succession and decomposition rates for Tennessee. The research was conducted from May, 1981, through May, 1982, in an enclosed “open wooded” area located at the University of Tennessee-Knoxville Anthropology Research Facility (ARF). The ARF study utilized four donated human cadavers. Procedural standards were established for the collection of meteorological data. Decomposition stages were defined as fresh, bloat, decay and dry. Rodriquez and Bass noted that seasonal variation in decomposition rates was dependent on both climatic conditions and the arthropod species present (p. 431). During the warm months of spring and summer, the different number of arthropod species present and their frequency increased; in the cooler months of fall and winter, there was a marked decrease in the different number of arthropod species present and their frequency (p. 426).

Mann et al. (1990) summarized the various factors that affect decomposition in the natural and uncontrolled setting at the ARF. The summation of the various factors, eleven in total, is the result of nearly ten years of experimental decomposition fieldwork conducted within the ARF’s biogeoclimatic zone. The eleven factors were ranked on a five-point scale. A ranking of five indicates that the factor was most influential to decomposition. The variables of temperature, insect access, and burial and depth were ranked as the most influential. Humidity was scored as a four due to its interrelatedness with temperature and insect access. Mann et al. noted that when the temperature is below 32° F, fly eggs and exposed larvae will die and that pupating larvae “will over-winter until warm weather returns” (p. 105). Cold weather will also reduce or completely stop the decay process. When weather is warm to hot, and accompanied with high humidity,
the dry stage (skeletonized) can occur within two to four weeks. The other factors noted were trauma, rainfall, body size, embalming, clothing, and surface (p. 104).

Since the mid 1980s, the study of decomposition and arthropod succession patterns within Hawaii’s diverse biogeoclimatic zones has been conducted by the staff and students at the University of Hawaii-Manoa. The results of the Hawaiian studies, similar to ARF’s continuous studies, have culminated in a relevant PMI database that is beneficial for local medico-legal cases. Goff and Flynn (1991) illustrate, through a medico-legal case, how PMI can be determined from entomological evidence (i.e., adult specimens, larvae, and empty puparial cases) collected at autopsy. The human remains were mummified with partial areas of skeletonization. By comparing the collected entomological evidence with the database’s information on identified arthropod species and their respective development and succession patterns, Goff and Flynn were able to provide law enforcement with a PMI estimate of 34 to 36 days (p. 612). The PMI estimate was consistent with the last sighting of the decedent 37 days earlier.

Research conducted in the coastal environment of Washington State showed that decomposition and arthropod activity can be markedly different between two closely spaced biogeoclimatic zones (Shean et al., 1993). To document the influence of different ambient temperatures on decomposition rates and arthropod activity, two study sites, sun-exposed versus shade, were located within 300 meters of each other. Shean et al. noted that ambient temperatures fluctuated more over a 24-hour-period for the exposed site than the shaded site. Maggot mass temperatures at the sun-exposed site averaged 16.7º C above the ambient temperature while the shaded maggot mass temperatures averaged
9.6°C above ambient temperatures (p. 941). The pig carcass in the shaded site took 15 days to reach maximum bloat, and the carcass in the exposed site took only nine days to reach maximum bloat (p. 943). At the shaded site, the maggots migrated from the carcass in a steady, gradual manner, while the exposed site’s maggots migrated in two separate masses.

Anderson and VanLaerhoven (1996) reported on the ongoing study of arthropod succession being conducted to establish a relevant PMI database for southwestern British Columbia. The study was conducted in the summer months and all carcasses were placed in an open field that was bordered by coniferous and deciduous trees (p. 617). Stages of decomposition were defined as fresh, bloat, active decay, advanced decay, and dry. Anderson and VanLaerhoven noted that arthropod succession continued for nine months after death. *Lucilia illustris* Meigen and *Phormia regina* Meigen, previously reported as late colonizers, were the first arrivals to the fresh carrion (p. 619). At the dry stage (43+ days after death), adult Calliphoridae, Muscidae, and Sarcophagidae were still attracted to the carrion; however, only larvae for Muscidae were collected. Contrary to previous studies, Dermestidae, Silphidae, and Cleridae adults were all present in the advanced decay stage (17-42 days after death), and Histeridae was observed and collected only during the dry stage (p. 620). Dermestidae larvae were collected 21 days after death.

Michael Johnson (1975) conducted the first seasonal study of arthropod succession and decomposition rates in Illinois from June, 1968, through November, 1969. The study took place in a red oak-basswood-sugar maple forest. Decomposition was divided into four stages: fresh, bloat, decay and dry. Arthropod types were classified as either necrophagous, predators and parasites, or non-carrion, and accidentals. Johnson’s
research provided the baseline seasonal averages for each of the decomposition stages and the variation of the arthropod species present. Johnson noted that during the winter months, when calliphorid flies do not breed, the decay stage was skipped entirely due to the absence of calliphorid larvae and their enzyme secretions (p. 81).

In 1986, Micozzi addressed how freezing and thawing can affect the various processes of postmortem change. Utilizing both frozen-thawed and freshly killed Wister rats, Micozzi noted histologic, microbiologic, and mechanical differences between the two control groups. In the freshly killed group, Micozzi noted that postmortem decomposition proceeds quickly from the inside out through putrefaction (anaerobic processes) of the internal organs. In the frozen-thawed group, Micozzi noted that postmortem decomposition proceeds from the outside in primarily through decay (aerobic processes) because of the “weakening of the skin, connective tissue, and joints” which facilitates the “invasion by foreign organisms and insects” (p. 960). There was no noted difference in the sequence of disarticulation between the two groups; however, the rate of complete skeletal disarticulation was faster in the frozen-thawed remains.

Tessmer (1994) conducted a seasonal research on arthropod succession and species composition in southern Louisiana from June, 1992, through May, 1993. Comparisons were made between exposed pasture habitats and wooded habitats. Tessmer noted that during all four seasons, arthropod species were more abundant in the wooded habitat than in the pasture habitat (36). Seasonal influences on habitat vegetation correlated with the species present and their abundance. Tessmer noted that during the summer months, when vegetation at both habitats was at its greatest diversity, there was a marked difference in species composition. On the other hand during the winter months,
when vegetation between the two habitats was similar, species composition showed the least variation (p. 39).

During the winter months, Hurst (2001) studied aquatic decomposition rates in south central Louisiana. Although her research focused on carrion decomposition rates in aquatic environments, Hurst utilized a fourth pig as a land control carrion specimen for comparison purposes. The decomposition of the land control specimen progressed through four stages: fresh, bloat, dried remains, and skeletonized remains (p. 25). During the cooler winter months, Hurst noted the complete absence of the decay decomposition stage with a prolongation of the bloat stage that lasted eleven days.

Rhine and Dawson (1998) conducted a study on decomposition stages in New Mexico by examining thirty surface exposure cases from the New Mexico Office of the Medical Investigator. All of the thirty cases were of identified persons with known times of disappearance and recovery (p. 148). The stages of decomposition were defined as soft tissue decomposition, exposure of bone, connective tissue only, and bone only. All of these stages were represented within the thirty cases. Utilizing the written descriptions and photographs for each case, Rhine and Dawson noted that the sequence of decomposition was uniform throughout the state; however, the rate of decomposition was highly variable. On the average, soft tissue was not present after twelve weeks, and the bone only stage began after six months. Contrary to normal expectations, mummification was noted to occur in “the higher, cooler, slightly wetter, northern regions of the state” during all seasons except for the winter when humidity levels are the highest (p. 156). Rhine and Dawson attributed the formation of natural mummification to three factors:
season of initial exposure, isolation from extreme moisture (high or low humidity), and isolation from arthropod access.

