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Forensic Entomology
The Use of Insects in Death Investigations to Determine Elapsed Time Since Death

Leigh Dillon, Graduate Researcher
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TECHNICAL REPORT

March 1995

Submitted by
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FORENSIC ENTOMOLOGY -- THE USE OF INSECTS IN DEATH INVESTIGATIONS TO DETERMINE ELAPSED TIME SINCE DEATH. ANNUAL REPORT -- MARCH 1994 TO MARCH 1995

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ABSTRACT

Research was conducted in order to develop a database of insect succession on carrion to determine elapsed time since death in homicide investigations. Decomposition experiments were conducted in the spring, summer and fall of 1994 in the Lower Mainland, B.C. which is typical coastal rainforest. This research proved that insects colonize remains in a predictable sequence and can be used to assist in determining time of death. The sequence of insect colonization varies with season and habitat but is predictable within each of these parameters. An extensive database has been established for shade and sun habitats and for victims killed in spring, summer and fall. This work has been used in the investigation of six death investigations to date. It will continue to be used in subsequent investigations in this area.

RÉSUMÉ

En vue de dater la mort des sujets lors de recherches sur des cas d'homicide, une étude a été menée pour créer une base de données relatives aux successions d'insectes sur les cadavres. Des expériences de décomposition ont eu lieu au printemps, en été et en automne 1994 dans la vallée du Bas-Fraser, Colombie Britannique, une zone représentant un cas typique de forêt humide côtière. Ces recherches montrent que les insectes conlonisent les cadavres de façon prévisible et qu'ils peuvent être utilisés pour déterminer la moment du décès. Bien que les séquences de colonisation par les insectes évoluent en fonction de la saison et de l'habitat, elles restent prévisibles en intégrant les dits facteurs. Une vaste base de données a été mise

research, approximate time of death in several homicide cases in 1994 could not have been established.

ORIGINAL OBJECTIVES OF PROJECT

During the spring, summer, and fall of 1994, detailed experiments were performed on the use of insects as indicators of time of death. The objectives of these experiments were to determine seasonal variations of insect succession as well as determine the rate of decomposition on domestic pigs (*Sus scrofa)* as human models, in two outdoor habitats; sunny and shady areas in order to develop data to determine elapsed time since death in homicide victims. This research provided a unique opportunity for interaction and co-operation between police officers, the B.C. coroners service and university researchers in order to develop the technology to determine time of death.

RESEARCH LOCATION

All research for the 1994 forensic entomology studies took place at the University of British Columbia's Malcolm Knapp Research Forest in Maple Ridge, located approximately 100 km east of Vancouver, British Columbia (Fig. 1). This forest, 5,153 hectares in size, was chosen because it represented typical climate and geographical characteristics found in Coastal and Lower Mainland British Columbia. The research area is located in the Western Coastal Hemlock biogeoclimatic zone, which extends throughout the Lower Mainland, the majority of Vancouver Island, the Gulf Islands and extends up the Pacific Coast to the Alaska border, so includes many of the areas for which forensic entomology has been required in homicide cases (B.C. Ministry of Forests 1991). This zone is characterized by mild temperatures with frequent cloudiness, a narrow temperature range, wet mild winters, cool relatively dry summers, a long frost free period and heavy precipitation, most of which occurs during the winter season (U.B.C. 1991).

This forest also had limited access to the public. Limited access restricted possible interference with the project from the local community. Map one depicts the sites utilized for the decomposition study.

A research facility, which included laboratory facilities, temporary living quarters, equipment and storage, running water, electricity *etc.* was generously donated for the duration of the experiments, free of charge by U.B.C. (Fig. 2). It was located within the forest, close to the research sites. Also, all individual decomposition sites were supplied by U.B.C. at no cost. It has been estimated that such facilities were worth approx. 250,000 dollars (VanHam, pers comm).

Due to the dangers of attracting large carnivores while conducting carrion-related work in the Research Forest, several precautionary measures were taken. Sites for carcass placement were located close to service roads to provide quick escape should danger arise. As well, a chemical repellent called "Bear Phaser", a loud sound device, as well as a cellular phone were carried at all times during field work. Telephone reception tests for safety precautionary measures were conducted prior to experimentation. A cellular phone with the best reception and recharging features was chosen and purchased by Simon Fraser University. Although studies sites were not located near public hiking trails, posting of hazard signs as a precautionary measure was conducted (Fig.3).

