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Title: Post Mortem Interval and Decomposition Rates: Biological Observations And Mathematical Analysis.

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Entomological evidence can be used for estimating post mortem interval (PMI). Decomposition studies have been conducted throughout the world and these studies have demonstrated that insect succession generally follows a similar pattern at a taxonomic level, specifically family, but varies at the genus and species levels with respect to geographic and seasonal differences. Insect succession data developed in one region cannot be used generally to estimate PMI in another region. Research has been conducted in a few regions of North America, but at this time there is no known forensic decomposition data for Northwestern Oregon. OBJECTIVES: (1) establish a preliminary insect succession model that can be used by regional law enforcement personal to

establish PMI and (2) present a standardized mathematical model that provides a basis for the empirical analysis and comparison of decomposition rates from different regions. RESULTS: Calliphoridae fly species, *L. illustris,* was the first insect species to arrive and did so in less than 10 minutes PMI. *L. illustris*, ovipositing took place 6 hours PMI, thus starting the time clock that measures PMI. Secondly, our mathematical analysis gives indication that decomposition has been over simplified. Decomposition has several parameters that have not been elicited; therefore, the next step in our decomposition rate research is to analyze the characteristics of the maggots mass separately from the decomposing carcass. Such controlled experiments would provide valuable understanding of the dynamics of carcass decay.

Post Mortem Interval and Decomposition Rates: Biological Observations and Mathematical Analysis

by

David B. England II

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I understand that my thesis will become part of the permanent collection of the Oregon State University Libraries. My signature below authorizes release of my thesis to any reader upon request.

David B. England II, Author

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DEDICATION

First and foremost, this thesis is dedicated to Shauna who is a constant source of support and happiness in my life; her patience with my nearly continuous antics is endless. It is also dedicated to my children Zoey, Ben and Dave and my parents David and Eileen... thank you all for your endless support during this and all that I do.

Chapter 1

Review of Forensic Entomology Post Mortem Interval Studies

1.1 Introduction

Forensic entomology is the name given to any study or application of arthropods to legal matters. Well known to many entomologists, the first documented application took place in the Far East in 1235 A.D. A Chinese "death investigator" named Sung Tz'u wrote a book called the *Washing Away of Wrongs*. In this text, Tz'u recounted a slashing murder that had taken place in a small Chinese village. After fruitless questioning, all farmers in the village were ordered to bring their sickles for examination. All sickles appeared clean; however, flies were attracted to one, most likely due to the invisible blood and tissue still remaining on the sickle. Shortly thereafter the owner relented and confessed to the crime (Catts and Haskell, 1990). Despite this early beginning the science of forensic entomology has struggled to maintain growth and application. However, the science is beginning to gain more recognition (Benecke, 2001; Catts and Haskell, 1990; Hall, 2001).

1.2 Current Literature

Within the last two decades, and more recently with the help of popular media, forensic entomology has experienced an accelerated growth in notoriety and application. Within the United States and around the world, entomologists are being called on more frequently to consult death investigators on insect

evidence that has been recovered from a death scene. A number of texts and reviews have summarized this knowledge (Catts and Goff, 1992; Erzinclioglu, 1983; Greenberg, 1991; Hall and Donovan, 2001; Kabkaew et al., 2000; Keh, 1985; Rodriguez and Bass, 1983; Smith, 1986).

Shortly after death, necrophagous insects are usually the first organisms to arrive on a carcass. Colonization of the carcass follows a predictable sequence, called 'succession' in an ecological context. Forensic entomology is therefore based on the analysis of the insects that are found on the carcass. Estimating a post mortem interval (PMI) is the primary focus of forensic entomology and is based on knowledge of the life cycles and succession patterns of necrophagous insects and determining the ecological variables that influence the insect's natural behaviors and growth rates. In conjunction with estimating PMI, entomological information can also be extremely useful in determining the cause and location of a death (Byrd and Castner, 2001; Catts, 1992; Catts and Goff, 1992; Catts and Haskell, 1990; Goff, 2000; Goff, 1993; Greenberg, 1991; Rodriguez and Bass, 1983; Smith, 1986; Wells, 2001).

At each stage, from fresh to skeletal, a decomposing carcass is a rapidly changing microenvironment that supports numerous arthropod species of every developmental stage. A decomposing carcass passes through well known and discernible stages of decomposition, i.e. fresh, bloated, active decay, advanced decay, and dry remains (Catts and Haskell, 1990). The stages of a decomposing carcass are marked by certain physical, biological and chemical changes, and as each of these various changes take place, the corpse becomes attractive or

unattractive to different groups of arthropods (Arnaldos, Romera, Garcia, and Luna, 2001; De Jong and Chadwick, 1999; Schoenly, 1992; Kimberly L. Tabor, Brewster, and Fell, 2004). It is this predictable sequence of insect colonization and their development that is used to establish post mortem interval (Amendt, Krettek, and Zehner, 2004; Anderson, 2001; Byrd and Castner, 2001; Catts and Goff, 1992).

Studies on necrophagous insect succession patterns have been conducted in limited regions throughout the world, and each of these studies have demonstrated that the succession of insects generally follows a similar pattern at the family level; however, there are variations at the genus and species levels with respect to differing geographicl locations (Amendt et al., 2004; Anderson, 2001; Grassberger and Frank, 2004; Payne, 1965; Tabor et al., 2004). Therefore, insect succession and decomposition data developed in one region cannot or should not be used with confidence to determine PMI in a different region (Amendt et al., 2004; Anderson, 2001; Grassberger and Frank, 2004; Greenberg and Kunich, 2002). Decomposition and insect succession research has been conducted in some parts of North America. Models exist for Hawaii (Goff, 2000), some areas in the Southern U.S. (Tabor, 2004), and (Anderson, 2001). At this time there is limited decomposition data for the Pacific Northwest (Shean, 1993) and no forensic decomposition date for Northwestern Oregon.

In chapter 2, a decomposition study conducted in the mid Willamette Valley on two pig carcasses provides necrophagous insect succession and decomposition data that were collected during the summer of 2005. The main

objective of this study is to establish a practical insect succession model that can be used by regional law enforcement personal to estimated PMI during death investigations. A second objective in the experiment was to establish basic data that will facilitate continued decomposition research in the region.

In chapter 3, a mathematical model is presented that provides a tool for the empirical analysis of decomposition rates. As entomologists conduct more decomposition studies, the science likely will develop a standardized mechanism for the empirical qualitative comparison of the decomposition rate data being collected. Such a tool will help researchers to quantify and explain differences in the stochastic variables that influence decomposition rates.

Decomposition data were collected to establish a model of insect succession data for the Northwest Oregon region. These data answer the question of which insects in the region are first to arrive on a decomposing carcass and which species can reliably be used in the estimation of PMI in the region. A baseline of biological observations and measurements for future scientific studies and for criminal investigations in Oregon are provided. In conjunction with these data, temperatures and developmental times of the green bottle fly (*Lucilia illustris)* (Meigen) are presented. The green bottle fly was the first fly to arrive and begin ovipositing on the carcass. Secondly, a mathematical analysis and model are suggested to enrich entomological decomposition research. Using this basic model it may be possible to achieve empirical experimental standardization and to incorporate variability as a function of model parameters. It is hoped that these data and observations will further the forensic application of entomology in

the Pacific Northwest and strengthen the empirical growth of forensic entomology.

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Chapter 2

Necrophagous Insect Succession in Northwestern Oregon: Biological Observations

2.1 Introduction

Insects of the orders Diptera (true flies) and Coleoptera (beetles) are the most forensically significant insect orders found on a decomposing carcass. Under most conditions, flies are the first to arrive on a corpse (Amendt, Krettek, and Zehner, 2004; Anderson, 2001; Byrd and Castner, 2001; Catts and Goff, 1992; Smith K. 1986). Soon after their arrival, they begin ovipositing in or near the moist mucosal openings such as the mouth, nose, genital area and any open wound. Flies prefer moist environments for their eggs and these areas allow the larvae, called maggots, to begin feeding soon after the eggs hatch. On the other hand, beetles usually prefer dryer desiccated material for feeding and egg lying, and it is for these reasons that flies are found primarily during the early stages of decomposition and most beetles, with the exception of the family Staphylinidae (rove beetles), are found in the later stages when a corpse is more desiccated. Rove beetles are predatory and arrive in the earlier stages of decomposition to feed on fly maggots (Arnaldos, Romera, Garcia, and Luna, 2001; Byrd and Castner, 2001; Easton and Smith, 1970; Goff, 2000; Kocarek, 2003; Payne, 1965; Richardson and Goff, 2001; Smith, 1986; Tabor, Brewster, and Fell, 2004)

Insect succession and decomposition research has been conducted throughout the world; however, there is still insufficient decomposition rate data for most regions of the world, and within those regions there is even less known about different seasons, death scenarios and altitudes, which all influence insect succession and the rate of decomposition (Amendt et al., 2004; Grassberger and Frank, 2004). Decomposition data do exist for North and South America, Hawaii, some areas in the Southern U.S, Brazil, and British Columbia (Joy, Herrell, and Rogers, 2002; Tabor et al., 2004; Tabor, Fell, and Brewster, 2005, Anderson, 1997, 2001; Anderson and VanLaerhoven, 1996; Carvalho, Thyssen, Linhares, and Palhares, 2000; Goff, 1993; Goff, Brown, Hewadikaram, and Omori, 1991; Hewadikaram and Goff, 1991; Rodriguez and Bass, 1983). Relevant studies will be analyzed in Chapter 3. However, at this time, there are no known insect succession or decomposition data for Northwestern Oregon. The main objective in this study is to establish an insect succession model that can be used by law enforcement agencies to establish accurate PMI estimation during death investigations within the Willamette Valley Region.

2.2 Methods and materials

Site Description. The study site was located approximately 18 km North of Corvallis Oregon on Soap Creek Ranch, which is a livestock facility operated by Oregon State University. No cattle had gazed in the research area for over six months prior to the beginning of the experiment nor were they present during the first three months of the experiment. At the ranch, the specific research location

on the ranch was situated on the Northeastern boundary (Latitude: 44° 40' 188", Longitude: 123° 16' 793", Elevation 378') bordering the McDonald State Forest Area (Fig. 2.1) The surrounding vegetation was grassy and wooded yet permitting direct sun exposure from mid-morning until late afternoon (Shean et al, 1993). This site was selected because it is the type of body disposal site that is common in many homicide scenarios, i.e. a low traffic wooded area.

Fig 2.1 Aerial photo of the Soap Creek Ranch. The precise research site location is indicated by the yellow arrow. GPS coordinates of the ranch area in lower left corner.

Carcasses. Two medium sized 36.3 kg gilt domestic pigs (*Sus scrofa* Linnaeus.) were used as surrogate models for human decomposition (Anderson, 1997;Catts and Goff, 1992; Grassberger and Frank, 2004; Rodriguez and Bass, 1983). The animals were obtained from a commercial organic pig farm when they were 90 days old. Both pigs were free of antibiotics and growth hormones.

Before dawn, on the morning of July 15, each pig was individually ushered into a press type of cage and euthanized on site using one .22 caliber shot delivered to the side of the skull (Longair et al., 1991). To further replicate a human murder situation, both carcasses were immediately clothed in denim shorts and white cotton short sleeve shirts (as in Anderson, 2001; Grassberger and Frank, 2004; Greenberg, 1991). Once clothed, each pig was placed directly into a separate wire enclosure. The method of euthanasia was approved by the Oregon State University Institutional Animal Care and Use Committee (Proposal #3227).