During the summer months in 1997, De Jong and Chadwick (1999) conducted a high altitude decomposition and arthropod succession study at five sites in north central Colorado. Site elevations ranged from 2,713 to 4,191 meters above sea level. Rabbit carcasses were used in this study. De Jong and Chadwick noted that as elevation increased there was a(n): 1) marked reduction in arthropod species, 2) delay in biomass loss, 3) extension of the bloat stage, and 4) reduction in larval development. Dehydration and drainage of fluids were noted as an alternate process for reduction in biomass loss. Several of the higher site’s carcasses were often subjected to temperatures below freezing. De Jong and Chadwick noted that the carcasses exposed to temperatures ≤ 0º C did not freeze; however, the decomposition rate was substantially extended (p. 842). Scavenging of several of the carcasses resulted in a faster decomposition rate.

Finally, the previous research studies have shown how decomposition rates and arthropod succession patterns are impacted by the variables of temperature, humidity, seasonal diversity, and elevation within a specific geographic region or biogeoclimatic zone. The results and guidelines from previous PMI studies are especially invaluable to researchers who are conducting initial PMI research in a new geographic region or biogeoclimatic zones. Since no previous PMI research has been conducted in southwest Colorado, this current research will provide a ground-breaking opportunity to identify the unique and variable factors that affect the rate of decomposition, and arthropod succession patterns at three different biogeoclimatic zones in southwest Colorado.
CHAPTER 3: MATERIALS AND METHODS

All three summer field studies for the current project were conducted on private land. Sites One and Two were conducted from June 17 through July 26 in two different biogeoclimatic zones within La Plata County, Colorado. Site One was established on a mesa top, in the southern region of La Plata County, at an elevation of 6,700 feet above sea level. It was located in an opening within a Pinyon-Juniper forest; however, it was a sun-exposed site. Site Two was set up on an east-facing slope in the northern region of La Plata County, at an elevation of 8,700 feet above sea level. It was located in a shaded Aspen Grove forest. The third summer field study was conducted from August 2 through August 31 in San Juan County, Colorado. Site Three was established on a west-facing slope in the northern region of San Juan County, Colorado, at an elevation of 11,100 feet above sea level. It was located in a treeless opening that was surrounded by a subalpine pine forest where the site received only four hours of direct sunlight.

Three young pigs (Sus scrofa L.), ranging in weight from 20 – 30 pounds, were used as models for human decomposition. At the beginning of each field study, each pig was euthanized by a single shot to the frontal bone from a .22 caliber handgun. Euthanization was administered by a local area Large Animal Veterinarian. After death was confirmed, each pig was immediately double bagged to prevent arthropod colonization and then transported to their respective site. The study protocol was approved by Louisiana State University’s Institutional Animal Care and Use Committee.

At each site, the carcass was protected from large animal scavenging by a metal cage. The metal cages measured 36 X 24 X 18 inches. Each cage had a hinged, lockable lid and an open base which allowed the pig carcasses to be in direct contact with ground.
The cage and lid frames were constructed with 1.5 X 1.5 X \( \frac{1}{4} \) angled iron. Three-fourths inch X #9 expanded flat metals were welded to the sides and on the lid’s frames. Four one-half inch rings, constructed from solid piping, were welded to the four exterior corners of the base frame. Four delineator posts placed through the exterior base rings were used to secure the cage to the ground. A weight-strength/support test showed that the cage would support 550 pounds on its lid. The open base and expanded flat metals allowed access to the carcass by insects and other arthropods; however, vertebrate access was hindered by the construction of and ground anchoring of the metal cages (Figure 1).

![Figure 1. Metal cage set up at Site Two.](image)

For the purpose of the field test, the morphological decomposition of the carrion was divided into the five stages of Fresh, Bloat, Active Decomp (decomposition), Advanced Decomp (decomposition), and Dry. The fresh stage began at the moment of death and continued until some characteristic of the bloat stage was noted. The bloat
stage was defined when a marbled body color, putrefactive odor, or a bloated abdomen and/or entire body was present. Deflation of the carcass, a strong putrefactive odor, and the beginning of skin and hair slippage defined the active decomposition stage. The completion of slippage, a reduction in odor, and very little remaining flesh defined the carcass as being in the advanced decomposition stage. When only skin, bones and some cartilage remained, the carcass was noted as being in the dry stage. If the derma darkened and retained a dried-out, leathery appearance with absence of internal organs, the carcass was noted as being mummified.

The carcasses were monitored daily until Diptera emergence occurred. After fly emergence, the carcasses were monitored every other day until the designated research project end date. Throughout the decomposition process, representative arthropod specimens, both adult and immature, on and near the carcasses, were collected. Adult flying insects were collected using a sweep net. At the time of collection, the flying insects were stored temporarily in plastic bags. The flying insects were then frozen later that same day. Crawling adult insects were collected by hand and placed in a jar charged with ethyl acetate for preservation. The adult flying and crawling insects were then pinned and stored for identification purposes. Larval specimens were collected using flex forceps or by hand and immediately placed in vials containing 70% ethanol. All of the larval specimens were washed using fresh water and returned to fresh 70% ethanol for storage. A representative sample of all collected adult insects was shipped to the Systematic Entomology Laboratory, Agriculture Research Service, with the U.S. Department of Agriculture (SEL), for species identification or verification of preliminary genus and/or species identifications.
Meteorological data (e.g., maximum, minimum, and current temperatures; weather conditions; relative humidity level; and precipitation amounts) were collected and recorded daily at each site until Diptera emergence was complete. Thereafter, only current temperature, weather conditions, and relative humidity levels were collected. Daily temperature data, up to and through Diptera emergence, were obtained by using a Taylor Minimum and Maximum thermometer. Precipitation data were collected and measured in a Taylor 126 mm rain gauge. Relative humidity levels were obtained by a Kestrel 3000 Pocket Weather Meter, as well as daily current temperatures after Diptera emergence. Meteorological data were also obtained from the National Oceanic and Atmospheric Administration (NOAA) recording station located at the Durango-La Plata County Airport (WBAN: #93005), and from the NOAA COOP recording station located at The Silverton Standard and The Miner Newspaper (Coop: #057656) in Silverton, Colorado. The Durango - La Plata County Airport WBAN recording station is approximately two miles from Site One and approximately 35 miles from Site Two. The Silverton COOP recording station is approximately ten miles from Site Three.

Photographic documentation of the decomposition stages was made each day that the three sites were monitored. The photographic data were recorded with both a 35 mm and digital camera. Photographs were also taken to document other natural phenomena and specific arthropod activities.
CHAPTER 4: RESULTS

The total number of arthropod taxa collected from carrion at all three sites was 63 (Table 1). Of the 63 arthropod taxa collected, 30 arthropod taxa overlapped between two biogeoclimatic zones. Preliminary indicator species for each biogeoclimatic zone, during the summer months, are presented.

Table 1. Arthropod taxa collected from carrion during the summer field studies in La Plata and San Juan County, CO (June – August 2002).

<table>
<thead>
<tr>
<th>ORDER</th>
<th>FAMILY</th>
<th>GENUS and SPECIES</th>
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</thead>
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</tr>
<tr>
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<td><em>Calliphora latifrons</em> (Hough)</td>
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<td><em>Cynomya cadaverina</em> Robineau-Desvoidy</td>
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<td><em>Cochliomyia macellaria</em> (Fabricius)</td>
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<td><em>Lucilia illustris</em> (Meigen)</td>
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<td><em>Protophormia terraenovea</em> Robineau-Desvoidy</td>
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<td><em>Ataenius spretulus</em> Harold</td>
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Of the 28 Diptera taxa collected, *Phormia regina* was the sole Calliphorid that overlapped all three biogeoclimatic zones (Table 2). *Cochliomyia macellaria* and *P. sericata* were collected only at Site One. *Mesembrina resplendens* was collected at Site Two only. *Calliphora alaskensis*, *C. cadaverina*, and *S. stercoraria* were exclusive to Site Three. Due to no overlapping, the Sarcophagid species show the strongest tendency for being biogeo-climatic zone specific. A previously undescribed *Boettcheria* species was collected only at Site Three.