EXPERIMENTAL DESIGN

Decomposition sites were prepared two weeks prior to carcasses placement. Sites were prepared by locating appropriate sites for each decomposition at least 50 m apart. Each protective cage was placed at the site and firmly staked to the ground. Detritus from the area was placed at the base of the cage so that the carcass would be in close association with the natural ground dwelling flora and fauna. The cages were placed *in situ* early to minimize any possible disturbances to the soil fauna created by disrupting the soil surface upon installation of cages.

As we intended to study the change in fauna over time in relation to the decomposing carcasses, it was important to determine the natural insect fauna of the area. Therefore, insect trapping was performed for two weeks prior to carcass placement.

Pitfall traps are an excellent means of collecting ground dwelling arthropods (Winchester & Scudder 19). Each trap consisted of a 250 ml jar buried so that the lip of the jar was flush with the surface of the ground (Fig. 4). Soapy water was placed into the bottom of the jar. This prevented insects from escaping but did not pose an environmental threat. The contents of each pitfall jar was filtered through a labeled piece of muslin cloth. Insects collected on the muslin cloth were identified, recorded and preserved. A 10 cm by 10 cm mesh was place at the opening of each pitfall in an attempt to exclude small mammals and amphibians.

Pig carcasses were used in these experiments as they have been widely accepted as human models for decompositional studies (Goff 1993). Pigs are omnivorous and possess a digestive system similar to that of humans. Therefore, their gut fauna will be similar which is important in the evaluation of the decomposition process of carcasses. As well, pigs are relatively hairless and have skin tissue so similar to that of humans that it has been used in human skin grafts. According to recent literature, a 23 kg (50 lb.) pig is approximately equivalent to an average adult male torso, which is the main site of decomposition and insect colonization (Catts & Goff 1992).

All pigs were shot and killed using a 15 cm pin gun to the head of the pig. Freshly killed carcasses were immediately transported to the research sites. Once located at field sites, all experimental carcasses were shot a second time in the side of the chest with a .22" caliber, short, low velocity bullet. This second bullet wound was created for the purpose of inserting a temperature probe into control carcasses.

Carcasses were placed a minimum of 50 meters apart so that olfactory orientation to each one was independent. All carcasses were placed in large steel barred cages, constructed by A&H Custom Fabrications Ltd, Maple Ridge, British Columbia (Fig. 5). Pig carcasses were placed in the middle of the cages so that no parts of the carcass were close to the edge of the cage. Cages were designed to protect carcasses from large carnivore attack (such as that by black bears, *Ursus americanus*), without impeding insect activity to and from the carcasses. Each cage measured 1.05 m long, 0.75 m wide, and 0.45 m high and was constructed with 1

cm^2 steel bars, evenly spaced 4 cm apart. Three chain-linked rings acted as hinges (Fig. 6) so that the cages opened upwards. Cages were bolted closed using 3 cm bolts (Fig. 7). Preliminary testing proved that the cages were able to withstand approximately 650 lb. of direct weight. (This testing led us to believe that the cages would be able to withstand bear tampering). All cages were secured to the ground with four 45 cm steel spikes.

Plastic coated ID cards were made for each site. These ID cards stated specific site numbers. The number (such as 94-1-1) represented the year of the experiment, the experiment set, and the carcass number. As well, smaller ID cards complete with metric scaling were created to be used in conjunction with photographs.

Photographs of each pig carcass were taken, on each sampling day. Photographs were taken to provide a means of recording the decomposition progress as well as a means of comparing pig carcasses from different sites and different seasons.

Three experiments, each taking place during a different season (spring, summer and fall) examined insect succession on pig carcasses in two different habitats, a sun habitat and a shaded habitat. Seasonal variation required sampling over the entire period of time. Each experiment consisted of two control and three experimental carcasses located in each habitat type, creating a total carcass number of 10 per experiment. Such replicate samples, taken within each combination of time, location, and season, were deemed necessary in order to provide replicable experiments, which are both scientifically sound, and will be defensible in court.