Animal Enclosures. At the site, each carcass was protected from large scavengers by wire cages. The cages were constructed from 231 gauge wire hog panels. Each hog panel measured 86.36 cm x 4.89 m (34"X16'), and 121 cm x 86.36 cm sections were cut from the panels. Each of the sections were fastened together using 10.16 cm plumbing clamps. One of the cages was constructed with a bottom so that that the cage could be lifted and weighed. The other cage was bottomless so that the carcass could lie in direct contact with the ground. The bottomless cage was staked to the ground using 38 cm plastic tent stakes so that the cage could not be lifted by scavengers (Fig. 2.2).

Fig. 2.2 Clothed pig shown shortly after euthanasia in bottomless protective enclosure(fresh stage, 0 hours PMI). Note the blood on the grass.

On Site Procedures. This study was conducted over a five month period (15 July – 30 November, 2005). During the first 15 days of the study, data were collected twice daily and then less frequently as the insect activity and rate of decomposition slowed. Immediately after the pigs were placed in the wire enclosures, a baseline weight of one carcass was obtained. Internal carcass temperature was also measured by inserting a temperature probe approximately 10 cm into the rectum immediately after the pig was euthanized. The probe was secured inside the carcass by attaching the probe to the tail using a plastic zip tie.

Ambient and carcass temperatures were recorded on a 2 channel HOBO® H8 data logger. Ambient and carcass temperatures were taken every 30 minutes by data logger and then downloaded to an Excel computer program.

The temperature of the maggot mass on the carcass was measured twice daily using a K-type general purpose probe thermometer from Forestry Suppliers Inc®. The probe was inserted into the middle of largest mass throughout the study. Wind speeds near the carcasses were also monitored twice per day using a Kestrel® 1000 hand held anemometer. Minimum and maximum temperatures were recorded during every 24 hour period with a standard minimum-maximum thermometer. Onsite precipitation was measured using plastic rain cup gauges attached to the cages and two locations within two meters of the cages. To confirm on site metrological readings, as suggested by Archer, (2004), data were also acquired from the Corvallis, Oregon AGRIMET Station (http://www.usbr.gov/pn/agrimet/agrimetmap/crvoda.html). The AGRIMET station is located approximately 5 km east of the research site (Latitude: 44° 38' 03", Longitude: 123° 11' 24", Elevation 230').

Biomass Data. During the first 30 days of the study, one of the carcasses was weighed daily to gather data on the change in weight. The carcass was weighed using a hanging zero dial big game scale. A frame was constructed around the cage using metal fence stakes that were 96 cm long so that the scale could be hung from a cross member and would not inhibit the cage and related insect activity. The cage was lifted onto the scale hooks via a ratchet system. This design made it possible for a single person to collect the weight data.

Insect Sampling Protocol. Data were collected twice daily during the first two weeks of the study, at mid-morning and then again in the late afternoon. During the first two weeks, decomposition and insect succession progressed rapidly. As the rates of decomposition and insect succession decreased, data was collected once a day and then in the latter part of the study, i.e. September-November, the site was only visited 2-3 times each week.

A typical daily sample regime included 8-10 aerial net sweeps approximately. 30.48 cm directly above and around the carcass. The samples were transferred to a kill jar. Shortly thereafter, samples were transferred to the entomology laboratory, removed from the jar and mounted for identification (Tabor et al., 2004, Catts and Haskell 1990). The aerial net was also used to sample predatory flying insects that were present above the soil after the postfeeding maggots had burrowed in the soil.

A companion sampling method was used with immature diptera samples. When present, 20-30 eggs or maggots were collected directly from the carcasses. The juveniles were collected by hand, placed in plastic 4oz. Solo® cups and then capped and catalogued. The samples were transferred to the laboratory within 45 minutes. Once in the laboratory, they were transferred to rearing containers and placed in the growth chamber (Byrd, 2001). On site, samples of diptera young were also preserved. Larvae were removed from the carcass and submerged in hot water (slightly less than 100°C) for approx 30 seconds. They were then removed form the water and preserved in glass vials containing a 70% Ethyl Alcohol solution.

Sticky traps were placed near the carcass (Catts and Haskell, 1990). Trécé Inc. Pherocon® AM No Bait Insect Monitoring Kits (TC/3506-03) were used. The traps were not baited with pheromones. The traps were constructed of yellow cardboard and contained sticky insect adhesive. Traps were hung from the cage and located inside the cages approximately 15 cm from the top of the cage in the mid-line and thoracic area of the carcasses. The traps were collected once every 24 hours and fresh traps were re-hung. Insects on each of the traps were counted and categorically recorded. A third trap was also set up approximately 30 meters away from the carcasses to act as a control trap for incidental insects in the area that were not forensically significant.

Pitfall traps were used to collect terrestrial insects. A small hole was dug by hand approximately 12 cm; a 16oz plastic Solo® cup was placed in the hole and soil around the outside of the cup was backfilled to create a smooth approach to the trap. For convenience, a 4oz. Solo® cup was placed in the bottom of each of the larger cups in the pitfall trap. When the samples in the pitfall traps were collected, the smaller cups could be removed from the bottom of each trap and a lid could be placed on the sample. Samples were removed and a new cup was replaced in the bottom of the larger cup when data was collected from the trap. The pitfall traps were located approximately 15-30 cm from the carcass. Four traps were constructed around the carcass, superior to the head, inferior to the feet, and two transverse and contra-lateral to the lower mid-thoracic area of the carcass (all insect data is listed as raw data in Appendix A).

Laboratory Procedures. Samples of eggs and maggots were reared under controlled conditions in the laboratory. Approximately 20-30 maggots were taken at each sampling. In the laboratory, approximately 50 g of ground pork was placed in each rearing container. Samples were reared in 4oz Solo® cups caped with perforated lids to allow ventilation. Each lid was removed at the onset of the postfeeding stage and the larval migration (Byrd, 2001). The containers containing the postfeeding larvae were then placed in a shoe box sized plastic container with approximately 2.5 cm of vermiculite on the bottom. The samples were then placed in a growth chamber and maintained at 22°C and 60-70% relative humidity. A controlled light source was administered in 12 hour intervals. It is important to note that samples that were not covered with the perforated lids desiccated and perished due to overexposure to the fan in the growth chamber.

Once the samples reached the postfeeding stage, larvae migrated to the vermiculite and burrowed below the surface. After the pupal cases were formed, each sample was sifted by hand from the vermiculite, placed in a petri dish and then in a sleeve container. Sleeve containers were fashioned using 15 cm x 15 cm x 30.5 cm plastic food container buckets. Two opposing holes approximately 15 cm in radius were cut out of the bucket and clear plastic was glued to one of the sides to cover the holes and allow viewing. One other side was cut in a similar fashion and fitted with a mesh sleeve attached to the opening. The sleeve and clear plastic viewing areas enabled manipulation and easy observation of the samples even after they emerged as adults. Once the adult samples emerged, the

samples were maintained for approximately 48 hours before euthanizing and preserving them. The samples were euthanized by placing the hatching containers in a freezer. Samples were removed from the freezer and counted. Representative species of different individuals found in the reared samples were pinned for identification and cataloging.

2.3 Results

Temperature. Summers in the region are warm and dry with relatively cooler nights. At the time (05:30 hours) of euthanasia, the recorded ambient temperature was 18.3°C, and the relative humidity was 70%. The soil temperature at 2 inches was recorded as 15.5°C. Also at that same time, a rectal temperature of one pig was recorded as 39.7°C. The measured wind speed was 6.4 kph. The maximum ambient temperature during the first day was 31°C recorded at 1400 hours. A 10 year (1995-2005) average of the temperatures for July 15 - 22 showed that the ambient temperatures during the maggot developmental period were average for the region. There was little variation in wind and relative humidity, and no variation in precipitation during the same period. No significant wind or rain was recorded during the first 60 days of the study.

Insect Succession

Fresh Stage (0-8 hours PMI). Within 10 minutes PMI, the first fly to frequent the carcass was Calliphoridae, species *Lucilia illustris* (Meigen). On the first day the *L. illustris,* common name green bottle fly, population increased as

the ambient temperatures increased. The first arrivals feed on body fluids around the carcass which resulted from the gunshot. Six hours PMI, egg clusters were observed on the eyes and nose of the carcass (Fig. 2.2)

Bloated Stage (8-72 hours PMI). Eight hours PMI, physiological signs indicative of bloating were observed; anaerobic gases inside the carcass began to expand the carcass and tissue was discolored (Anderson and VanLaerhoven, 1996; Catts and Haskell, 1990). At 9 hours PMI, a large cluster of eggs was also observed along the jaw line and ground interface where body fluids had pooled (Fig. 2.3). At 12 hours PMI, bald-face hornets (*Dolichovespula maculata)* (Linnaeus), were observed feeding on the adult flies; often arresting them in flight.

Fig. 2.3 The first large cluster of eggs along the jaw line and ground interface where body fluids had pooled. Green bottle flies can also be observed (bloated stage, 9 hours PMI).

At 33 hours PMI, the green bottle fly eggs hatched and first instar maggots were observed in large numbers around the snout; at less than 48 hours PMI second instar maggot masses were present on all of the natural orifices of the head, i.e. nose, eyes, and mouth. As the carcass continued to bloat, built up gases, presumably from anaerobic fermentation, forced body fluids from the mouth, gum line, nose, and genital areas. Sixty hours PMI, adult flies gathered on the clothing as they became soaked with fluids around the genital area. Adult flies continued

to be attracted in large numbers and fed on discharged body fluids. Maggot masses in the genital area developed under the clothing within a few hours following the observation of fluids on the clothing; egg clusters were also observed inside the pant leg along the inseam. Adult fly activity was highest during the first 24-48 hours of the PMI (Fig. 2.4).

Fig 2.4 Adult fly activity seen on body fluids resulting from the bloating (bloated stage, 60 hours PMI).

Approximately 60 hours PMI, large maggot masses could be seen in the waste line and underarm areas of the clothing that covered the carcass; however the largest mass engulfed nearly the entire head of the carcass (Fig 2.5). Species

were sampled again and reared in the laboratory growth chambers and then identified as the same green bottle species. The same species continued to dominate the colonization process throughout this stage. It is also important to note that the intense maggot activity in this stage resulted in displacement of the clothing (Fig. 2.9) which could be falsely construed as assault (Komar and Beattie, 1998).

Fig. 2.5 The first large maggot mass on the head and snout of the carcass. The first maggot mass developed in this same area and coincided with the first observed egg clusters (bloated stage, 60 PMI).

As fly adult and larval populations increased, predatory and parasitic activity also increased. Hymenoptera, particularly the bald-face hornet, began to visit the carcass and feed on the adult flies. The common wasp (*Vespula vulgaris)* was also observed, although its activity was much less aggressive than the bald-face hornet; it seemed to feed mainly on the carcass fluids. Small ants were also seen leaving the carcass with fly eggs, but the ants' predatory feeding was minimal and it is hypothesized that the activity had little or no impact on the decomposition rate.