Of the 28 Coleoptera taxa collected, Carabidae species and *Thanatophilus lapponicus* overlapped all three biogeoclimatic zones (Table 2). Of the four dermestid species, *D. marmoratus* was collected only at Site One and *D. lardarius* at Site Two. Scarabs were collected from Site One and Three. *Trox sonorae* was the sole scarab collected from Site One. The scarabs collected from Site Three were *A. fimetarius* and *A. spretulus*. Specific to Site One was also *Nitidula ziczac*, *N. marginatus* and *Cynaeus angustus*. *Omosita discoidea* and *Ontholestes cingulatus* were exclusive to Site Two.
Table 2. Diptera taxa collected from carrion at three different biogeoclimatic zones in La Plata and San Juan County, CO.

<table>
<thead>
<tr>
<th>ORDER</th>
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<th>SITE 3</th>
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<td>Cynomyca cadaverina Robineau-Desvoidy</td>
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<tr>
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</table>

Diptera identifications by Norman E. Woodley and Ethan C. Kane, Systematic Entomology Laboratory, Agriculture Research Service, US Department of Agriculture. A plus sign denotes a pending verification by an out-of-facility specialist.

Table 3. Coleoptera taxa collected from carrion at three different biogeoclimatic zones in La Plata and San Juan County, CO.

<table>
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<th>ORDER</th>
<th>FAMILY</th>
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<th>SITE 3</th>
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<tr>
<td>Tenebrionidae</td>
<td>Cynaeus angustus (LeConte)</td>
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</table>

Coleoptera identifications by Natalia Vandenberg and Steven W. Lingafelter, Systematic Entomology Laboratory, Agriculture Research Service, US Department of Agriculture. A plus denotes a pending verification by an out-of-facility specialist.
Due to factors outside the researcher’s control, the research at Site Three had to be terminated after 30 days. Having reached only the active decomp stage, a possibility exists that the total of arthropod taxa and taxa overlapping may be greater due to the Coleopteran species that arrive later in the decomposition process.

**Biogeoclimatic Zone Site One**

With approximately a two-mile distance between Site One and the NOAA WBAN station located at the Durango-La Plata County Airport, substantial differences occurred between the maximum and minimum temperatures recorded at both locations. The two recording stations are located on mesa tops in the Pinyon-Juniper forest ecosystem at approximately the same elevation. During the time period of June 17 through July 2, 2002, the NOAA WBAN station recorded a maximum temperature of 98°F and a minimum temperature of 40°F (Figure 2). The maximum temperatures ranged from 88°F to 98°F with a mean maximum temperature of 92.2°F. The minimum temperatures recorded at the NOAA WBAN station ranged from 40°F to 57°F with a mean minimum temperature of 49.1°F (Appendix A). At no time during this sixteen-day-time period was a temperature of 100°F or higher recorded.

During the same time period, a maximum temperature of 106°F and a minimum temperature of 48°F were recorded at Site One (Figure 3). The maximum temperatures ranged from 94°F to 106°F with a mean maximum temperature of 99.6°F. The minimum temperatures recorded on-site ranged from 48°F to 61°F with a mean minimum temperature of 55.3°F (Appendix B). On seven days, temperatures of 100°F or higher were recorded.
Precipitation amounts recorded at both locations were essentially the same. The NOAA WBAN station recorded 0.02 inches of rain from June 17 through July 2, 2002 (Appendix C). The 0.02 inches of rain occurred on June 21. Site One recorded no measurable precipitation, in millimeters, during the same time period (Appendix D). The relative humidity levels at Site One ranged from 8 % to 45 % with a mean of 19.9 %. On-site relative humidity levels above 20 percent were recorded on just six days (Appendix E).

![Figure 2](image2.png)

**Figure 2.** Site One: NOAA Maximum and Minimum Temperatures from Durango-La Plata County Airport WBAN Station.

![Figure 3](image3.png)

**Figure 3.** Site One: On-site Maximum, Current, and Minimum Temperatures.
On June 17, a pig carcass was placed inside the metal cage at 11:21 A.M. at Site One. The first fly, a Calliphora species, arrived twenty-one minutes later. The decomposition of the sun-exposed pig carcass at Site One progressed through the stages of fresh, bloat, active decomp, advanced decomp, and into the dry stage in seven days (Figure 4). In fact, the fresh stage lasted less than twenty-four hours.

![Diagram showing decomposition stages, maggot migration, and fly emergence.](image)

**Figure 4.** Site One: Length of Decomposition Stages, Maggot Migration, and Fly Emergence.

The bloat stage lasted for two days (Days Two - Three). On June 18, abdominal bloating was present; however, no odor was evident. No egg masses were present in the mouth, nares, eyelids, anus, or ears. On June 19 (Day Three), the entire carcass was bloated and a slight odor was detected within the immediate area of the cage (Figure 5). Marbling of the body color occurred. Egg masses were located in the mouth, nares, and at the exit wound towards the back of the throat area. First instar maggots were present in the mouth and nares. Calliphorid and sarcophagid species were present. Coleopteran species present consisted of histeridae, dermestidae and one carabidae.
Figure 5. Site One: Bloat Stage on 6/19/02.

The **active decomp stage** lasted two days (Days Four - Five). On June 20, the pig carcass had deflated and a strong putrefactive odor was present. Hair and skin slippage was beginning. First and second instars were located in the mouth, nares, behind both ears, and the ground contact abdominal area. The maggot mass at the ground contact abdominal area was overflowing past the carcass. Calliphorid and sarcophagid species were present, as well as histeridae, dermestidae and staphylinidae species.

On June 21 (Day Five), hair and skin slippage was continuing. Flesh was still present in the thoracic-abdominal areas, the lower limbs, and hind quarters. First, second and third instar maggots were concentrated within the thoracic and abdominal areas. Maggot mass temperature was recorded at 104° F. Histeridae, dermestidae and silphidae species were present. Calliphorid and sarcophagid species were present but at a reduced concentration from the previous days.
The **advanced decomp stage** lasted 24 hours. On June 22 (Day Six), odor was reduced and just over 50 percent of the flesh was still present. Hair and skin slippage was complete (Figure 6). Late second and third instar maggots were migrating from the carcass. Maggot mass temperature was 101º F. Calliphorid and sarcophagid activity was minimal with less than twenty flies observed. Histeridae, silphidae and dermestidae species were present. Ants were abundant, and they were observed preying on the migrating maggots.

![Figure 6. Site One: Advanced Decomp Stage on 6/22/02.](image)

On June 23 (Day Seven), the carcass had entered the **dry stage** of decomposition. All that remained of the pig carcass was skin, bones, and cartilage. First and second instars maggots were still present; however, late second instar maggots were now migrating from the carcass. A total of ten calliphorid and sarcophagid species were observed in the proximity of the carcass. Histeridae and dermestidae species were
abundant with only one silphidae species present. Due to the depletion of a food source on June 24 (Day Eight), the remaining first and second instar maggots migrated from the carcass, dug into the dirt under the carcass, and/or died. At the research end date on July 26 (Day Thirty-nine), the pig carcass was near the completion of the dry stage with only bones and a minimal amount of desiccated skin left (Figure 7).

![Figure 7. Site One: Dry Stage on Research End Date 7/26/02.](image)

**Fly emergence** sporadically occurred between June 28 and June 30. At no time was a mass emergence observed. During the three days of emergence, June 29 yielded the highest number of newly emerged flies observed with a total of 23. No new emergence of flies was observed between June 30 and July 2, or afterwards when the site was monitored every other day until the designated research end date on July 26.
The patterns of arthropod colonization are affiliated with the morphological decomposition stages and their duration. Table 4 provides a listing of the arthropod taxa present and their respective collection dates of the sun-exposed carcass at Site One.