EXPERIMENTAL CARCASSES

Three carcasses in each experiment were designated as experimental carcasses. The carcasses were examined daily for the first few days, then every two days throughout the experiment. At each time, carcasses were first weighed, visually examined and photographed. Then samples of all insects were collected from the carcass. Carcasses were placed on a large mesh platform, which could be raised by a pulley system (Fig. 8). This allowed for weight

measurements to be taken and also facilitated insect sampling beneath the carcass. The mesh platform also allowed the carcass to maintain contact with the ground. Weight loss over time was recorded and insects directly associated with experimental carcasses were collected every second day during experimentation. All insects collected were examined, identified and catalogued. These insects were also used to create a large reference collection for future use in homicide investigations.

Such regular collection no doubt resulted in the majority of insects on the remains being recorded. However, many carrion insects are nocturnal or crepuscular, and would, therefore, be missed by hand collection. Therefore, pitfall trapping was carried out at each carcass. At the beginning of the experiments, we were concerned that the numbers and species of insect collected in the trap may be biased by its location in relationship to carcass position or compass orientation. Therefore, four traps were originally placed, at each side of the protective cage, approximately 10-20 cm from the carcass. The samples from each of the four traps, in all carcasses were compared for the first three weeks post mortem. No bias was seen so it was concluded that a trap placed anywhere within ~20 cm of the carcass would catch a representative sample of insects attracted to and leaving the carcass. Therefore, the four traps were replaced with just one trap at each carcass, for all subsequent experiments.

Also, although baseline data for naturally occurring fauna was established prior to carcass placement, seasonal changes could be expected, so a control pitfall trap was placed ~20 m away from each carcass, and collected every second day, as with carcass-related pitfall traps, to determine which insects were carcass-associated and which were merely naturally occurring in the area for that time of year.

CONTROL CARCASSES

Control carcasses were used in order to determine whether or not the sampling method employed in the experimental carcasses disturbed the rate of decomposition and insect fauna associated with the carcasses. Therefore, control pig carcasses were not disturbed. Only

temperature measurements and visual observations were made. Ambient and internal carcass temperatures were recorded at each control pig. Internal carcass temperatures were obtained by means of inserting a permanent temperature probe approximately 8-10 cm into a small entrance wound on the carcass immediately after death (Fig. 9). The entrance wound was created by shooting the carcass with a .22" caliber short, low velocity bullet, as previously mentioned. This probe was connected to a datalogger (SmartReader 1, Young Environmental Systems, Richmond, B.C.) which recorded temperature every half hour. Maggot masses are capable of raising the temperature of the carcass which in turn can affect the developmental rate of blow flies (Goff, 1993) Temperature measurements were taken in order to compare ambient with internal carcass temperature between carcasses in the same habitat, different habitats and different seasons. Such comparisons were important in determining insect developmental rates at these carcasses. No insects were collected directly from the control carcasses, however extensive visual analysis was made for comparison with experimental carcass fauna. As well, pitfall traps were placed near each carcass, together with control pitfalls 20 m away. Pitfall traps were not considered to affect the actual insect succession on the carcass or the rate of decomposition, but allowed for a direct comparison with experimental carcasses, and served as a back-up to visual insect identification on control carcasses. Pitfalls were the only means of collecting insects on control carcasses.

Two additional carcasses, fully clothed in cotton jogging suits, were examined during the fall experiment (Fig. 10). It was hypothesized that clothing may influence insect succession. Clothing may act as a shelter for insect species and also act to retain body fluids, making the carcass more attractive to carrion insects. Two extra pig carcasses were, therefore, added to the fall experiment, making a total of 12 carcasses for that experiment. These were compared with the normal, unclothed carcasses. These carcasses were clothed in undergarments and loose clothing, to simulate common human attire. Clothing was obtained from the Salvation Army Thrift Store, Vancouver.

RESULTS

CONTROL *VERSUS* EXPERIMENTAL CARCASSES

No major differences were observed between that of the control pigs and the experimental pigs in the same habitat regardless of season. Key groups of insects, such as Piophilidae and Fanniidae, colonized both experimental and control carcasses in each experiment within 1-2 days of each other. Such trends were reflected both in hand collections and pitfall traps, and were seen irrespective of habitat or season. This observation is important as it means that the methodology utilized for experimental carcasses did not disturb insect succession or the rate of decomposition to any significant degree.