After the first green bottle fly eggs had hatched, 48 hours PMI, the first beetles were observed. The first two arrivals were rove beetles (Staphylinidae), golden and brown rove (*Ontholestes cingulatus)* and shortly thereafter the hairy rove (*Creopilus maxillosus)* was also observed. The gold and brown rove beetles were more numerous. Rove beetle feeding focused mostly on the maggots; however, the hairy rove beetle was also seen attempting to catch adult flies as they landed on the carcass; their attempts were usually unsuccessful. These two staphylinid species were common during the bloated, active and advanced decay stages of the decomposition.

At the end of the bloated stage and 72 hours PMI, the average ambient temperature since the first maggot eggs were observed (66 hours) was 20.6°C with a maximum of 33.2°C and minimum of 10.6°C. The carcass temperature maintained an average temperature of 22.5°C (maximum of 33.6°C and minimum 17.5°C). The first maggot mass temperature was recorded 51 hours PMI at 35°C.

Active Decay Stage (72-120 hours PMI). The onset of the active decay stage was marked when feeding maggots penetrated the external body surface of the carcasses thus allowing the internal anaerobic gases to escape the body cavity. As a result the carcass deflated, ending the bloated stage and beginning the active decay stage (Fig 2.6). At this time, a pungent ammoniacal odor was associated with the carcasses. In the beginning of this stage, the majority of the flesh was still present, and most of the carcasses' external surface was a mucosal consistency. The afore mentioned fly and beetle families were present in high numbers

Fig. 2.6 Illustrated is the carcass after anaerobic gasses were released from the thoracic cavity. A large maggot mass can also be observed at the waistline. A sticky trap is also present in the upper left with a few adult flies. Decreased adult fly activity is indicated on the trap (active decay stage, 72 hours PMI).

Early in the active decay stage, the overall insect activity reached an apex in population and richness. However, 72 hours PMI, maggots appeared that were clearly different than the dominant green bottle fly maggots. These were sampled and reared out in the laboratory. The adult stage samples were identified as the red-tailed flesh fly (*Sarcophaga haemorrhorrhoidalis)* (Sarcophagidae).

Seventy two hours PMI, large numbers of terrestrial isopods were found and persisted through the active decay stage and into the next stage. The most common isopods were pill bugs. Predatory wasps, specifically the bald-face hornet continued to visit the carcass and feed on the maggots. Seventy two hours PMI the adult green bottle fly population had decreased significantly, and rove the rove beetles population had increased. Hairy rove and gold and brown rove species were first observed 48 hours PMI, and became more numerous over the following 24 hours. It was these two rove beetle species that were most common among the coleopteran population. Other beetles present during this stage were the Dermestidae (skin and larder beetles), Silphidae (carrion beetles) and Histeridae. The large pill bug population remained stable. The bald-face hornet had a constant presence of 6-8 individual at any given time. Other Hymenoptera species continued to be seen periodically at the carcass, but not in significant numbers.

During the active decay stage there was a period of nearly 72 hours where the carcass temperature exceeded 37.7°C with a maximum of 50.7°C. It is hypothesized that the greatest peak in the temperature was due in part to the maggot mass presence around the data logger probe which was located in the posterior region of the body cavity. At 120 hours PMI, 114 hours since the first green bottle fly egg clusters were observed, the average ambient temperature was 20.5°C with a maximum of 34.9°C and minimum of 9.03°C. For the same period, the carcass maintained an average temperature of 27.5°C (maximum of 45.4°C

and minimum of 17.5°C). The average maggot mass temperature during the active decay stage was 45.3°C, with a maximum temperature of 50.7°C (Fig. 2.7).

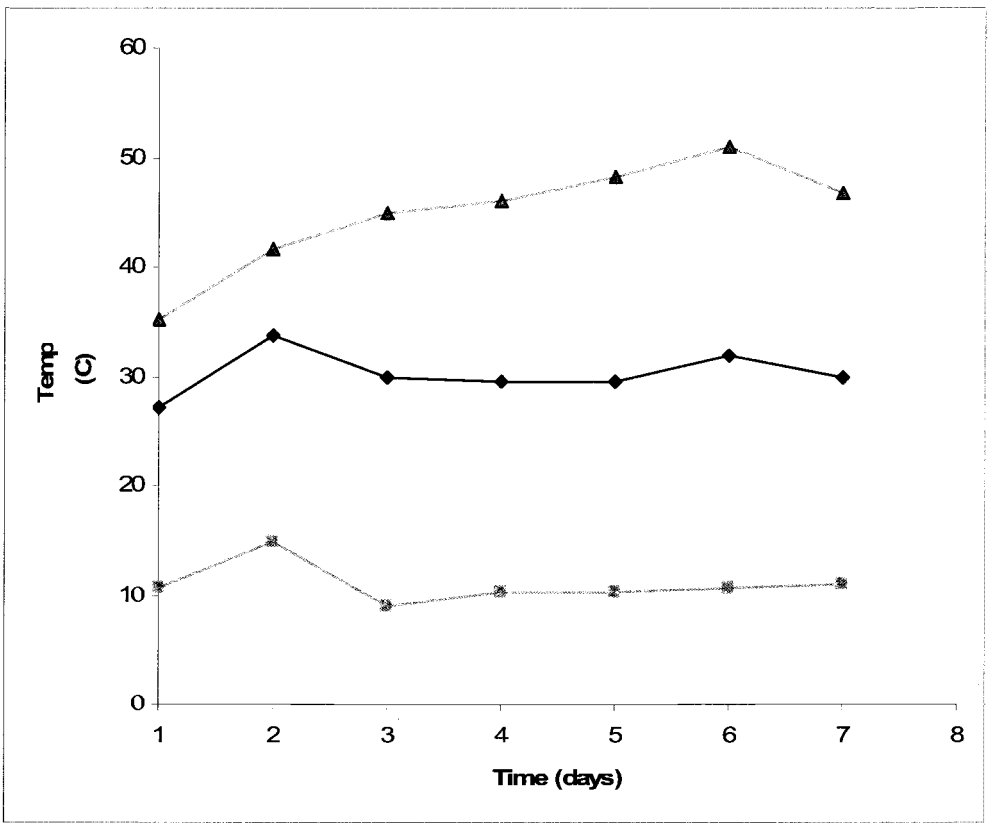

Fig. 2.7 Illustrated are temperatures that occurred during the first 7 days of the study (period of maggot colonization). The yellow line is the maggot mass temperatures. The dark blue line indicates maximum temperatures, the pink indicates minimum.

Advanced Decay Stage (120-288 hours PMI). The carcass began to desiccate approximately 120 hours PMI. The advanced decay stage was marked as the carcass began to dry out and the remaining hide hardened. The majority of the body tissue was gone, and the thoracic area of the carcass was flat. At this point, a less pungent cheesy odor was associated with the carcass. The jaw and

skull bones were visible where the first egg clusters had been present and some of the most intense maggot activity had taken place (Fig. 2.8). Vertebrae and ribs could also be seen due to the intense maggot activity that took place in the thoracic region, which began with the maggot masses that first developed on the waistline.

Fig. 2.8 The carcass is beginning to desiccate and the maggot feeding activity had begun to slow. Large patches of tissue had been removed in areas where the most intense maggot activity had taken place (advanced decay stage, 120 hours PMI).

Approximately 120 hours PMI, larval casings were observed and a few of the maggots were moving away from the carcass, but no more than one-half meter

from the carcass. At 132 hours PMI, most of the maggots on the carcass were large third (and final) instar maggots and had begun to enter the post-feeding instar stage. Post-feeding maggots were observed in the folds, pockets, and beneath loose clothing such as the sleeves and waistline where the carcass had receded. A few maggots were even seen as they started burrowing into the loose soil located a few meters from the carcass. However; the majority of the maggots still remained on the carcass at this time (Fig 2.9).

Fig. 2.9 Maggots are partially off carcass and can be seen in the soil and interface area. Carcass thoracic area is also more flattened. Displacement of clothing is also visible here (advanced decay stage, 135 PMI).

Approximately 147 hours PMI, what can best be described as a mass exodus began. The majority of the postfeeding maggots was observed exiting the carcass and forming a yellowish opaque 'stream' cascading downhill over twigs and grass, almost directly east (Fig. 2.10). The grade of the hill was approximately 3% and the mass moved down the one and only foot trail that was used to approach the carcass. This stream of maggots measured a distance of a little over 10 m in length and no more than 35 cm in width. At the end of the path, they began to spread out and burrow into the loose soil. The rove beetles were observed following the mass downhill. The bald-face hornets were also seen hovering over the mass as it migrated down the path. The pace of the progression was approximately 24 cm per minute.

Fig. 2.10 Illustrated is the maggot mass moving down hill (10 meters from the carcass) and over a stick that crossed the only footpath used to approach the carcass (advanced decay stage, 147 hours PMI).

Less than 8 hours following the exodus and 155 hours PMI, nearly all maggots were gone from the carcass and were below the soil surface (Fig. 2.11). Off the path in the taller grass, a few stragglers could still be seen searching for loose soil. When the mass spread out, many maggots could be found in small patches of loose soil near the trail. Approximately 90% of the mass settled and burrowed in an area that measured 4 x 1.5 m. A separate group moved to a

smaller area of loose soil that was located 90° from the main pupa bed and on the other side of the trail. A smaller third group migrated 6 m from the carcass downhill and then in a Southeastern direction perpendicular to the foot path. It appeared that as one area of soil became populated with burrowing maggots, others would migrate beyond to a less populated area. It is unclear whether or how burrowing space was partitioned.

It is important to note that rove beetle activity persisted in the pupal bed area but decreased soon after the maggots were below the surface. However, the bald-face hornet continued to hover over the surface searching for prey even after no maggots remained on the surface. The hornet's activity persisted into the early evening nearly four hours after the maggots were below the surface. Hornet activity provided a clear indicator of where the pupae were located below the surface.

Fig. 2.11 The condition of the carcass is illustrated shortly after the postfeeding maggots had exited and begun to pupate (advanced decay stage, 155 hours PMI). Vegetation under and around the carcass shows the damage that resulted from the body fluids.

At 147 hours PMI, and 141 hours after the first maggot egg clusters were observed, the average ambient temperature was 20.6°C; the maximum and minimum still remained 34.9°C and 9.03 respectively. The carcass temperature maintained an average temperature of 30.9°C with a maximum of 50.7°C and the minimum remained 17.5°C. 155 hours PMI the 2" soil temperature was 19.8°C in

the pupal bed area. It is noteworthy that after the maggots migrated from the carcass, the carcass continued to maintain an average temperature of 30.3°C (maximum of 46.9°C and a minimum of 16.4°C) for nearly 48 hours after their departure.

Dry Remains Stage (288-4752 hours PMI). At 288 hours PMI, the carcass was almost entirely desiccated and the hide had hardened, and there was no detectable odor associated with it. Some dry bones, such as the spine and ribs were visible where maggot feeding activity had removed the tissue and hide. The rate of decay had slowed down significantly and insect activity was minimal. Seasonal rain that began in mid October rehydrated the carcass but no further fly eggs were observed (Keh, 1985). Beetle activity was also at a minimum. The vegetation around and beneath the carcass was noticeably impacted by the decomposition process. In a 20-25 cm radius out from the carcass all the grass appeared dead, as if it were chemically burnt. It was also observed that all of the vegetation below that carcass had deceased (Fig 2.12). It is hypothesized that the condition of the grass is due to seeping body fluids that took place during the initial three stages of the decomposition process (Fielder et al 2004).