*Phormia regina* and *C. coloradensis* were the dominant diptera taxa present. *Phormia regina* was first collected on June 18 and *C. coloradensis* was initially collected on June 20. *Cochliomyia macellaria* and *P. sericata* were only observed and collected on June 19. The sarcophagid taxa were collected from June 19 through June 28. Although *Calliphora. coloradensis* was collected on July 11, the carrion attendance by the Diptera taxa had essentially ended by the sixth day of the dry stage.

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<td>Hymenoptera</td>
<td>Formicidae unidentified sp.</td>
<td>6/18-7/9</td>
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</table>

The initial appearance and collection of the Coleoptera taxa *Carabidae* sp., *Dermestes talpinus, D. marmoratus*, and three *Hister* species occurred on June 19 during the bloat stage. Adult predatory beetles (Carabidae, Histeridae, Silphidae and Staphylinidae) were present and collected beginning in the bloat stage and into the dry
stage. Adult dry carrion-feeding beetles (Dermestidae, Nitidulidae, Scarabaeidae, and Tenebrionidae) were present and collected beginning in the bloat stage. The collection of the dermestid beetles ranged from June 19 through July 20. *Nitidula ziczac* was initially collected on June 24. Initially, the scarab beetle *Trox sonorae* was collected on July 5 and collection of this species continued up to the research end date. An unidentified ant species (Formicidae) was abundantly present and predacious in activity from June 18 through July 9; thereafter, the presence of this ant species was incidental in occurrence.

**Biogeoclimatic Zone Site Two**

The distance between Site Two and the NOAA WBAN station located at the Durango-La Plata County Airport is approximately 35 miles with a 2,000 feet difference in elevation. The substantial differences between the maximum and minimum temperatures recorded at both locations were not unexpected. During the time period of June 17 through July 14, 2002, the NOAA WBAN station recorded a maximum temperature of 98º F and a minimum temperature of 40º F (Figure 8). The maximum temperatures ranged from 82º F to 98º F with a mean maximum temperature of 91.2º F. The minimum temperatures recorded at the NOAA WBAN station ranged from 40º F to 58º F with a mean minimum temperature of 50.9º F (Appendix F). At no time during this twenty-eight day time period was a daytime temperature of 80º F or lower recorded.

At Site Two, a maximum temperature of 89º F and a minimum temperature of 50º F were recorded, during the same time period (Figure 9). The maximum temperatures ranged from 69º F to 89º F with a mean maximum temperature of 82.2º F. The minimum temperatures recorded on-site ranged from 50º F to 60º F with a mean
minimum temperature of 54.1º F (Appendix G). Temperatures equal to 80º F or less were recorded on nine days.

**Figure 8.** Site Two: NOAA Maximum and Minimum Temperatures from Durango-La Plata County Airport WBAN Station.

**Figure 9.** Site Two: On-site Maximum, Current, and Minimum Temperatures.
Precipitation amounts recorded at both locations for the 28-day-period were similar. The NOAA WBAN station recorded 0.49 inches of rain from June 17 through July 14, 2002 (Appendix C). The highest amount of rain (0.31 inches) occurred on July 3. Site Two recorded a total of 15.5 millimeters of rain. The 15.5 mm of rain occurred between July 4 and July 9 (Appendix H). The relative humidity levels at Site 2 ranged from 6% to 65 % with a mean of 23.1 %. On-site relative humidity levels above 20 percent were recorded on thirteen days (Appendix I).

The fresh stage lasted three days (Days One - Three). On June 17, the pig carcass was placed inside the metal cage at 1:28 P.M. Within three minutes, the first flies to arrive were two Calliphorid species. The first Sarcophagid species arrived twelve minutes later. The decomposition of the aspen grove shaded pig carcass at Site Two progressed through the stages of fresh, bloat, active decomp, advanced decomp, and into the dry stage in thirteen days (Figure 10).

![Graph showing decomposition stages and maggot migration](image)

**Figure 10.** Site Two: Length of Decomposition Stages, Maggot Migration, and Fly Emergence.
On the second day (June 18), egg masses and first instar maggots were present inside the mouth area. Calliphorid and Sarcophagid species were observed depositing eggs and larvae. The Coleopteran species Histeridae and Leiodidae were present, and an unidentified ant species (Formicidae) was observed preying on the eggs and first instar maggots.

On June 19 (Day Three), egg masses were located in the mouth, behind both ears, on the abdomen, and in the skin folds of the hind limbs. First and second instar maggots were collected from the mouth. The presence of Calliphorid and Sarcophagid had increased from the previous day.

The **stage of bloat** lasted five days (Days Four - Eight). On June 20 (Day Four), the entire carcass was bloated and a putrefactive odor was detected. New egg masses were located in the mouth, behind the left ear, and on the abdomen near the left hind limb. First instar maggots were collected from behind the left ear. All three instar stages were collected from inside the mouth. The attendance of Calliphorid and Sarcophagid species was consistent with that of the previous day. A Silphidae species was collected from under the carcass.

On June 21 (Day Five), marbling in the abdomen region and distention of the anus was observed (Figure 11). New egg masses were found behind both ears, anus, and between the hind limbs. First instar maggots were collected from behind both ears. Second and third instar maggots were present and collected from inside the mouth. With the addition of a Dermestidae species, the Coleopteran species present consisted of Histeridae, Leiodidae and Silphidae.
On Day Six (June 22), the epidermis in the throat region had ruptured due to maggot penetration. Second instar maggots were present behind both ears. Second and third instar maggots were collected from inside the mouth. Calliphorid were observed depositing eggs in the anus region. Muscidae and a Staphylinidae species were present and collected.

On June 23 (Day Seven), the marbled body coloring had extended to the pelvic and thoracic regions. The epidermis was drying out and beginning to separate from the derma. Maggots were observed moving below the epidermis in the thoracic and abdominal regions. A split in the abdominal epidermis allowed the collection of those maggots (first and second instar maggots). Eggs and first and second instar maggots were collected from behind the right ear. With the exception of another new
Staphylinidae species, the Dipteran and Coleopteran species present were the same as Day Six.

On June 24 (Day Eight), the epidermis was separated from the derma on the face, abdomen, fore limb, and hind limb areas. The beginning of mummification was noted due to the derma beginning to darken and dry out. The derma surrounding the urethral and anal orifices was hard and dried; however, second instar maggots were observed inside those orifices and subsequently collected. First instar maggots were found behind the ears. All three instar stages were collected from the mouth. A maggot mass temperature of 90º F was recorded from the mouth. The Dipteran and Coleopteran species were the same as the previous day.

The active decomp stage lasted two days (Days Nine - Ten). On June 25, the carcass had deflated and a strong, putrefactive odor was present. Mummification of the carcass was continuing and the epidermis was separating from the derma over the entire carcass (Figure 12). The derma had darkened in the neck, thoracic, abdominal, pelvic, and lower limb areas and had a leathery appearance. Minimal derma penetration was observed on the ground contact portion of the abdomen. Second and third instar maggots were observed between the lower limbs’ epidermis and derma, and inside the anal and urethral orifices. Postfeeding third instar maggots were collected as they migrated from the mouth. Maggot mass temperatures from the mouth and urethral orifice were 84º F and 82º F, respectively. Dipteran presence was sporadic in attendance and no new Coleopteran species were collected.

On June 26 (Day Ten), the maggot’s penetration of the ground contact derma had progressed and now included locations in the abdomen, thoracic, and pelvic regions.
Maggot mass temperature, taken at the abdominal derma penetration site, was recorded at 105º F. Second and third instar maggots were collected from the abdomen, mouth and pelvic regions. Postfeeding third instar maggots were observed migrating intermittently from the carcass. Dipteran presence was infrequent and greatly reduced in attendance. With the exception of a Cleridae species, all previously reported Coleopteran species were observed or collected.

Figure 12. Site Two: Active Decomp Stage and Mummification on 6/25/02.