HABITAT DIFFERENCES (SUN *VERSUS* SHADE)

Many differences were observed between carcasses located in a sunny location and carcasses located in a shady location, during all three seasons examined. Variations in rates of decomposition and mean temperature insect succession were observed.

1. GENERAL OBSERVATIONS

During all seasons, carcasses located in a sun habitat decomposed faster than those located in the shade habitat. In general, temperature and climate in the exposed sun habitats were more extreme than those of the shade habitats. This led to differences in rates of blow fly development (as seen in internal, external carcass temperature measurements depicted in Fig.11-16), decomposition (as shown in changes in weight measurements depicted in Fig.17-19), as well as differences in insect succession (a portion of which is represented in tables 1 and 2).

2. RATE OF BLOW FLY DEVELOPMENT

Figures 11-16 depict average ambient or external temperatures (shown as black solid line with the rectangular marker) and internal carcass temperatures (the black solid line with the circular marker) recorded during the period of active decay for both shade (figures 11,13, 15) and sun (figures 12,14,16) sites during the spring and summer season. Ambient

temperatures in the sun habitat averaged approximately 5°C higher than was experienced in the shade habitat during the spring season and approximately 10°C higher during the summer season. Variations in temperature for the fall season are still under analysis.

Internal carcass temperatures, which indicate third instar dipteran larvae activity consistently peaked earlier in the sun carcasses than in shade carcasses. For example, during the spring experiment such peaks occurred six days earlier in the sun than in the shade. (Fig. 11,12)

3. RATE OF DECOMPOSITION

During experimentation, weight measurements were taken in order to record the loss of weight as a result of maggots feeding upon the carrion. Figure 17-19 illustrates the loss of weight of sun and shade carcasses over time. In general, regardless of season, pigs located in a sunny location lost weight at a faster rate than those pigs located in shady sites. However, as demonstrated in figure 17, shade carcasses affected by vertebrate scavengers had a weight loss pattern that matched that of unaffected sun carcasses.

4. INSECT SUCCESSION

Tables 1 and 2 represent the presence and absence of several key successional insects on pig carcasses, in both habitats for the spring experiment. These tables depict only a few differences observed in the timing of successional insects. For example, Piophilidae larvae, which are key insects in timing of death, were first observed on sun carcasses after 42 days while they were not observed on shade carcasses until 48 days. Although successional data from both summer and fall experiments are currently being processed, trends indicate habitat variation.

A greater diversity of successional insects were found on shade carcasses than was found on sun carcasses. As well, several expected successional insects such as *Fannia* sp. were not observed as frequently as expected on sun carcasses For example, *Fannia* larvae, present on most shade carcasses after 50 days since death during the spring season, 72 days since death during the summer season, and **X** days since death during the fall season were **never**

observed on any sun carcasses during the spring and fall season, and only observed on one sun carcass (after 82 days) from the summer season.

SEASONAL DIFFERENCES

1. GENERAL OBSERVATIONS

The effects of three seasons, spring, summer and fall were examined. Season of death was observed to have a major effect on the rate of development of blow flies, the rate of decomposition of the carcass and the succession of carrion insects. In general, the more intense the heat during a season, the faster the rate of development of blow flies, faster the rate of decomposition, and the more limited the insect succession.

2. BLOW FLY RATE OF DEVELOPMENT

In figures 11-16, the timing of peak maggot mass activity (illustrated by the peaks experienced in internal temperatures) varied per season. Peaks during the spring season occurred after approximately 15-20 days post mortem. In comparison, peaks during the summer months occurred after only 5-9 days post mortem, and after ~10-15 days post mortem in the sun carcass only during the fall.

During the spring experiment, blow fly development ranged from a period of 28-32 days for carcasses located in the shade habitat and 24-28 days for carcasses located in the sun habitat.

3. RATE OF DECOMPOSITION

Figures 17-19 represent the loss of weight of experimental carcasses as a result of foraging maggots, over time. Upon comparing figures 17, 18 and 19, trends indicated that the rate of decomposition proceeded quickest during the hottest season, summer, and slowest during the coolest season, fall.