At 25 days PMI the first sign of scavenger activity was noted. At the end of the bloated stage the carcass had deflated and slumped toward one side of the cage. Thus it was possible for a scavenger, presumably coyote (*Canis latran*), to access the carcass through the hog panel (Fig. 2.12). Some disarticulation was observed but it did not appear that any bones were removed. The only indication of scavenger activity was that the shirt sleeve had been pulled and stretched

outside of the cage and small holes that appeared to be caused by teeth were in the sleeve of the garment. It also appeared that the scavenger had attempted to pull on the shorts but was unable to pull anything outside of the cage. No other tampering, such as digging or feeding was observed at that time.

Fig. 2.12 Carcass shown during the dry remains stage (288 hours PMI). Burnt vegetation can be seen around the carcass. The carcass is flattened and desiccated. Also illustrated in mid-right of the image is the disturbance of the clothing caused by large scavengers.

On November 30, 2005 the protective cages were removed from the carcasses. The research site was visited one month later and it was observed that the carcasses had been removed by scavengers. Remaining at the site was one pair of tattered and torn denim shorts and one cotton shirt. Two vertebrae were also found approximately 20 m from the site on a livestock trail that exited the site into the bordering tree line. However, the rest of the clothing and the balance of both carcasses could not be located.

2.4 Discussion and Conclusion

The green bottle fly was the first insect species to arrive and did so in less than 10 minutes PMI; their first egg clusters were observed six hours PMI. This same species, mostly maggots, were present and dominated the entire colonization period by flies. Approximately 168 hours PMI, a mass exodus took place and less than 8 hours later all maggots were below the soil surface. Predators arrived shortly after the first green bottle flies had deposited their eggs. At 12 hours PMI, bald-face hornets began to arrive at the carcass and persisted there until after the postfeeding maggots had pupated and burrowed below the soil. At 74 hours PMI the first two rove beetles were observed. Although further studies should address this issue, it is hypothesized that the observed predatory hornet and beetle activities were not heavy enough to slow the decomposition rate significantly. The maggot mass reached the postfeeding stage and then exited the carcass 147 hours PMI. While on the carcass, the largest mass maintained an average temperature of 30.9°C with a maximum temperature of 50.7 which was measured

128 hours PMI. During maggot colonization the average ambient temperature was 20.8°C (minimum of 9°C and maximum of 34.9°C). The relative humidity averaged 51% with no measurable precipitation. These meteorological observations are well within the norm for the region for this time of the year. These were probably ideal conditions for green bottle fly activity and further studies need to document fly activity during colder periods.

In this study, a clear pattern of forensic insect succession and colonization was observed. This succession was characterized primarily by two insect orders: Diptera and Coleoptera. Flies were the first necrophagous insects to arrive on the carcass and the adult activity peaked early in the study and then declined significantly 72 hours PMI.

Several valuable fundamental questions were answered. The green bottle fly was the first to arrive, supporting the premise that forensic entomologists, courts, and other wrongful death investigators can rely on them within the region. As in other studies (Greenberg and Kunich, 2002) of this type that were conducted throughout the world and during various seasons, not only were green bottle flies the first to arrive, but dependably oviposited shortly after their arrival. Once the eggs hatched and the larvae were present, predators were attracted to the carcass. However, there was no indication that their activity significantly impacted the maggot population. The literature also supports this observation (Wells and Greenberg, 1994). Diptera ovipositing and developmental activities described here provide a clear and dependable time clock for establishing PMI in the region. It is hoped that these data will assist regional law enforcement in the

estimation of PMI and further decomposition research within the Willamette Valley region.

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Chapter 3

Analysis of Decomposition Rates of Pig Carcasses: A Proposed Mathematical Model

3.1 Introduction

With the help of popular media, forensic entomology has experienced an upsurge in notoriety and application. Establishing a precise postmortem interval (PMI) is still the main objective in forensic entomology (Amendt, Krettek, and Zehner, 2004; Anderson and VanLaerhoven, 1996; Byrd and Castner, 2001; Catts and Goff, 1992; Catts and Haskell, 1990; Goff, 2000; Goff, 1993; Greenberg and Kunich, 2002; Hall and Donovan, 2001; Haskell, 1997; Smith, 1986). The growth rate of arthropods, particularly fly maggots, is one method for establishing PMI. There is an intuitive inverse relationship between maggot growth rate and carcass loss, i.e. the rate of decomposition, entomological studies have focused on carcass decomposition rates (Anderson and Hobischak, 2004; Centeno, Maldonado, and Oliva, 2002; Hewadikaram and Goff, 1991; Richards and Goff, 1997; Rodriguez and Bass, 1983; Watson and Carlton, 2003). However, there is a paradox in that carcass mass loss cannot be a direct representation of maggot growth if maggots stay on the carcass. We shall propose experiments to account for the direct contribution of maggot to carcass mass.

Animal and human carcasses have demonstrated that insect succession patterns, species composition, and rate of decomposition vary with respect to the

geoFiguresy, environment, season, death scenario and carcass size (Anderson and VanLaerhoven, 1996; Goddard, 1985; Grassberger and Frank, 2004; Introna, Suman, and Smialek, 1991; Payne, 1965; Richards and Goff, 1997; Watson and Carlton, 2003). Data collected in one location cannot be used to accurately establish PMI in another region. Therefore, it is often necessary for a forensic entomologist to collect data in differing geographic regions, seasons and scenarios to understand how each of these variables impacts arthropod activity and PMI (Amendt et al., 2004).

The decomposition rates of carrion have been a subject of forensic entomology field studies. Authors have calculated the rate of biomass removal, i.e. the relationship between time and biomass reduction (Anderson and VanLaerhoven, 1996; Grassberger and Frank, 2004; Richards and Goff, 1997). Several authors have published figures demonstrating rates of biomass reduction over time (Haefner, Wallace, and Merritt, 2004b; Hewadikaram and Goff, 1991), and select studies have provided linear regression analysis for their individual decomposition studies (Haefner, Wallace, and Merritt, 2004a; Hewadikaram and Goff, 1991) These analyses provide valuable information about the intrinsic stochastic system in the given region and potentially general assumptions about rates of decomposition in different regions. However, none of these data were compared to other decomposition data from different regions. Moreover, at this time no research has specifically proposed a mathematical analysis of these data to yield a general model. Such a model would be useful: 1) to compare different

data sets and reach general conclusions and 2) to hypothesize rates of decomposition in previously unstudied death scenarios.

The main objective of this study was to quantify and compare decomposition rate data from our study to those conducted in other national and international locations. A general model and standardized methodology for further forensic entomological studies will also be proposed.

3.2 Materials and Methods

See chapter 2 Section.

3.3 Carcass Decomposition in Willamette Valley, Oregon

Decomposition data were collected from two decomposing pig carcasses from July 15-November 30, 2005 in the mid Willamette Valley of Oregon at the Soap Creek Ranch located approximately 18 km North of Corvallis Oregon. The precise location was (Latitude: 44° 40' 188", Longitude: 123° 16' 793", Elevation 378') situated on the Northeastern boundary bordering the McDonald State Forest area. The surrounding vegetation was grassy and wooded yet permitting direct sun exposure from mid morning until late afternoon (Shean, 1993). The site elevation was 115 m. The experiment began July 15, 2005 at 05:30 hours. Both pigs were clothed. The average temperature during the study was 20.8°C with a maximum temperature of 34.9°C minimum temperature of 9°C. The average relative humidity for the period was 51% with no measurable precipitation.

After euthanasia, the carcass maintained its weight throughout the bloated stage. At the beginning of the active decay stage and 72 hours PMI, the total weight of the carcass had declined to 33.8 kg; 88% of the original body mass. However, at the end of the active decay stage and 120 hours PMI the total carcass weight was 15.75 kg; 56% of the carcass had been removed. At 155 hours PMI and shortly after the maggots had left the carcass over 80% of the body mass had been removed, and the total clothed weight of the carcass had been reduced to 6.8 kg. The observed pig carcass reached the dry remains stage in 12 days, and the measured decomposition rate was -0.24 (Fig. 3.1).

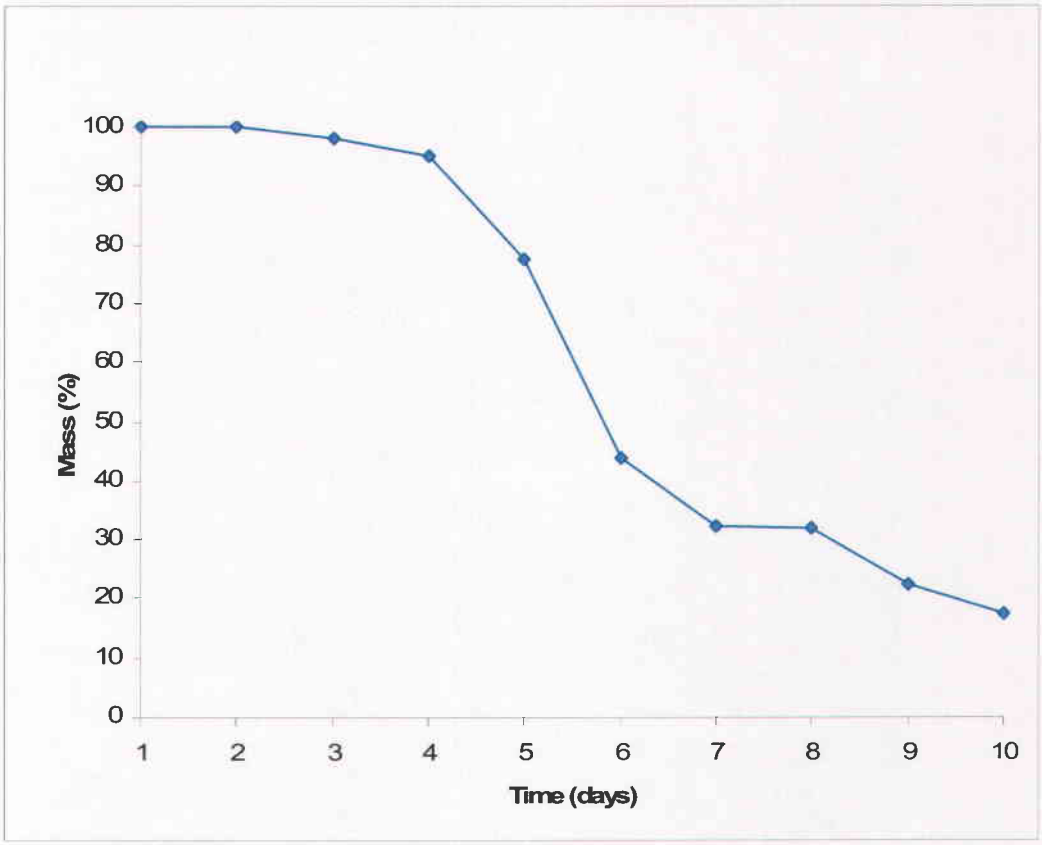

Fig. 3.1 Decline of carcass weight loss over the first 10 days of the decomposition. The vertical axis is the percentage of carcass weight that was lost.