The **advanced decomp stage** lasted two days (Days Eleven – Twelve). On June 27, odor was reduced and less than 50 percent of the flesh remained. Maggot mass was strictly concentrated to the ground contact derma penetration areas where a maggot mass temperature was recorded at 104º F. Third instar maggots were migrating from the carcass. Dipteran activity was minimal with less than twenty-five flies observed. Although the previously reported Coleopteran species were present, the ants and
Histeridae were the most abundant and they were observed preying on the migrating maggot masses at distances up to fifteen feet away from the carcass.

On June 28 (Day Twelve), maggot masses were still present and a temperature of 100º F was recorded from the ground contact abdominal area. Third instar maggots were continuing to migrate from the carcass. Second instar maggots were sporadically migrating; however, the range of their migration did not extend outside the metal cage’s parameters. Dipteran presence was minimal with ten flies observed. Histeridae and the ant species continued their predacious activities on the migrating maggots.

On June 29 (Day Thirteen), the carcass had entered the dry stage of decomposition. All that remained of the pig carcass was the mummified skin, bones and joint cartilage. Postfeeding third instar maggots had completely vacated the carcass and were observed migrating in a north/northeast direction. The migration range of the late second instars extended approximately three feet outside of the cage’s parameters. Early second instar maggots were still present within the mummified hide. Dipteran activity was minimal in the proximity of the carcass. Histeridae, Staphylinidae, and the ant species were preying on the migrating maggots.

Due to the depletion of a food source on June 30 (Day Fourteen), the remaining second instar maggots were burrowing into the dirt under the carcass, and/or dying. No maggots were observed migrating outside of the metal cage. The predacious activities of Histeridae and Staphylinidae were concentrated within the metal cage. At the research end date on July 26 (Day Thirty-nine), the mummified pig carcass was still intact except for the ground contact surface (Figure 13).
An initial fly emergence occurred during two phases. The first phase occurred on July 6 and July 7 (Days Twenty and Twenty-one). During the initial emergence, the newly emerged flies were observed roosting directly on the ground or on ground clutter (i.e., twigs, dried leaves). The second phase occurred between July 10 and July 14. In the second phase, the newly emerged flies were observed roosting on the ground, ground clutter, bushes, and about 15 feet up an aspen trunk. Throughout both phases, the unidentified ant species was observed preying on the newly emerged flies. No additional phase of fly emergence was observed after July 14, when the site was monitored every other day until the designated research end date on July 26.

Table 5 provides a listing of the arthropod taxa present and their respective collection dates of Site Two’s shaded pig carcass. The eight Calliphorid species were the dominant diptera taxa collected and the lengths of their presence are within similar time
frames. The Calliphorid species with the lengthiest collection dates were *C. latifrons* at 15 days, and *C. vomitoria, C. livida* and *P. regina* at nine days. With the exception of one collection on July 7, the sarcophagid species were present and collected from June 19 through June 26. Although *C. latifrons* was collected through July 5, the carrion attendance by the majority of the Diptera taxa essentially ended by the first day of the dry stage.

**Table 5.** Site Two: Arthropod Taxa and Respective Collection Dates.

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<td>Staphylinidae</td>
<td><em>Chephilus maxillosus</em> (Linnaeus)</td>
<td>6/22-7/11</td>
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<td>Hymenoptera</td>
<td><em>Otholenes cingulatus</em> Grav.</td>
<td>6/23-7/11</td>
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<td>Araneae</td>
<td>unidentified sp.</td>
<td>7/11-7/13</td>
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<td><em>Pardosa</em> sp.</td>
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<td><em>Dolichovespula maculata</em> (Linnaeus)</td>
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The initial appearance of the Coleoptera taxa occurred on June 18, during the fresh stage, with the collection of two *Hister* species and *Catops* species. Silphidae and Staphylinidae were initially present and collected in the bloat stage. The adult predatory
beetles (Histeridae, Silphidae and Staphylinidae) were still present and collected during the dry stage. The initial appearance of the adult dry carrion-feeding beetles (Dermestidae and Nitidulidae) occurred in the bloat and dry stages. The collection of *D. talpinus* ranged from June 21 through July 5. *Omosita discordea* was collected from June 30 through July 26. No scarab beetles were observed or collected from Site Two. An unidentified species of ant (Formicidae) was abundantly present and predacious in activity from the fresh stage until maggot migration was completed. From July 22 through July 26, a *Pardosa* species was continuously present inside the mummified hide.

**Biogeoclimatic Zone Site Three**

The distance from Site Three and the NOAA COOP station located in the town of Silverton, CO is approximately ten miles with an elevation difference of 1,800 feet. During the time period of August 2 through August 31, 2002, the NOAA COOP station recorded a maximum temperature of 82º F and a minimum temperature of 29º F (Figure 14). The maximum temperatures ranged from 53º F to 82º F with a mean maximum temperature of 72.7º F. The minimum temperatures recorded at the NOAA COOP station ranged from 29º F to 47º F with a mean minimum temperature of 37.1º F (Appendix J). During this thirty-day period, only eight days had a daytime temperature below 70º F.

At Site Three, a maximum temperature of 73º F and a minimum temperature of 32º F were recorded, during the same time period (Figure 15). The maximum temperatures ranged from 43º F to 73º F with a mean maximum temperature of 62.9º F. The minimum temperatures recorded on-site ranged from 32º F to 48º F with a mean minimum temperature of 41.8º F (Appendix K). Daytime temperatures equal to or greater than 70º F were recorded on six days.
Figure 14. Site Three: NOAA Maximum and Minimum Temperatures from COOP Station in Silverton, CO.

Figure 15. Site Three: On-site Maximum, Current, and Minimum Temperatures.

Precipitation amounts recorded at both locations for the 30 day period were slightly different. The NOAA COOP station recorded 2.56 inches of rain from August 2 through August 31, 2002 (Appendix L). The highest amount of rain (0.56 inches)
occurred on August 30. Site Two recorded a total of 72 millimeters of rain. The highest amount of rain occurred over a two day period (August 19–20) when a combined total of 20 mm was recorded (Appendix M). The on-site relative humidity levels at Site Two ranged from 10% to 93% with a mean of 38%. Relative humidity levels above 20 percent were recorded on eighteen days (Appendix N).

The fresh stage lasted four days (Days One-Four). On August 2, a pig carcass was placed inside the metal cage at 1:45 P.M. at Site Three during a steady downpour. No flies were observed in the proximity of the carcass and site. On August 3 (Day Two), no egg masses were found on the carcass. Rigor mortis was present in the distal end of the lower limbs, and livor mortis was fixed.

On August 4 (Day Three), egg masses were found and collected from the tip of the tongue, right eyelid, and behind the right ear, which were all in contact with the ground. At 10:40 A.M., the first Calliphorid was observed on the carcass. Staphylinidae were collected from under the carcass. On August 5 (Day Four), rigor mortis had broken down. The abdomen was pliable and no odor was detected. Egg masses were located in the mouth, inside the right ear and right eyelid, behind the ears, between the fore and hind limbs, and on the neck that was in contact with the ground. Calliphoridae, a previously undescribed Boettcheria species, and Staphylinidae species were present and collected.

The total length of the bloat and active decomp stages was twenty-six days (Figure 16). Due to the length of these two stages, on-site observation or detection of decomposition change was difficult if not impossible. Therefore, only significant decomposition changes will be highlighted regarding these two stages. A listing of the
observed locations of egg masses and maggot instars, by date, for each decomposition stage is presented in Table 6.

Figure 16. Site Three: Length of Decomposition Stages and Maggot Migration.

The bloat stage lasted fifteen days (Days Five - Nineteen). On August 6 (Day Five), the abdomen was slightly bloated and faint marbling was observed; however, no odor was detected. On August 7 (Day Six), the abdomen had a greenish tint and opaque fluid was purging from the nares. Egg masses were observed on the ground after being washed off the carcass by the previous day’s rain storm.