It was also found that the intensity, and length of the stages of decomposition; fresh, bloated, decay, post-decay, and skeletal stage varied according to season. In general, the more

intense the ambient and internal carcass temperature, the more intense and quicker the carcass progressed through most of the various stages of decomposition. Other seasonal environmental factors as well as vertebrate scavengers also played a crucial role in controlling the rate of decomposition in carcasses. These factors will be further discussed.

4. INSECT SUCCESSION

The abundance, intensity levels, timing and presence of most successional insect species did vary according to season. The presence of *Fannia* species, first observed after 50 days since death in the spring were not observed until 72 days since death in the summer experiment. Data from the fall as well as from all seasons is in the process of being analyzed for such trends. All data will be entered into a computer program developed by Dr. Kenneth Schoenly in order to facilitate the application of this database to homicide cases (Schoenly 1992).

5. CLOTHING

As previously mentioned, higher temperatures experienced at the sun sites during the summer experiment acted to dramatically limit insect succession at these carcasses. It was hypothesized that clothing may act to retain body fluids, making the carcass more attractive to successional insects. Therefore, two carcasses were clothed with undergarments and sweat suits. Several significant differences between clothed and unclothed carcasses were noted. It was observed that the blow fly oviposition pattern on clothed pig carcasses differed dramatically from unclothed carcasses. Blow flies on unclothed carcasses tend to oviposite on facial and genital orifices and/or directly on wounds sites. This pattern was expected to also occur on clothed carcasses. However, in addition to expected oviposition sites, blow flies oviposited directly on skin tissue concealed by clothing (Fig. 20). Oviposition on skin tissue was rarely observed to occur, much less the first instar larvae survive, on unclothed carcasses. As a result, it was found that such increased numbers of blow fly eggs led to enormous maggot colonization. As a direct result, the rate of decomposition was also increased. Figure 21 illustrates the rate of blow fly development on clothed carcasses in comparison to unclothed carcasses, located in the same habitat, same season. From this

graph, it can observe that the internal temperature in the clothed carcass is dramatically higher than that of the unclothed carcass. This increase is a direct result of the larger maggot mass created with the presence on clothing.

Important successional insect species such as *Fannia* were found to inhabit clothed carcasses 60 days after death. These successional insects were rarely found on unclothed carcasses located in the same habitat. This may indicate that clothing carcasses would lead to successful insect succession on carcasses. As well, clothed carcasses more accurately represent typical homicide scenarios. Most homicide victims are clothed, at least partially.

DISCUSSION

HABITAT DIFFERENCES

In general, regardless of season, ambient temperatures in sun sites in comparison to shade sites were both higher in temperature and displayed greater fluctuations (please refer to figures 11-16).

Insect development is temperature dependent; that is, the normal metabolic rate is increased with increased temperature, which results in a faster rate of development, so that the duration of development decreases in a linear manner with increasing temperature (Chapman 1955). For this reason, both internal and ambient temperature must be determined. Temperatures were measured by utilizing dataloggers which were calibrated to record internal and external temperature every half hour. In general, it was found that internal carcasses temperatures were greatly elevated above ambient temperatures during the period of active decay. Higher internal carcasses temperatures reflected increased heat caused by both frictional and metabolic action by maggots. This corresponds to the findings in other field projects (Anderson and VanLaerhoven in prep; Catts & Haskell 1990).

As expected internal temperature varied from ambient temperature, regardless of habitat (sun or shade). However the degree and time of temperature variation differed between the two

sites. In both habitats, minimal internal and external (ambient) temperature fluctuations occurred during the initial stages of decomposition although in general, more erratic temperatures were recorded at the exposed, sun carcasses. Elevated and peak internal carcass temperatures were a direct result of maggot activity within the carcass. Peak temperatures occurred earlier at the exposed carcasses than was experienced at shade carcasses. It is interesting to note that these peaks also coincided with larval migration. This infers that the growth and development of maggots in the sun habitat occurred at a more accelerated rate than in the shade habitat.