3.4 Decomposition Model

Previous Studies on Decomposition Rate. Three previously published decomposition studies conducted in differing geographic locations (Austria, British Columbia, and Hawaii) were compared to the Corvallis, Oregon study (Anderson and VanLaerhoven, 1996; Grassberger and Frank, 2004; Richards and Goff, 1997). In each of these studies, a Figures of carcass decomposition was available, but none of the numerical data points. We estimated points along the decomposition activity while ignoring 'flat' areas typically at the beginning and end of the activity. From these estimates, we converted the data to their natural logarithms. In all cases, the resulting data were clearly linear, and the slope of regression was the 'intrinsic' decomposition rate. A regression analysis was completed and a numerical value was assigned to each of the differing rates of decomposition. Decomposition rate data from all three studies plus our own were compared using their associated regression values. A brief review of the three studies follows (Tab. 3.1,3.2; Fig. 3.2).

Austria. Grassberger and Frank (2004) conducted two decomposition studies in Vienna, Austria at an elevation of 175 m. The first experiment began May 2, 2001 at 1200 hours. The second experiment began August 20, 2001 at 22:00 hours. Both pigs were clothed and weighed 44 and 37 kg, respectively. The average temperature during the spring study was approximately 20°C (approximate range: 15°C-30°C) Approximately 100 mm of precipitation fell during both experiments. In the late summer experiment, the average temperature

was approximately 16.6°C (approximate range: 15°C -33°C). In both cases, the carcasses reached the dry remains stage in approximately 30 days. From their figures, we estimated decomposition rates of -0.08 and -0.06 for the spring and late summer experiments respectively.

Hawaii. Richards and Goff (1997) conducted three separate pig decomposition experiments. The experiments were conducted at different elevations, seasons and habitats. The highest elevation experiment (1877 m) began on May 24, 1995. The site was described as upland forest with partial shade. The mean daily temperature during the study was 17.1°C with a recorded maximum and minimum of 33.3°C and 1.7°C respectively, and a total rainfall of 39.5 mm. At the intermediate elevation (1169 m), the study began on November 23, 1993 in a rainforest. The mean daily temperature during the study was 15.7°C with a recorded maximum of 23.3°C, minimum of 5.5°C, and total rainfall of 184.9 mm. At the lowest elevation (646 m), the study began June 8, 1995 at a site described as mid-elevation woodlands with sparse vegetation. The carcasses were exposed to direct sunlight most of the day. The mean daily temperature during the study was 22.5°C with a recorded maximum of 31.7°C and a minimum of 6.1°C. A total rainfall of 20.5mm was recorded. Despite variation in precipitation, elevation and ecology, each study reached the dry remains stage in approximately 10 days. We estimate, the decomposition rates to be -0.11, -0.11, and -0.12 respectively for each.

British Columbia. Anderson and VanLaerhoven (1996) began their study in Southwestern British Columbia beginning June 9, 1992. The area in which the

study took place was described as rural farming country in the Fraser Valley region of British Columbia (estimated elevation 50-150 m). The average ambient temperature during this study was 21°C with a recorded maximum of 40°C, minimum of 12°C, total rainfall of 200 mm (meteorological date were obtained from a figure). They reported that significant amounts of rain fell on the carcasses early in the study and washed away the first wave of fly eggs that had been deposited on the carcass. The dry remains stage was reached in this study after 43 days. From their figures, which provided data on two carcasses, we estimated two similar carcass decomposition rates of -0.04 and -0.03.

Investigator(s)	GeoFiguresy, Elevation, Habitat	Time of study (month, year)	Meteorological Data (temperature, rainfall)	Carcass (weight, methods)
Grassberger and Frank	Vienna, Austria Elev. 175 m Urban	1) May 2001 2) Aug. 2001	1) Ave. 18°C Min. 10°C Max. 32°C Precip. 150mm 2) Ave. 16.5°C Min. 10°C Max. 33°C Precip. 115mm	1) 44 kg Clothed pig offsite pin gun euthanasia 2) 37 kg clothed pig, offsite pin gun euthanasia
Richards and Goff	1) Hawaii, USA Elev. 1877 m Upland Forest 2) Hawaii, USA Elev. 1169 m Rain Forest 3) Hawaii, USA Elev. 646 m Mid- woodland	1) May 1995 2) Oct. 1993 3) June 1995	1) Ave. 17.1°C Min. 1.7°C Max. 33.3°C Precip. 40mm 2) Ave. 15.7°C Min. 5.5°C Max. 23.3°C Precip. 185m 3) Ave. 22.5°C Min. 6.1°C Max. 31.7°C Precip. 20.5mm	1) 10.44 kg pig unclothed offsite gunshot euthanasia 2) 10.44 kg pig unclothed offsite gunshot euthanasia 3) 10.44 kg Pig unclothed offsite gunshot euthanasia
Anderson and VanLearhoven	Southwest, BC Elev. Approx. 50-150 m Rural Farm	1) June 1992	1) Ave. 26°C Min. 12°C Max. 40°C Precip. 200mm	1. 22kg Not Clothed Onsite Gunshot
England	Oregon, USA Elev. 115 m Wooded Rural	1) July 2005	1) Ave. 21°C Min. 9°C Max. 35°C Precip. Trace	1. 36.3kg Clothed Gunshot on site

Tab. 3.1. Summary of published studies used in the analysis. Also illustrated are the significant differences in methods and research design that were used in each of the studies. These variables are hypothesized to impact PMI.

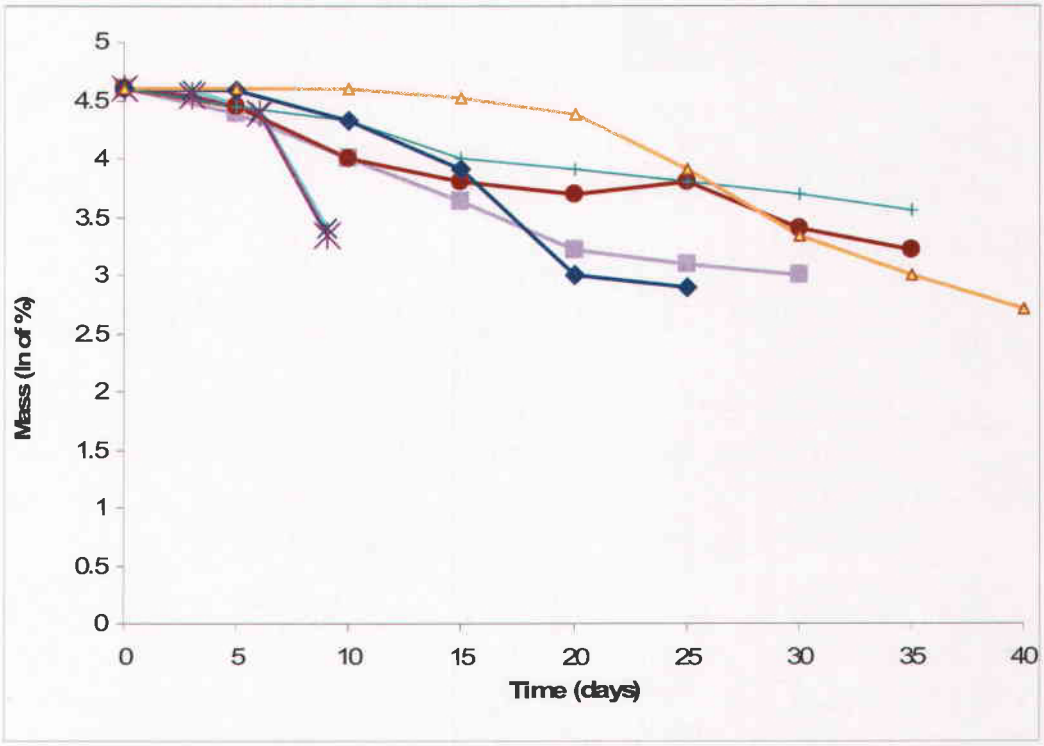

Fig. 3.2 Each line indicates a decomposition rate from each one of the studies used in the analysis. The y axis is mass (natural log of percentage of weight) over time (days). The navy blue represents the England study, yellow, purple and turquoise represents the Richards study, gray and maroon represents the Anderson study and dark blue and pink represents the Grassberger study.

LINEARIZED REGRESSION ANALYSIS

Studies	R^2	Regression	Intercept
Grassberger and Frank, European Urban Habitat			
1) May	0.907	-0.0786	4.8662
2) Aug.	0.9677	-0.0586	4.5838
Richards and Goff, Hawaiian Islands			
1) 1877 m	0.9338	-0.1075	4.8338
2) 1169 m	0.8651	-0.1104	4.2047
3) 646 m	0.8834	-0.1204	4.7315
Anderson and VanLearhoven, Southwestern British Columbia			
1) Carcass 1	0.9253	-0.0372	4.5235
2) Carcass 2	0.9781	-0.0303	4.5730
England, Corvallis, Oregon			
1) Carcass 1	0.9517	-0.2378	5.2954

Tab. 3.2 A summary of results from the linearized regression analyses that were conducted on each of the four studies.

3.5 Mathematical Model

Our data and those available from other studies clearly indicate that there is a period of time during the initial decomposition where the loss in weight of the overall carcass (sum of net carcass and maggot mass) is exponential. In this study, we proposed a simple linearization of this process, to be estimated by the equation:

$$m_{t+1} = r*m_t+m_0 \qquad \text{Eq. 1}$$

Where t is time, r is the (negative) rate of decomposition, m_t is the carcass mass (m_0 = initial mass). Two significant factors that directly affect the rate of

decomposition are first, ambient temperature (α) accelerates the maggot development and bacterial decay and second, carcass mass (m), plays a role in generating and maintaining the heat which is generated by the decomposition process. An increase in either one will cause an increase in the decomposition rate and thus shortening the decomposition period (Eq. 2, Fig. 3.3). We can thus represent the overall dynamic process in the general continuous form:

$$\frac{dm}{dt} = r(\alpha, m_0)m \qquad \text{Eq. 2}$$

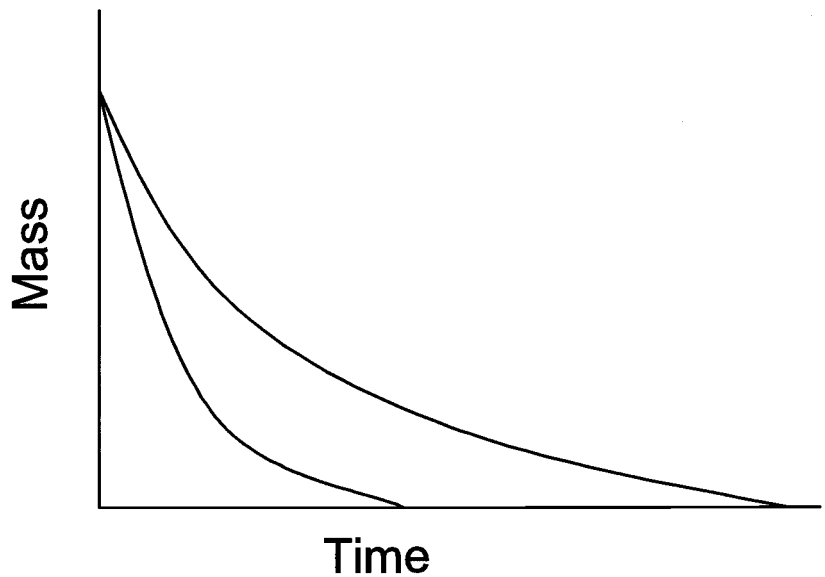

Fig. 3.3 A representation of Equation 2. The two lines represent changes in mass as a function of time. The line to the left (lower) represents the influence of high temperature (α) and/or larger carcass and maggot mass (m), all of which will accelerate decomposition.