On August 8 (Day Seven), the derma around the nares had darkened and no fluid was observed purging from the nares. The epidermis was beginning to separate from the derma near the exit wound in the throat area. On August 9 (Day Eight), the abdomen was hard but only slightly bloated. On August 10 (Day Nine), opaque fluid was purging from the nares. Muscle stiffness along the spinal column was detected. The tongue was dried and had retracted inside the mouth. The derma surrounding both eyes was
darkened and dried. The lower limbs were still flexible. A *Catops* sp. and an unidentified Formicidae species were present and collected.

Table 6. Site Three: Dates and Locations of Egg Mass and Instar Maggots Present on Carrion per Decomposition Stage (August 2 – 31, 2002).

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<tr>
<th>Date</th>
<th>Mouth</th>
<th>Exp. Rt Eye</th>
<th>Exp. Lt Eye</th>
<th>Exp. Rt Ear</th>
<th>Exp. Lt Ear</th>
<th>Exp. Abdomen</th>
<th>Between Fore Limbs</th>
<th>Between Hind Limbs</th>
<th>Below Epidermis</th>
<th>Above Epidermis</th>
<th>G.C. Shoulder and Thoracic Area</th>
<th>Exp. Shoulder and Thoracic Area</th>
<th>Urethral Orifice</th>
<th>Anal Orifice</th>
<th>Overflow Onto Ground</th>
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Egg Mass denoted with 0; First Instar denoted with 1; Second Instar denoted with 2, and Third Instar denoted with 3. Exp denotes exposed and G.C. denotes ground contact. The gray shaded portion of August 19 denotes that a thorough examination of the carcass was not completed due to lightning strikes in the immediate area of Site Three.

On August 11 (Day Ten), the skin around the mouth was dry. On August 12 (Day Eleven), distinctive marbling of the abdomen was observed. The epidermis of the exposed right shoulder, behind the right ear, and lower limbs was beginning to dry out. On August 13 (Day Twelve), a transparent fluid was purging from the nares. The anal region was beginning to swell and fecal matter was visible at the orifice. On August 14 (Day Thirteen), the abdomen was bloated and the greenish tint had faded. The entire anal region was swollen. The derma of the exposed pelvic region and hind limbs was beginning to darken. Maggot penetration of the derma was located behind the right ear. Calliphorid activity was pronounced.
On August 15 (Day Fourteen), the carcass was bloated and a faint odor was detected. **Mummification** of the carcass was defined because the ground contact derma was darkened, devoid of hair and leathery in appearance. Calliphorid activity was pronounced and concentrated at the mouth, right eye, and anal orifice. On August 16 (Day Fifteen), the epidermis was separating from the derma behind the right ear. The urethral orifice was hard and dry. Calliphorid activity was pronounced at the same locations reported for August 15.

On August 17 (Day Sixteen), first and second instar maggots were observed moving between the epidermis and derma on the exposed portions of the carcass. A Silphidae species was collected from under the carcass. A maggot mass temperature was recorded at 82° F from the right ear. On August 18, the entire carcass was bloated and epidermis separation was prominent throughout the facial area (Figure 17). The derma around the mouth was darkened and dried. A Scarabaeidae species was collected from beneath the carcass on August 19. On August 20 (Day Nineteen), the entire exposed surfaces of the carcass were covered with second and third instar maggots. The instar maggots were moving all over the epidermis surface as well as between the epidermis and derma. The above mentioned activity of the maggots correlates with the 10 mm of rainfall that occurred on August 19 at Site Three.
The **active decomp stage** was defined on August 21 (Day Twenty) with the detection of a strong putrefactive odor being emitted from the carcass. Second instar maggots were concentrated within the carcass’ natural orifices. The first indication of carcass deflation was noted on August 23 (Day Twenty-two) with a slight lowering of the right fore limb. On August 24 (Day Twenty-three), the right fore limb had returned to its pre-bloat position. Postfeeding third instar maggots were observed burrowing into the ground directly beneath the carcass.

On August 26 (Day Twenty-five), the beginning of epidermis separation was found on the right fore limbs, the abdominal area, and the pelvic region. Calliphorid attendance at the carrion was minimal. On August 28 (Day Twenty-seven), epidermis separation was beginning on the exposed right shoulder area. Third instar maggots were the dominant growth stage found at the ground contact derma penetration sites. The
abdomen was completely deflated on August 29 (Day Twenty-eight). Two small derma penetration sites were located on the exposed pelvic region.

On August 30 (Day Twenty-nine), epidermis separation was present on the majority of the exposed surfaces and the exposed surface of the derma was continuing to darken and dry out. Figure 18 shows the overall condition of the carrion and Figure 19 shows the epidermis separation and small derma penetration sites on the lower abdominal and pelvic regions.

Figure 18. Site Three: Active Decomp Stage on 8/30/02.

On the research end date, August 31 (Day Thirty), second and third instar maggots were concentrated within the natural orifices, at the derma penetration sites, on the exposed derma surface, and on the ground beneath the carcass. Third instar maggots were observed burrowing into the ground directly under the carcass. The derma penetration sites on the ground contact surface were minimal in size and concentrated in
the facial and thoracic areas. Figure 20 shows the darkened and leathery appearance (mummification) of the derma in contact with the ground. Calliphorid species were still attracted to the carrion and subsequently collected. Staphylinidae and Catops sp. were present and collected, in addition to the unidentified ant species. During the active decomp stage, the migration of third instar maggots was strictly limited to under the carcass and at no time during site monitoring were third instar maggots observed migrating from the carcass at any distance.

**Figure 19.** Site Three: Epidermis separation and derma penetration sites on 8/30/02.
Table 7 provides a listing of the arthropod taxa present and their respective collection dates of Site Three’s sun-exposed/shaded carcass. Nine Calliphorid species were the dominant Diptera taxa present. The Calliphorid species with the longest collection dates were *P. terraenovea* at twenty-eight days, *C. vomitoria* at twenty-seven days, and *C. livida* and *P. regina* at twenty-two days. *Calliphora alaskensis* was present for fourteen days. A previously **undescribed** *Boettcheria* species was initially collected on August 5. The unidentified *Sarcophaginae* species was collected the last time on August 27; therefore, the Sarcophagid species were present from the fresh stage through the active decomp stage. The majority of the Diptera taxa had not reduced by the research end date.

The initial appearance of the Coleoptera taxa occurred on August 6 with the appearance of an unidentified *Staphylinidae* species. Silphidae and Scarabaeidae were
initially collected in the bloat stage. *Thanatophilus lapponicus* was the dominant Silphidae species collected; however, no collection was made after August 25. The Scarabaeidae *Ataenius spretulus* was collected over an eleven-day period with the last collection occurring on August 29. Histeridae and Dermestidae were not observed at any time over the thirty-day period. An unidentified ant (Formicidae) species was present sporadically from the bloat stage to the last day of the research.

Table 7. Site Three: Arthropod Taxa and Respective Collection Dates.