Although temperature was seen to be a major difference between the sun and the shade habitats, there are many other environmental differences. These include depth of shade, sun exposure (none, partial *etc.*) type of canopy, amount of shelter for insects, small rodents *etc.*, effect of rainfall (may be ameliorated somewhat in shade, but moisture may remain for longer), light intensity, wind levels, to list just a few. Such parameters may affect the number and presence of insects and other fauna in the habitat prior to and during carcass placement. In particular, shelter is a vital resource to small rodents, so such animals will remain near shelter and will rarely venture into exposed areas (Carter, pers. comm.). This, in turn, means that small rodents are more likely to be found in shady areas.

Time of insect colonization on the carcasses was also found to differ depending on habitat location. Tables one and two illustrate several insect species collected and observed at the carcasses in both sun and shade habitats during the spring months. In these tables, it can be seen that the appearance of specific species such as third instar dipteran larvae, Piophilidae larvae occurred earlier at sun sites than at shade sites. Piophilidae larvae were first observed on sun carcasses after 42 days since death, and 47 days since death in shade carcasses. Decomposition studies in different geographic locations found Piophilidae larvae colonizing carcasses after approximately 3-6 months since death (Smith 1986).

Insect succession was found to be more extensive in shade sites than at sun sites. One important and expected successional insect species, *Fannia*, was rarely found colonizing the

carcasses in sun habitats. The first *Fannia* larvae found on a sun carcass 82 days postmortem. In comparison, shade carcasses frequently hosted *Fannia* larvae. *Fannia* larvae were quite often found on a shade carcass within 50 days of death.

SEASONAL DIFFERENCES

Climatic factors such as rainfall and temperature greatly varied from season to season. The spring season was initially characterized by warm temperatures and dry weather conditions. This allowed for successful primary colonization of the carcass by blow fly species. However, as the spring experiment progressed (at approximately 6-14 days after death), wet weather conditions persisted. Despite this change in weather, dipteran larvae were able to feed and grow at a constant and uninhibited rate. The peak internal temperature recorded for a maggot mass during this season was 33°C.

The climate experienced during the summer experiment was dry and hot. The high temperatures experienced during the summer months acted to intensify insect activity on the carcasses regardless of habitat. Competition for food and space intensified between dipteran larval species. As a result, dipteran larvae were observed to migrate away from the carcasses in search of food (Fig. 22). This observation is important as maggots will normally migrate from a carcass in search of a suitable site for pupation. In this case, larval migration was occurring due to lack of food rather than stage of development. This important observation emphasises the need for a forensic entomologist to attend death scene investigations. Misinterpretation of migrating larvae could lead to incorrect assessments of time of death.

In the southern U.S., competition between calliphorid species may be seen and can effect time of death determinations (Hanski 1977). Normally, competition for food is not a limiting factor in British Columbia, as the corpse can normally support complete maggot development, so such competition between larvae has not been observed to effect time of death determinations. However, these experiments suggest that such competition might arise in corpses that decompose extremely rapidly due to season, as in this case, and may also be an

important factor in small victims, such as children or infants.

Another difficulty encountered when dealing with carcasses from the summer season involved recognition of the most advance stage of maggot development. With the intense dipteran competition on summer carcasses, identifying the oldest developed maggot was obscured by the shear presence of all stages of maggots. This observation was unlike the spring and fall experiments where a distinct mass of age-related maggots co-inhabited the carcasses together. The developmental rate of blow flies during the summer months was greatly increased so that recognition of early instar stages of dipteran larvae on the corpse as a whole was difficult. Some dipteran larvae were observed to pupate after only ten days since death, compared to 14 days since death as experienced in same habitat, yet the spring experiment.

Figures 13 and 14 illustrate the extreme internal temperatures achieved during the summer experiment. In both habitats, maggot mass temperatures reached as high as 40°C. It is important to note that these trends took place during a shorter time period in both habitats. For example the carcass located in the sun habitat, reached peak elevated internal temperatures at a mere 5 days since death. This peak occurred 10 days earlier than observed in the sun carcass during the spring season depicted in the previous figures 11 and 12. The duration of elevated temperatures also varied depending on season, lasting longer during the spring experiment than in the summer experiment.