We suggest that the function $r(\alpha,m)$ requires quantification. More than likely it will not be a simple linear function and there will be drastic behavior at the extremes, for example very cold temperatures will induce freezing and stop the process entirely. Therefore, in order to quantify these parameters and functions, a series of experiments could be conducted with carcasses of different mass (weight) at the same ambient temperatures and differing ambient temperatures using carcass of the same mass (weight). To our knowledge, such experiments have not been undertaken in forensic entomology but would provide a step towards increasing the predictability of observations, particularly at a novel crime scene.

Furthermore, it can be observed that the overall curve of decomposition has plateaus at both ends. The curve has similarity to logistic growth, wherein the rate of decomposition is inhibited by the loss of carcass mass (Eq. 3, Figures 3.4). The equation above could thus be modified as follows:

$$\frac{dm}{dt} = r(\alpha, m_0)m - r(\alpha, m_0)m^2 \qquad \text{Eq. 3}$$

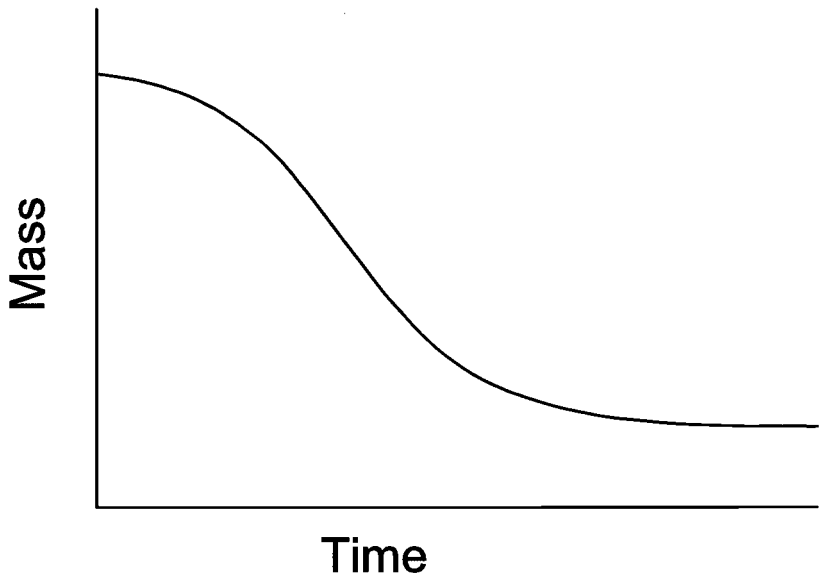

Fig. 3.4 A representation of Equation 3. The line represents a logistic inhibition of decomposition, wherein decomposition rate slows down with decreasing mass and reaches a non-zero threshold below which no further loss occurs due to decomposition.

This postulated self-inhibition function causes decomposition to slow down as mass is lost. The plateaus at both ends of the decomposition process seem poorly documented. We suggest that they can be incorporated in a logistic equation and that the parameters are measurable in the field.

One further point is raised by these theoretical considerations. Decomposition, in terms of lost carcass mass, is occurring while the maggot mass itself is increasing. Therefore, the growth characteristics of the maggot mass should be analyzable separately from the decomposing carcass (Figures 3.5). We do not know of studies that separate the two processes. Information on maggot growth could be obtained by careful sampling and by comparison of carcasses

with and without maggots. Longitudinal estimates of maggot numbers and weight would also allow us to separate the two paradoxical processes, namely carcass weight loss and increase in maggot mass.

Such controlled experiments would provide valuable understanding to the dynamics of carcass decay, which is lacking at this time. Other factors remain unanswered also. Such as the initial 'inoculation dose' of fly eggs and their species, and possibly several other biological considerations presumably influence decomposition. Observations and documentation of these factors would be best collected in a theoretical framework. Logically, two separate models, one for carcass mass and one for maggot mass should be developed and combined. In studies so far, measurements of carcass mass include maggot mass. Therefore the changes of maggots mass are hypothetical and incorporate natural history characteristics such as post-feeding and mass exodus. The actual relative proportion of net carcass mass (without maggots) to maggot mass is unknown.

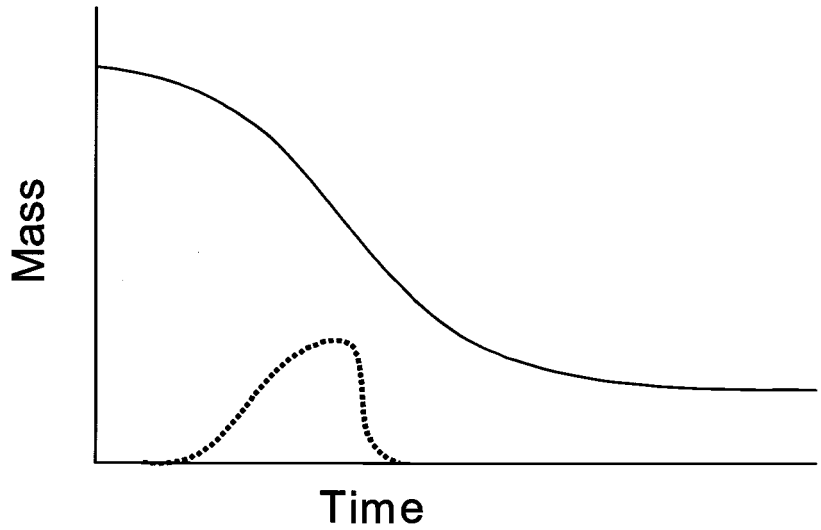

Fig. 3.5 Conceptual representation of maggot mass dynamics (dashed line) in contrast to gross (with maggots) carcass mass (solid line).

3.6 Discussion and Conclusion

The main conclusion of our study is that the decomposition rate of a carcass follows a definable model. Differences in decomposition rates between studies are quantitative and procedural, and not qualitative. All studies, including ours, presented data that fit a simple exponential decay that could be linearized. Based on these observations, we propose a general mathematical equation for carcass decomposition rate that is applicable to future studies. Using this basic model, it is possible to achieve standardization of experiments by incorporating variability as a function of model parameters.

The strengths of the linearized decomposition analysis are 1) it allows the researcher to place a numerical value on the rate of decomposition and reach general conclusions about the region, 2) differing regional, seasonal, or death scenario decomposition experiments can be compared in an empirical manner and

3) with repetition within the same region, the model can elicit the most influential stochastic variables that were present and influenced the rate of decomposition. Thus, entomological researchers can begin to understand not only what influences decomposition, but quantify how much influence any given variable has on the decomposition rate. Furthermore, forensic entomologists can hypothesize rates of decomposition in previously unstudied regions and death scenarios.

The greatest value of linear decomposition rate analysis is that it places a standard numerical value on the rate of decomposition so that different regional, seasonal, or death scenario decomposition experiments can be compared in an empirical manner. With that said, it is imperative that certain research design criteria are met in each regional experiment. It is important to follow established research methodology and strive for continuity in forensic entomological research design so that linearized decomposition regression results can be attributed to stochastic differences rather than variations in research design (Catts and Haskell, 1990; Richards and Goff, 1997). Such efforts would serve the field both in the courtroom and the science as a whole.

The consideration of not only a greater number of differing geographic locations but also differing death scenarios will be essential for continued growth in forensic entomology (Amendt et al., 2004). The next step in this research is repetition within the same region and the comparison of more geographic areas using the decomposition rate model that has been presented here. Repetition within the same region will elicit the most influential stochastic variables that were present at the time of the experiments.

After basic decomposition studies have been conducted in a region and the decomposition rate is known, researchers will be better suited to experiment with differing death scenarios such as buried, burned, or enclosed carcasses as well as seasonal and elevation differences to name just a few (Amendt et al., 2004; Richards and Goff, 1997). With each scenario, a decomposition rate will define precisely how each of these variables impacts the rate of decomposition.

Currently there is a growing body of decomposition studies. However, it is unreasonable to believe that forensic entomology can develop a controlled decomposition model for every death scene. Once raw data from these studies are compared we can place a numerical value on the degree of impact that certain common variables (i.e. elevation, ecology, climate, death scenario, season and geographic region) have on the rate of decomposition. Thus, when a forensic entomologist is called upon to estimate the PMI at a novel crime site within an established region, he can more accurately state not only what impacted the decomposition rate, but how much and which variable had the greatest impact. We have proposed a general model and standardized methodology for further forensic entomological studies. We also suggest studies to dissect the growth rate of maggots independent of carcass mass. Not only would such data add to our understanding of the decomposition process but also provide crucial life table parameters to necrophagous fly species, for which we have little if any. It is hoped that this study will be the first step toward developing a knowledge base for comparing and contrasting differing geographic locations and death scenarios in an application-based functional manner.

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Chapter 4

Summary

Developmental and biological data were presented for the Willamette Valley in Oregon. Among these observations valuable fundamental questions were answered. First and foremost of these is that the Calliphorid fly, green bottle fly (*L. illustris),* was the first insect to arrive and did so in less than 10 minutes PMI. Shortly following the arrival of the green bottle fly, it began ovipositing and thus starting the time clock that measures PMI. It is clear that a reliable Calliphorid fly species performs a major necrophagous function in the Willamette Valley Region. These data also establish important timelines for the estimation of PMI that may be valuable information for local law enforcement.

Furthermore, the data that is presented in the chapter two set the stage for more forensic research to take place. The next step will be to establish more detailed data on differing death scenarios and season, and a more in depth look at the regional taxonomy; all of these were beyond the scope of this experiment. As can be expected these data in this region and other similar regional studies conducted by forensic entomologists will add to the growing body of research data and publications. It is necessary for the science to compare this data beyond the current qualitative approach.

Next a mathematical analysis was presented to accomplish this task. It is hoped that the mathematical analysis presented here will establish a standardized procedure, or at least serve as a guide to develop one, for the comparison of

different decomposition rates that result from studies conducted throughout the world and in differing death scenarios. This will allow forensic entomology researchers to place a quantitative value on the rate of decomposition that takes place in a given region, season and/or scenario. This methodology, in conjunction with the qualitative methods already in use, will help entomologists understand not only what impacted the decomposition rate, but how much and which variable(s) had the greatest impact. With this said, it will be important for research design to follow a more standardized protocol. Using this model, the elimination of controllable confounding variables must be accomplished before specific variables can be measured. It is hoped that such steps will promote greater internal and external reliability and thus a more generalizability, both in research and when a forensic entomologist is called on by law enforcement to estimate PMI at a novel crime scene.

Some unforeseen results were elicited during our mathematical analyses. Clearly, the maggot mass has the ability to maintain its own temperature and thus the growth rate of poikilothemic individuals such as maggots is a function of mass and is not directly dependent on the ambient temperatures. Thus, our analysis gives indication that decomposition has been oversimplified. Decomposition has several parameters that have not been elicited; therefore, the next step in our decomposition rate research is to analyze the characteristics of the maggots mass separately from the decomposing carcass. Such an experiment would allow us to separate the two paradoxical processes, namely carcass weight loss and increase in maggot mass. Such controlled experiments would provide valuable

understanding to the dynamics of carcass decay. Some other factors that remain unanswered were also introduced by our model and analysis, i.e. initial 'inoculation dose' of maggot eggs and their species. It is hoped that this data and our related results will stimulate much more needed research on different decomposition rates and the variables that influence decomposition so that forensic entomologist can better understand the eclectic and stochastic indicators that must be considered when establishing PMI.