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<th>FAMILY</th>
<th>GENUS and SPECIES</th>
<th>COLLECTION DATES</th>
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<td><strong>Diptera</strong></td>
<td><strong>Anthomyiidae</strong></td>
<td>unidentified sp.</td>
<td>8/4, 8/6, 8/9</td>
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<tr>
<td></td>
<td><strong>Calliphoridae</strong></td>
<td><em>Calliphora alaskensis</em> (Shannon)</td>
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<td></td>
<td><em>Calliphora livida</em> (Hall)</td>
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<td><em>Calliphora terraenovae</em> (Macquart)</td>
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<td><em>Calliphora vomitoria</em> (Linnaeus)</td>
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<td><em>Cynomya cadaverina</em> Robineau-Desvoidy</td>
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<td><em>Lucilia illustris</em> (Meigen)</td>
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<td><em>Fannia</em> sp.</td>
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<td><strong>Leiodidae</strong></td>
<td><em>Catops</em> sp.</td>
<td>8/10-8/31</td>
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<td><strong>Scarabaeidae</strong></td>
<td><em>Aphodius fimetarius</em> (Linnaeus)</td>
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<td></td>
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<td><em>Ataenius spretulus</em> (Harold)</td>
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<td><strong>Formicidae</strong></td>
<td>unidentified sp.</td>
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Due to the sun-exposed/shaded carrion at Site Three not having reached the dry stage, the data for the arthropod taxa associated with carrion, rates of decomposition, and arthropod succession patterns are incomplete. However, based on the decomposition rates from the lower biogeoclimatic zones and the prolongation of the bloat stage at Site Three, the prevalence of an extensive decomposition rate is strongly suggested within the subalpine biogeoclimatic zone due to elevation.
CHAPTER 5: DISCUSSION

The current study on the identification of the arthropod taxa associated with carrion, decomposition stage lengths, and arthropod succession patterns has shown similarities and differences in each of the biogeoclimatic zones in southwest Colorado. *Phormia regina* was collected at the three biogeoclimatic zones and carrion scenarios. Seven of the thirteen collected Calliphorid species (*Calliphora latifrons, C. livida, C. terraenovea, C. vomitoria, Lucilia illustris*, and *Protophormia terraenovea*) overlapped the two highest biogeoclimatic zones (elevation from 8,700 – 11,100 feet) and the shaded and sun-exposed/shaded carrion scenarios. *Calliphora coloradensis* overlapped the two biogeoclimatic zones between 6,700 – 8,700 feet in elevation, as well as the sun-exposed and shaded carrion scenarios. At Site One, the collection of *C. coloradensis* occurred when the carrion was in direct sunlight. De Jong and Chadwick (1999) reported that as elevation increased the number of taxa was drastically reduced. In the current study, the number of Calliphorid taxa present did not reduce as elevation increased; however, the difference between the two findings may reflect the biogeoclimatic differences between the northern and southern portions of the Rocky Mountain range in Colorado.

Two preliminary Calliphorid indicator species for PMI determination were noted for the lowest biogeoclimatic zone (Site One) and highest biogeoclimatic zone (Site Three). At the sun-exposed carrion, *Cochliomyia macellaria* and *Phaenicia sericata* were exclusively collected at Site One on June 19. In accordance with Hall (1948), the presence of *C. macellaria* was limited (one specimen) during extreme high temperatures and low humidity levels. *Calliphora alaskensis* and *C. cadaverina* were collected solely at the sun-exposed/shaded carrion at Site Three (elevation 11,100 feet). The only
collection data pertaining to *C. alaskensis* in Colorado was reported by Hall (1948) and De Jong and Chadwick (1999) in the north and north central area of the state, respectively. The current research has extended the range of *C. alaskensis* to southwestern Colorado.

The Sarcophagid taxa showed the strongest tendency for being biogeoclimatic zone specific. Of the eight Sarcophagid taxa collected, the four identified species (*Blaesoxipha plinthopyga, Sarcophaga nearctica, Tripanurga sulculata* and *Toxonagria montanensis*) were exclusive to a respective biogeoclimatic zone. *Blaesoxipha plinthopyga, T. sulculata*, and a *Ravinia* species were collected solely at Site One (elevation 6,700 feet). *Sarcophaga nearctica, T. montanensis* and a *Liosarcophaga* species were collected at Site Two (elevation 8,700 feet). At Site Three (elevation 11,100 feet), an *undescribed Boettcheria* species was collected. The undescribed *Boettcheria* species did not overlap at the two lower biogeoclimatic zones; therefore, the undescribed *Boettcheria* species appears to be specific to the high elevational biogeoclimatic zone.

In the current study, half of the twenty-eight Coleopteran taxa collected overlapped at least two of the biogeoclimatic zones even though the carrion at Site Three had not completed the active decomposition stage. However, a preliminary finding from this study does suggest a biogeoclimatic boundary below 8,700 feet of elevation for *Trox sonorae*. *Trox sonorae* was initially collected on the thirteenth day of the dry stage at Site One and was present for the next twenty-one days. At Site Two, the dry stage, up to the research end date, totaled twenty-seven days. Throughout those twenty-seven days, *Trox sonorae* was never observed or collected at Site Two.
The length of carrion decomposition varied markedly between the three biogeo-climatic zones. The carcasses at Site One, Site Two, and Site Three remained in the fresh stage for less than 24 hours, three days, and four days, respectively. The length of the bloat stage lasted two days at Site One and five days at Site Two. At Site Three, the bloat stage lasted fifteen days. In accordance with De Jong and Chadwick (1999), prolongation of the bloat stage did occur as elevation increased. The active decomp stage lasted two days at both Site One and Two; however, by Site Three’s research end date, the carrion was in the eleventh day of active decomposition with no observable or detectable sign of entering the advanced decomp stage. The advanced decomp stage lasted only one and two days at Site One and Site Two, respectively. On the eighth day since death, the carrion at Site One entered the dry stage of decomposition. At Site Two, the carrion had entered the dry stage on the thirteenth day since death.

Mummification of carrion occurred at the two highest biogeoclimatic zones. At both sites, the onset of mummification began in the bloat stage. Epidermis separation and derma dehydration with darkening were the initial morphological indicators of the onset of mummification. The attraction of the carrion remained constant to the arthropod taxa; however, the arthropod attendance was concentrated to the natural orifices and ground contact areas. In support of Mann et al. (1990), the current study found the overall destruction of the mumified derma to be limited and primarily restricted to the thoracic/abdominal areas in contact with the ground. Minimal destruction (i.e., maggot penetration sites) occurred on the carrion’s exposed surface.

The patterns of arthropod colonization of carrion are variable from one region or biogeoclimatic zone to another. Lacking of prior regional PMI research to reference,
colonization findings from this study can act as an initial baseline for future studies conducted in the southwestern Colorado region. At the sun-exposed carrion (Site One), the first Dipteran taxon to arrive but not collected was a blueblow fly after twenty-one minutes of carrion placement. Thereafter, Calliphoridae and Sarcophagidae were consistently present through the advanced decomposition stage with sporadic appearances into the dry stage. Dermestidae and Histeridae were present in the bloat stage and continued to be collected in the dry stage. Silphidae arrived in the active decomposition stage and continued to be present into the early portion of the dry stage. Cleridae and Scarabaeidae were exclusive to the dry stage. Hymenoptera was consistently present from the bloat stage through the early portion of the dry stage.

At the shaded carrion (Site Two), the first Dipteran taxa to arrive were Calliphoridae species after three minutes of carrion placement and Sarcophagidae arrived twelve minutes later. Eight Calliphoridae and three Sarcophagidae species were continually present through the advanced decomposition stage. Histeridae arrived in the fresh stage and continued to be present throughout the dry stage. Two Dermestidae species were present in the bloat stage; however, the three Dermestidae species continued to be collected through the seventh day of the dry stage. Silphidae arrived during the bloat stage and exited the carrion in the dry stage. Staphylinidae were present from the bloat stage through the early portion of the dry stage.

The colonization data for the sun-exposed/shaded carrion (Site Three) are incomplete and include the arrival of the arthropod taxa through the active decomposition stage. Nine Calliphoridae and two Sarcophagidae species were in attendance of the carrion beginning in the fresh or bloat stage through the research end date. Silphidae
arrived during the last two days of the bloat stage and were collected during the initial five days of the active decomposition stage. Staphylinidae were present on the first day of the bloat stage and continued to be present to the research end date. Leiodidae and Scarabaeidae were present from the bloat stage through the active decomposition stage.

The meteorological data recorded at the NOAA WBAN and COOP stations did not reflect the actual meteorological conditions recorded, during the same time periods, at the three research sites. The recorded meteorological differences are best illustrated by Site One. The Durango-La Plata County Airport NOAA WBAN station is approximately two miles from Site One. Both locations are within the same biogeoclimatic zone with an elevational difference of twenty-six feet. Although precipitation amounts were essentially the same, the difference in recorded maximum temperatures was significant. The NOAA WBAN station recorded a mean temperature of 92°F with maximum temperatures ranging between 88°F to 98°F. In the same time period, the on-site mean temperature at Site One was 99°F, with maximum temperatures ranging between 94°F to 106°F.