Although, the carcasses reached such high temperatures, the maggots themselves were observed to be moving from the center of the mass to the outside and back again, continuously. This allowed them to regulate their temperatures, to a certain extent. Therefore, although the mass temperatures were extremely high, it is probable that each individual insect was living at a temperature somewhere between the mass temperature and the ambient temperature. It would be desirable, therefore, to determine exactly what temperatures the maggots were developing at, by tracking the temperature of individual insects. This should be a focus of future work.

It was found that seasonal variation influenced the rate of decomposition. During the spring months, the transformation from a freshly killed carcass state to a carcass devoid of soft muscle and fatty tissue took approximately 15-20 days in a sun location and 25-30 days in the shade location. In comparison, the same transformation in the summer months took 5-7 days in the sun location and 8-10 days in the shade location. Decomposition in the fall was greatly impaired by the cold weather. In fact, it took over 2 months in both locations to achieve the same decompositional transformation. These details are evident upon analysis of weight loss by carcasses in each of the three seasons (please refer to figures17-19).

Such intense temperatures experienced in the summer months, particularly in the sun habitat acted to reduce insect succession. These sun carcasses become desiccated and mummified. Very little insect activity was observed at carcasses in this state. Clothing was used in the fall experiment to alleviate this problem.

Climatic conditions in the fall were characterised by wet and cold climatic conditions. Cooler temperatures in the fall acted to retard the decomposition process. Figures 15 and 16 demonstrate temperatures recorded in both habitats during this season. Insect activity as well as bacterial colonization was greatly reduced. Dipteran larvae such as Piophilidae as well as other insects appeared sluggish, and seemed to feed very slowly if at all. It was suspected that many of the dipteran larvae observed entered diapause, in order to overwinter until more favourable weather conditions occurred. It is important to realize that fall data can not be used to analyze insect succession on carcasses from spring or summer seasons due to large differences in time of colonization and length of time an insect species would be found on a carcass. Such realization further illustrates and justifies an insect database which takes into account seasonal variation.

Fall carcasses located in the shade locations were primarily invaded not by insects by rather by scavengers, utilising it as a food resource. Both shrews and larger vertebrate scavengers such as racoons were linked to the scavenging action on carcasses. Figure 19 depicts the loss of weight by all carcasses in the fall experiment.

SCAVENGERS

During experimentation, it was discovered that vertebrate scavengers fed upon the carcasses mostly in the shade. This feeding activity acted to dramatically increase the rate of decomposition and seriously affect the insect succession as well as create postmortem artifacts. Shrews are suspected to be the culprit of feeding activity as there were shrew-like droppings found at the site of chews as well as dead shrews found in pitfall traps located near the carcass (Fig.23).

In the shade location, shrews consumed the skin and muscle tissue surrounding the bullet wound, and were able to enlarge the wound. This chewing exposed muscle tissue and extended the surface area available for flies to lay their eggs. More eggs laid would mean more maggots would be available to consume the carcass. Also first instar larvae, unable to break skin tissue, would have a more open feeding area. This chewing by shrews simultaneously reduced the amount of carrion available for successional insects. In effect, shrews were observed to greatly advance the decomposition process.

During experimentation, weight measurements were taken in order to record the loss of weight as a result of maggots feeding upon the carrion. In general, regardless of season, pigs located in a sunny location lost weight at a quicker rate than those pigs located in shady sites. However, during both the spring and fall experiments, two experimental pigs located in the shade were devastated by shrew feeding and lost weight faster than unaffected shade pigs. Figure 17 shows that weight losses by the carcass affected with shrew feeding patterned that of weight loss in the sun rather than the weight loss in the shade during the spring experiment. The only variable among shade pigs was the presence or absence of shrew feeding. Hence, it is felt that this one variable, shrew feeding, was responsible for the dramatic change in rate of decomposition. Figures 24-31 represent a series of photographs of an unaffected (unchewed) carcass in comparison to an affected (chewed) carcass in the same habitat and season during the same time period.

The effects of vertebrate scavengers were not observed during the summer experiments. Any possible effects from shrews were not observed, due to the speed of decomposition that took place during the hot ambient temperatures in July.