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Appendix A

Explanation of Data

The main objective of this study was to (1) establish a preliminary insect succession model that can be used by regional law enforcement personal to establish PMI and (2) present a standardized mathematical model that provides a basis for the empirical analysis and comparison of decomposition rates from different regions. The taxonomic work in this study was limited to the diptera species that first visited carcass and begin ovipositing. Taxonomic focus was also given to the specific predator species of the ovipositing diptera due to their potential impact on the egg and larvae population. An extensive taxonomic list of all the arthropod species that visited the carcass was beyond the focus of this work (presented in chapter 2) which was intended to serve as an application based model for law enforcement personal. However, all of the samples that were trapped were counted and cataloged. The raw data from this work in presented below. From right to left: First column, titled DATA, is the date on which the sample was obtained. Each sample was sorted and given a number for identification. Specimens that looked similar were all given the same ID number. The second column titled ID #, is each specimens identification number. The third column, titled Stage, is the life stage in which the specimen was in at the time of the sample (1=egg, 2=larvae, 3= adult). The fourth column, titled Source, is the method that was used to trap the sample (1=stick trap, 2= hand, 3= pit fall trap, 4= sweep net). The fifth column, titled Total, is the number of samples that were obtained during the capture (the maggot mass population was estimated and

is indicated by est.). The sixth column, titled Dec. Stg, is the stage of decomposition at which the sample was obtained. The seventh and final column indicates the carcass that the sample was obtained from. The two participants were warmly referred to as Thelma (Thel) and Louise (Lou). We thank them for the help.

Data

DATA	ID #	Stage	Source	Total	Dec. Stg	SUB
15-Jul	1	3	1	130	Fresh	Lou
15-Jul	2	3	1	5	Fresh	Lou
15-Jul	3	3	1	4	Fresh	Lou
15-Jul	4	3	1	1	Fresh	Lou
15-Jul	5	3	1	3	Fresh	Lou
15-Jul	6	3	1	4	Fresh	Lou
15-Jul	7	3	1	2	Fresh	Lou
15-Jul	1	1	2	50	Fresh	Lou
15-Jul	1	1	Est	500	Fresh	Lou
16-Jul	8	2	1	10	Bloated	Lou
16-Jul	1	3	1	130	Bloated	Lou
16-Jul	10	3	2	1	Bloated	Lou
16-Jul	12	3	1	10	Bloated	Lou
16-Jul	13	3	1	10	Bloated	Lou
16-Jul	14	3	1	10	Bloated	Lou
16-Jul	14	3	1	8	Bloated	Lou
16-Jul	6	3	1	15	Bloated	Lou
16-Jul	6	3	1	20	Bloated	Lou
16-Jul	7	3	1	20	Bloated	Lou
16-Jul	1	2	Est	500	Bloated	Lou
17-Jul	5	3	1	80	Bloated	Lou
17-Jul	12	3	1	10	Bloated	Lou
17-Jul	6	3	1	9	Bloated	Lou
17-Jul	7	3	1	3	Bloated	Lou
17-Jul	2	3	1	5	Bloated	Lou
17-Jul	1	3	1	148	Bloated	Lou
18-Jul	2	3	1	4	Act. Dec.	Lou
18-Jul	1	3	1	2	Act. Dec.	Lou
18-Jul	7	3	1	2	Act. Dec.	Lou
18-Jul	5	3	1	5	Act. Dec.	Lou
18-Jul	6	3	1	80	Act. Dec.	Lou
18-Jul	2	3	1	5	Act. Dec.	Lou
18-Jul	1	3	1	8	Act. Dec.	Lou
18-Jul	14	3	1	8	Act. Dec.	Lou
18-Jul	12	3	1	4	Act. Dec.	Lou
19-Jul	9	3	1	2	Act. Dec.	Lou

19-Jul	3	3	1	450	Act. Dec.	Lou
19-Jul	7	3	1	1	Act. Dec.	Lou
19-Jul	3	3	1	200	Act. Dec.	Lou
19-Jul	12	3	1	1	Act. Dec.	Lou
20-Jul	3	3	1	150	Act. Dec.	Lou
20-Jul	3	3	1	100	Act. Dec.	Thel
20-Jul	2	3	1	3	Act. Dec.	Thel
20-Jul	8	3	1	2	Act. Dec.	Thel
20-Jul	12	3	1	2	Act. Dec.	Thel
20-Jul	17	3	1	2	Act. Dec.	Thel
20-Jul	7	3	1	4	Act. Dec.	Thel
20-Jul	18	3	1	2	Act. Dec.	Thel
20-Jul	19	3	1	2	Act. Dec.	Thel
20-Jul	3	3	1	100	Act. Dec.	Thel
20-Jul	7	3	1	5	Act. Dec.	Thel
20-Jul	6	3	1	2	Act. Dec.	Thel
21-Jul	3	3	1	90	Adv. Dec	Thel
21-Jul	3	3	1	100	Adv. Dec	Thel
21-Jul	12	3	1	4	Adv. Dec	Thel
21-Jul	14	3	1	2	Adv. Dec	Thel
22-Jul	3	3	1	30	Adv. Dec	Thel
22-Jul	1	3	1	3	Adv. Dec	Lou
22-Jul	20	3	1	1	Adv. Dec	Lou
22-Jul	5	3	1	2	Adv. Dec	Lou
22-Jul	6	3	1	9	Adv. Dec	Lou
22-Jul	7	3	1	15	Adv. Dec	Lou
22-Jul	21	3	1	50	Adv. Dec	Lou
22-Jul	12	3	1	2	Adv. Dec	Lou
22-Jul	1	3	1	4	Adv. Dec	Lou
22-Jul	3	3	1	200	Adv. Dec	Lou
22-Jul	MCB	3	1	150	Adv. Dec	Lou
22-Jul	5	3	1	2	Adv. Dec	Lou
22-Jul	20	3	1	3	Adv. Dec	Lou
22-Jul	7	3	1	4	Adv. Dec	Lou
22-Jul	6	3	1	6	Adv. Dec	Lou
22-Jul	14	3	1	50	Adv. Dec	Lou
23-Jul	21	3	1	1	Adv. Dec	Lou
23-Jul	3	3	1	40	Adv. Dec	Lou
23-Jul	3	3	1	90	Adv. Dec	Thel
24-Jul	5	3	1	3	Adv. Dec	Thel
24-Jul	3	3	1	134	Adv. Dec	Thel
24-Jul	22	3	1	1	Adv. Dec	Lou
24-Jul	4	3	1	1	Adv. Dec	Lou
24-Jul	3	3	1	15	Adv. Dec	Thel
25-Jul	3	3	1	119	Adv. Dec	Thel
25-Jul	23	3	1	1	Adv. Dec	Thel
25-Jul	3	3	1	15	Adv. Dec	Thel
26-Jul	3	3	1	9	Adv. Dec	Thel
26-Jul	24	3	1	1	Adv. Dec	Thel
26-Jul	25	3	1	1	Adv. Dec	Thel

26-Jul	26	3		1	1	Adv. Dec	Thel
26-Jul	3	3		1	32	Adv. Dec	Thel
27-Jul	16	3		1	1	Dry Rems	Thel
27-Jul	3	3		1	90	Dry Rems	Thel
27-Jul	12	3		1	3	Dry Rems	Lou
27-Jul	3	3		1	25	Dry Rems	Lou
28-Jul	3	3		1	120	Dry Rems	Thel
29-Jul	1	3		1	3	Dry Rems	Thel
29-Jul	3	3		1	180	Dry Rems	Thel
29-Jul	4	3		1	1	Dry Rems	Thel
29-Jul	13	3		1	1	Dry Rems	Thel
1-Aug	16	3		1	1	Dry Rems	Thel
1-Aug	1	3		1	2	Dry Rems	Thel
1-Aug	25	3		1	1	Dry Rems	Thel
1-Aug	3	3		1	120	Dry Rems	Thel
2-Aug	3	3		1	100	Dry Rems	Thel
2-Aug	2	3		1	1	Dry Rems	Thel
3-Aug	3	3		1	60	Dry Rems	Thel
4-Aug	25	3		1	1	Dry Rems	Thel
15-Jul	28	3		2	3	Fresh	Lou
15-Jul	1	3		2	100	Fresh	Lou
15-Jul	1	1		2	25	Fresh	Lou
15-Jul	1	1	Est		500	Fresh	Lou
15-Jul	1	1	Est		1000	Fresh	Lou
16-Jul	28	3	Count		4	Bloated	Lou
16-Jul	1	3	Est		500	Bloated	Thel
16-Jul	8	3	Est		50	Bloated	Thel
16-Jul	1	2	Est		500	Bloated	Thel
16-Jul	1	2	Est		500	Bloated	Lou
17-Jul	50	3		2	5	Bloated	Lou
17-Jul	1	2		2	100	Bloated	Lou
17-Jul	1	2	Est		1000	Bloated	Lou
17-Jul	50	3		2	15	Bloated	Lou
17-Jul	1	2	Est		2000	Bloated	Lou
17-Jul	52	3	Count		50	Bloated	Lou
17-Jul	1	3	Est		100	Bloated	Lou
17-Jul	50	3		3	10	Bloated	Lou
18-Jul	51	3		3	4	Act. Dec.	Lou
18-Jul	53	3		3	25	Act. Dec.	Lou
18-Jul	54	3		3	8	Act. Dec.	Lou
18-Jul	55	3		3	10	Act. Dec.	Lou
18-Jul	56	3		3	1	Act. Dec.	Lou
18-Jul	57	3		3	10	Act. Dec.	Lou
18-Jul	58	3		3	1	Act. Dec.	Lou
18-Jul	1	3	Est		2000	Act. Dec.	Lou
19-Jul	58	3		3	1	Act. Dec.	Lou
19-Jul	51	3		3	6	Act. Dec.	Lou
19-Jul	60	3		3	7	Act. Dec.	Lou
19-Jul	61	3		3	2	Act. Dec.	Lou
19-Jul	57	3		3	14	Act. Dec.	Lou