Southwest Colorado is a region comprised of multiple biogeoclimatic zones with extreme elevational changes. Different weather conditions are commonplace from one area to the next on any given day. The majority of the meteorological data available is recorded in towns at NOAA COOP stations and these towns are located at considerable distances from the commonly used recreational areas. To establish a relevant PMI determination database for medico-legal cases in this region, the current study has shown
the necessity of recording meteorological data for extended periods of time during all
seasons in the region’s different biogeoclimatic zones.
CHAPTER 6: CONCLUSION

Carrion decomposition rates and arthropod succession patterns are affected by a variety of factors unique to a geographic region or biogeoclimatic zone. The sequence of decomposition has been well established; however, the rate of decomposition can be highly variable between regions and from one biogeoclimatic zone to another. This in turn has a direct impact on arthropod taxa associated with carrion and arthropod succession patterns. This study provides preliminary information on the rate of decomposition, arthropod taxa and their patterns of carrion colonization in the summer months for three different carrion exposure scenarios (sun-exposed, shaded, and sun-exposed/shaded) at three biogeoclimatic zones (Pinyon-Juniper, Aspen Grove, and Subalpine Pine Forest) in southwest Colorado.

In the current study, the preliminary findings do suggest a biogeoclimatic boundary, based on elevation, for the Dipteran taxa associated with carrion. Two preliminary Calliphorid indicator species were noted in both the lowest and highest biogeoclimatic zones. The Sarcophagid taxa did not overlap between biogeoclimatic zones, and therefore, showed the strongest tendency for being biogeoclimatic zone specific. At the highest biogeoclimatic zone (elevation 11,100 feet), a previously undescribed *Boettcheria* species was collected. This undescribed Boettcheria species was not collected at either of the two lower biogeoclimatic zones.

The current study also showed a marked difference in the length and pathways of carrion decomposition between the three biogeoclimatic zones. At the two highest biogeoclimatic zones, the prolongations of the bloat stage lengthen proportionately with the increase of elevation. Natural carrion mummification also occurred at the two highest
biogeoclimatic zones, and the onset of mummification was noted in the bloat stage with continued attendance by the necrophilous insects.

In the current study, the NOAA meteorological data did not reflect the on-site meteorological conditions that occurred at the three sites. Significant differences were noted in maximum and minimum temperatures, as well as precipitation amounts, and the dates of occurrence. In southwest Colorado, the relevance of the NOAA meteorological data for PMI determination is problematical because the NOAA recording stations are located at great distances from the commonly used recreational areas. Therefore, on-site meteorological data is paramount. Due to the mosaic landscape and the diverse weather conditions of southwest Colorado, further work is required in each biogeoclimatic zone and season to establish a relevant database. Currently, this work is being undertaken.
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Micozzi, Marc S.

Payne, Jerry A.

Rhine, Stanley and James E. Dawson

Rodriquez, William C. and William M. Bass
Shean, Blair S., Lynn Messinger and Mark Papworth

Tessmer, Jeanine W.
### APPENDIX A

**STATISTICAL ANALYSIS OF TEMPERATURE AND PRECIPITATION DATA FROM THE NOAA WBAN LOCATED AT DURANGO-LA PLATA COUNTY AIRPORT (JUNE 17 – JULY 14, 2002).**

<table>
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APPENDIX B

STATISTICAL ANALYSIS OF TEMPERATURE, PRECIPITATION AND RELATIVE HUMIDITY DATA RECORDED AT SITE ONE
(JUNE 17 – JULY 2, 2002).

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APPENDIX C. NOAA PRECIPITATION AMOUNTS FROM DURANGO-LA PLATA COUNTY AIRPORT WBAN STATION

APPENDIX D. SITE ONE: ON-SITE PRECIPITATION AMOUNTS
APPENDIX E. SITE ONE: ON-SITE RELATIVE HUMIDITY LEVELS IN PERCENT

![Graph showing relative humidity levels from June 17 to July 2, 2002.](attachment:image.png)
APPENDIX F

STATISTICAL ANALYSIS OF TEMPERATURE AND PRECIPITATION DATA FROM THE NOAA WBAN LOCATED AT DURANGO-LA PLATA COUNTY AIRPORT (JUNE 17 – JULY 14, 2002).

<table>
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<tr>
<td>Mode</td>
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<tr>
<td>Standard Deviation</td>
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</tr>
<tr>
<td>Kurtosis</td>
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<tr>
<td>Skewness</td>
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<tr>
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<tr>
<td>Minimum</td>
</tr>
<tr>
<td>Maximum</td>
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APPENDIX G

STATISTICAL ANALYSIS OF TEMPERATURE, PRECIPITATION AND RELATIVE HUMIDITY DATARecorded at Site Two (June 17 – July 14, 2002).

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<tr>
<th>Maximum Temperatures</th>
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<tr>
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<table>
<thead>
<tr>
<th>Precipitation (mm)</th>
<th>Relative Humidity (%)</th>
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<td>Sample Variance 181.28</td>
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<td>Kurtosis 5.18</td>
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APPENDIX H. SITE TWO: ON-SITE PRECIPITATION AMOUNTS

June 17 - July 14, 2002

APPENDIX I. SITE TWO: ON-SITE RELATIVE HUMIDITY LEVELS IN PERCENT

June 17 - July 14, 2002
### APPENDIX J

**STATISTICAL ANALYSIS OF TEMPERATURE AND PRECIPITATION DATA FROM THE NOAA COOP STATION LOCATED IN SILVERTON, CO (AUGUST 2 – AUGUST 31, 2002).**

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<td><strong>Minimum</strong></td>
<td>29.00</td>
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<td><strong>Count</strong></td>
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<td><strong>Confidence Level (95.0%)</strong></td>
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<table>
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<tr>
<th><strong>Precipitation (In)</strong></th>
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<tr>
<td><strong>Mean</strong></td>
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<td><strong>Median</strong></td>
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<td><strong>Mode</strong></td>
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<td><strong>Standard Deviation</strong></td>
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<td><strong>Sample Variance</strong></td>
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<td><strong>Range</strong></td>
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<td><strong>Minimum</strong></td>
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<td><strong>Maximum</strong></td>
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<tr>
<td><strong>Count</strong></td>
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<tr>
<td><strong>Confidence Level (95.0%)</strong></td>
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# APPENDIX K

## STATISTICAL ANALYSIS OF TEMPERATURE, PRECIPITATION AND RELATIVE HUMIDITY DATA RECORDED AT SITE THREE

(AUGUST 2 – AUGUST 31, 2002)

### Maximum Temperatures

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### Minimum Temperatures

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### Precipitation (mm)

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### Relative Humidity (%)

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APPENDIX L. NOAA PRECIPITATION AMOUNTS FROM COOP STATION IN SILVERTON, CO.

APPENDIX M. SITE THREE: ON-SITE PRECIPITATION AMOUNTS
VITA

Maria T. Allaire was born on February 28, 1955, in Milwaukee, Wisconsin. She began her career in law enforcement in 1978. During her nineteen years in law enforcement, Maria initially attained the rank of detective and sergeant in the Crimes against Person Division. In addition, she was a sergeant in the Burglary, Patrol, and Correctional Divisions. In 1995, she was hired by the La Plata County Coroner’s Office as a deputy coroner. She graduated from Fort Lewis College in 1997 with a bachelor’s degree in anthropology. In 1998, Maria was promoted to chief deputy coroner. In the fall of 2000, she entered the master’s program at Louisiana State University. Currently, Maria is continuing her career with the La Plata County Coroner’s Office as chief deputy coroner. Her future plans are to remain in the applied medico-legal field and to earn a doctorate in anthropology.