19-Jul	53	3	3	40	Act. Dec.	Lou
19-Jul	62	3	3	5	Act. Dec.	Lou
19-Jul	1	2	3	2000	Act. Dec.	Lou
19-Jul	52	3	3	10	Act. Dec.	Lou
20-Jul	51	3	3	3	Act. Dec.	Lou
20-Jul	53	3	3	31	Act. Dec.	Lou
20-Jul	56	3	3	4	Act. Dec.	Lou
20-Jul	57	3	3	20	Act. Dec.	Lou
20-Jul	59	3	3	8	Act. Dec.	Lou
20-Jul	53	3	3	6	Act. Dec.	Lou
20-Jul	54	3	4	1	Act. Dec.	Lou
20-Jul	62	3	4	3	Act. Dec.	Lou
20-Jul	57	3	4	13	Act. Dec.	Thel
20-Jul	60	3	3	1	Act. Dec.	Thel
20-Jul	61	3	3	1	Act. Dec.	Thel
20-Jul	59	3	3	3	Act. Dec.	Thel
20-Jul	56	3	3	3	Act. Dec.	Thel
20-Jul	53	3	3	70	Act. Dec.	Thel
20-Jul	57	3	3	1	Act. Dec.	Thel
20-Jul	63	3	3	1	Act. Dec.	Thel
20-Jul	65	3	3	1	Act. Dec.	Thel
20-Jul	66	3	3	4	Act. Dec.	Thel
20-Jul	53	3	3	6	Act. Dec.	Thel
20-Jul	56	3	3	1	Act. Dec.	Thel
20-Jul	57	3	3	3	Act. Dec.	Thel
20-Jul	1	3	3	2000	Act. Dec.	Thel
20-Jul	50	3	3	4	Act. Dec.	Thel
20-Jul	67	3	3	4	Act. Dec.	Thel
20-Jul	53	3	3	3	Act. Dec.	Thel
20-Jul	54	3	3	12	Act. Dec.	Thel
20-Jul	53	3	3	5	Act. Dec.	Thel
20-Jul	57	3	3	5	Act. Dec.	Thel
20-Jul	53	3	3	8	Act. Dec.	Thel
20-Jul	57	3	3	1	Act. Dec.	Thel
20-Jul	64	3	3	1	Act. Dec.	Thel
21-Jul	54	3	3	2	Act. Dec.	Thel
21-Jul	57	3	3	1	Act. Dec.	Thel
21-Jul	58	3	3	1	Act. Dec.	Thel
21-Jul	50	3	3	1	Act. Dec.	Thel
21-Jul	53	3	3	4	Act. Dec.	Thel
21-Jul	51	3	3	1	Act. Dec.	Thel
21-Jul	60	3	3	1	Act. Dec.	Thel
21-Jul	64	3	3	2	Act. Dec.	Thel
21-Jul	55	3	3	1	Act. Dec.	Thel
21-Jul	2	3	3	4	Act. Dec.	Thel
21-Jul	57	3	3	14	Act. Dec.	Thel
21-Jul	60	3	3	1	Act. Dec.	Thel
21-Jul	51	3	3	2	Act. Dec.	Thel
21-Jul	54	3	3	1	Act. Dec.	Thel
21-Jul	57	3	3	13	Act. Dec.	Thel

21-Jul	53	3		3	6	Act. Dec.	Thel
21-Jul	54	3		3	1	Act. Dec.	Thel
21-Jul	59	3		3	4	Act. Dec.	Thel
21-Jul	1	1	Est		500	Act. Dec.	Lou
21-Jul	57	3		3	5	Act. Dec.	Thel
21-Jul	53	3		3	9	Act. Dec.	Thel
21-Jul	54	3		3	3	Act. Dec.	Thel
21-Jul	62	3		3	5	Act. Dec.	Thel
21-Jul	28	3		3	4	Act. Dec.	Thel
21-Jul	60	3		3	2	Act. Dec.	Thel
21-Jul	66	3		3	3	Act. Dec.	Thel
21-Jul	57	3		3	2	Act. Dec.	Thel
21-Jul	54	3		3	1	Act. Dec.	Thel
21-Jul	54	3		3	1	Act. Dec.	Thel
21-Jul	67	3		3	1	Act. Dec.	Thel
21-Jul	67	3		3	1	Act. Dec.	Thel
21-Jul	51	3		3	1	Act. Dec.	Thel
21-Jul	54	3		3	1	Act. Dec.	Thel
21-Jul	68	3		3	1	Act. Dec.	Thel
21-Jul	57	3		3	3	Act. Dec.	Thel
21-Jul	68	3		3	1	Act. Dec.	Thel
22-Jul	68	3		3	1	Act. Dec.	Thel
22-Jul	53	3		3	14	Act. Dec.	Thel
22-Jul	66	3		3	3	Act. Dec.	Thel
22-Jul	69	3		3	1	Act. Dec.	Thel
22-Jul	53	3		3	5	Act. Dec.	Thel
22-Jul	54	3		3	1	Act. Dec.	Thel
22-Jul	62	3		3	4	Act. Dec.	Thel
22-Jul	57	3		3	4	Act. Dec.	Thel
22-Jul	53	3		3	6	Act. Dec.	Thel
22-Jul	51	3		3	2	Act. Dec.	Thel
22-Jul	59	3		3	2	Act. Dec.	Thel
23-Jul	59	3		3	1	Act. Dec.	Thel
23-Jul	53	3		3	9	Act. Dec.	Thel
23-Jul	68	3		3	1	Act. Dec.	Thel
23-Jul	51	3		3	3	Act. Dec.	Thel
23-Jul	62	3		3	2	Act. Dec.	Thel
23-Jul	61	3		3	3	Act. Dec.	Thel
24-Jul	71	1		2	1	Act. Dec.	Thel
24-Jul	72	1		2	6	Act. Dec.	Thel
24-Jul	54	3		3	1	Act. Dec.	Thel
24-Jul	57	3		3	2	Act. Dec.	Thel
24-Jul	51	3		3	1	Act. Dec.	Thel
24-Jul	62	3		3	8	Act. Dec.	Thel
24-Jul	54	3		3	1	Act. Dec.	Thel
24-Jul	69	3		3	1	Act. Dec.	Thel
24-Jul	53	3		3	5	Act. Dec.	Thel
24-Jul	72	3		3	1	Act. Dec.	Thel
24-Jul	55	3		3	1	Act. Dec.	Thel
24-Jul	72	2		3	10	Act. Dec.	Thel

24-Jul	71	2	3	2	Act. Dec.	Thel
24-Jul	53	2	3	2	Act. Dec.	Thel
24-Jul	66	2	3	1	Act. Dec.	Thel
24-Jul	54	3	3	1	Act. Dec.	Thel
24-Jul	51	3	3	2	Act. Dec.	Thel
24-Jul	62	3	3	1	Act. Dec.	Thel
24-Jul	73	2	3	1	Act. Dec.	Thel
24-Jul	74	3	3	1	Act. Dec.	Thel
24-Jul	62	3	3	2	Act. Dec.	Thel
24-Jul	54	3	3	1	Act. Dec.	Thel
24-Jul	72	2	3	2	Act. Dec.	Thel
24-Jul	71	2	3	1	Act. Dec.	Thel
24-Jul	66	2	3	2	Act. Dec.	Thel
24-Jul	74	2	3	1	Act. Dec.	Thel
24-Jul	52	3	3	1	Act. Dec.	Thel
24-Jul	72	2	3	2	Act. Dec.	Thel
24-Jul	62	3	3	2	Act. Dec.	Thel
24-Jul	52	3	3	2	Act. Dec.	Thel
24-Jul	51	3	3	1	Act. Dec.	Thel
24-Jul	72	2	3	4	Act. Dec.	Thel
24-Jul	66	2	3	3	Act. Dec.	Thel
24-Jul	52	3	3	4	Act. Dec.	Thel
26-Jul	73	2	3	15	Act. Dec.	Lou
26-Jul	75	3	3	1	Act. Dec.	Lou
26-Jul	74	3	3	6	Act. Dec.	Lou
26-Jul	60	3	3	3	Act. Dec.	Lou
26-Jul	76	3	3	1	Act. Dec.	Lou
25-Jul	62	3	3	6	Act. Dec.	Lou
26-Jul	71	2	3	4	Act. Dec.	Lou
26-Jul	53	3	3	8	Act. Dec.	Lou
26-Jul	75	3	3	2	Act. Dec.	Lou
26-Jul	51	3	3	5	Act. Dec.	Lou
26-Jul	54	3	3	4	Act. Dec.	Lou
26-Jul	69	3	3	1	Act. Dec.	Lou
26-Jul	57	3	3	4	Act. Dec.	Lou
26-Jul	60	3	3	1	Act. Dec.	Lou
26-Jul	71	2	3	1	Act. Dec.	Lou
26-Jul	72	2	3	25	Act. Dec.	Lou
27-Jul	54	3	3	14	Adv. Dec	Thel
27-Jul	53	3	3	8	Adv. Dec	Thel
27-Jul	69	3	3	3	Adv. Dec	Thel
27-Jul	57	3	3	2	Adv. Dec	Thel
27-Jul	63	3	3	1	Adv. Dec	Thel
27-Jul	51	3	3	2	Adv. Dec	Thel
27-Jul	62	3	3	10	Adv. Dec	Thel
27-Jul	71	3	3	10	Adv. Dec	Thel
27-Jul	73	3	3	3	Adv. Dec	Thel
27-Jul	72	3	3	4	Adv. Dec	Thel
27-Jul	72	3	3	28	Adv. Dec	Thel
27-Jul	71	2	3	6	Adv. Dec	Thel

27-Jul	73	2	3	5	Adv. Dec	Thel
27-Jul	63	3	3	1	Adv. Dec	Thel
27-Jul	72	3	3	28	Adv. Dec	Thel
27-Jul	54	3	3	8	Adv. Dec	Thel
27-Jul	51	3	3	1	Adv. Dec	Thel
27-Jul	59	3	3	1	Adv. Dec	Thel
27-Jul	53	3	3	1	Adv. Dec	Thel
27-Jul	59	3	3	1	Adv. Dec	Thel
27-Jul	62	3	3	11	Adv. Dec	Thel
28-Jul	53	3	3	4	Adv. Dec	Thel
28-Jul	72	2	3	20	Adv. Dec	Thel
28-Jul	71	2	3	8	Adv. Dec	Thel
28-Jul	69	3	3	1	Adv. Dec	Thel
28-Jul	54	3	3	5	Adv. Dec	Thel
28-Jul	51	3	3	1	Adv. Dec	Thel
28-Jul	73	3	3	6	Adv. Dec	Thel
28-Jul	62	3	3	11	Adv. Dec	Thel
29-Jul	73	2	3	12	Adv. Dec	Thel
29-Jul	71	2	3	2	Adv. Dec	Thel
29-Jul	77	2	3	3	Adv. Dec	Thel
29-Jul	72	2	3	14	Adv. Dec	Thel
29-Jul	51	3	3	4	Adv. Dec	Thel
29-Jul	69	3	3	3	Adv. Dec	Thel
29-Jul	54	3	3	7	Adv. Dec	Thel
29-Jul	53	3	3	5	Adv. Dec	Thel
29-Jul	62	3	3	18	Adv. Dec	Thel
29-Jul	65	3	3	4	Adv. Dec	Thel
29-Jul	78	2	1	1	Adv. Dec	Thel
31-Jul	58	3	3	1	Adv. Dec	Thel
31-Jul	54	3	3	8	Adv. Dec	Thel
31-Jul	71	2	3	2	Adv. Dec	Thel
31-Jul	73	2	3	4	Adv. Dec	Thel
31-Jul	72	2	3	6	Adv. Dec	Thel
31-Jul	62	3	3	8	Adv. Dec	Thel
31-Jul	51	3	3	2	Adv. Dec	Thel
31-Jul	54	3	3	3	Adv. Dec	Thel
31-Jul	71	2	3	5	Adv. Dec	Thel
31-Jul	73	2	3	4	Adv. Dec	Thel
31-Jul	76	3	3	3	Adv. Dec	Thel
31-Jul	62	3	3	6	Adv. Dec	Thel
31-Jul	79	3	3	1	Adv. Dec	Lou
31-Jul	51	3	3	3	Adv. Dec	Lou
31-Jul	69	3	3	1	Adv. Dec	Lou
31-Jul	73	3	3	5	Adv. Dec	Lou
31-Jul	54	3	3	6	Adv. Dec	Lou
31-Jul	57	3	3	3	Adv. Dec	Lou
31-Jul	71	2	3	1	Adv. Dec	Lou
31-Jul	72	2	3	8	Adv. Dec	Lou
31-Jul	62	3	3	15	Adv. Dec	Lou