Insect succession was also affected. Shrew action interrupted the expected insect successional fauna. With unaffected experimental pigs, maggot activity is followed by a wave of succession insects such as other species of flies, skin beetles, and various other types of insects (Smith 1986). These insects will feed on skin, or fatty tissue or other parts of the corpse that were not consumed by blow fly maggots. Shrews removed flesh, fat tissue and muscle mass of affected pigs, eliminating a possible food resource for the expected insect fauna, as well as feeding on insects found on the carcass. As a result, very little insect succession was observed to occur on affected carcasses.

The effects of vertebrate scavengers has potential applications towards homicide cases. Postmortem artifacts such as feeding by shrew create difficulties in identification of bullet wounds. It was noticed that scavengers quickly made the bullet wound unrecognizable. As well, feeding by shrew scavengers may create difficulties in establishing time of death by means of forensic entomology. Successional insect species required for the dating procedure may not have had a sufficient food resource and as a result may not be found associated with human remains. This has potential implications for human cases discovered in the outdoors in shady conditions.

It is important to be aware of the possible effects created by other vertebrate and invertebrate scavengers. Other scavenger action such as that by ants and wasps were observed. Both ants and wasps were observed to feed directly upon Diptera eggs and maggots. This action seemed to delay or retard the process of decomposition to some degree, in the initial stages only. Scavenger feeding acted to reduce the net amount of maggots available to feed upon the carcass. However, it was found that this type of feeding was not found significant and did not influence the rate of weight loss nor the insect succession. Red Imported Fire Ants (*Solenopsis invicta*) pose a major problem in the determination of time of death of carcasses

located in Southern U.S.A. (Hayes, pers. comm). However, fire ants do not occur as far north as Canada, and it is felt, from this work, that other species of ants are unlikely to pose a major threat to determining time of death using insects.

Predator-prey relationships among insects found on carcasses have been found to be important in determining time of death. In tables one and two, a Staphylinid beetle species, *Creophilus maxillus* was only found present on the carcass when maggots reached a 3rd instar larval developmental stage.

One carcass was severely affected by a larger vertebrate scavenger. In this case, a raccoon is suspected to be the culprit, based on past experience with preliminary carrion studies. This scavenger was able to decapitate the carcass, exposing the entire cross-section of the neck. As a result, fly eggs were laid upon the exposed surface and a large maggot mass was created, increasing the rate of decomposition.

CLOTHING

During the fall experiments, clothed carcasses were added as a comparison to determine their effects on insect colonization and carcass decomposition. Considerable differences were noted between clothed and unclothed carcasses in the same habitat. These included larger maggot masses and greater insect diversity and resulted in the carcass being attractive to insects for much longer than unclothed carcasses. These results are extremely important, as all previous decomposition experiments in other geographic regions have used naked carcasses, including both animal and human corpses (Rodriquez and Bass 1983, Goff 1991, Payne 1965). However, clothing clearly makes a difference, and should be included in all future studies. In most human cases that have been investigated using forensic entomology in B.C., the victims were completely or partially clothed. Rarely were completely naked victims found. Therefore, a clothed carcass is a much more realistic model for human death investigations.

4. Networking - One of the most important parts of research is collaboration between the basic (research) and applied (actual use in cases) partners. This is rarely achieved in some research, or may take years before the research can be actually tested and applied in a practical situation. This is not the case with the above research in forensic entomology. This project contributed many short and long term benefits by performing research through the collaboration of university personnel and the police community. It combines the extensive research facilities of the university with the immediate, practical mandate of the police, and has allowed a large, intensive research program to be successfully completed and immediately implemented.

5. Collaboration - This work has also been of value in attracting research partners. One of the objectives of the CPRC is to forge partnerships with the national and international research community. This work has been presented at both Canadian and American national meetings and has received widespread support. It has also resulted in partnerships with other research and funding agencies. Conservation officers across Canada and the U.S. now wish to use forensic entomology in their investigations, and several wildlife organizations are now funding collaborative work in human and animal death cases. These include The Vancouver Foundation, The Metcalf Foundation, World Wildlife Fund - Endangered Species Recovery Fund, Animal Welfare Foundation of Canada, Northwest Wildlife Preservation Society and the Wildlife Forensic Lab in Oregon.

ACKNOWLEDGMENTS

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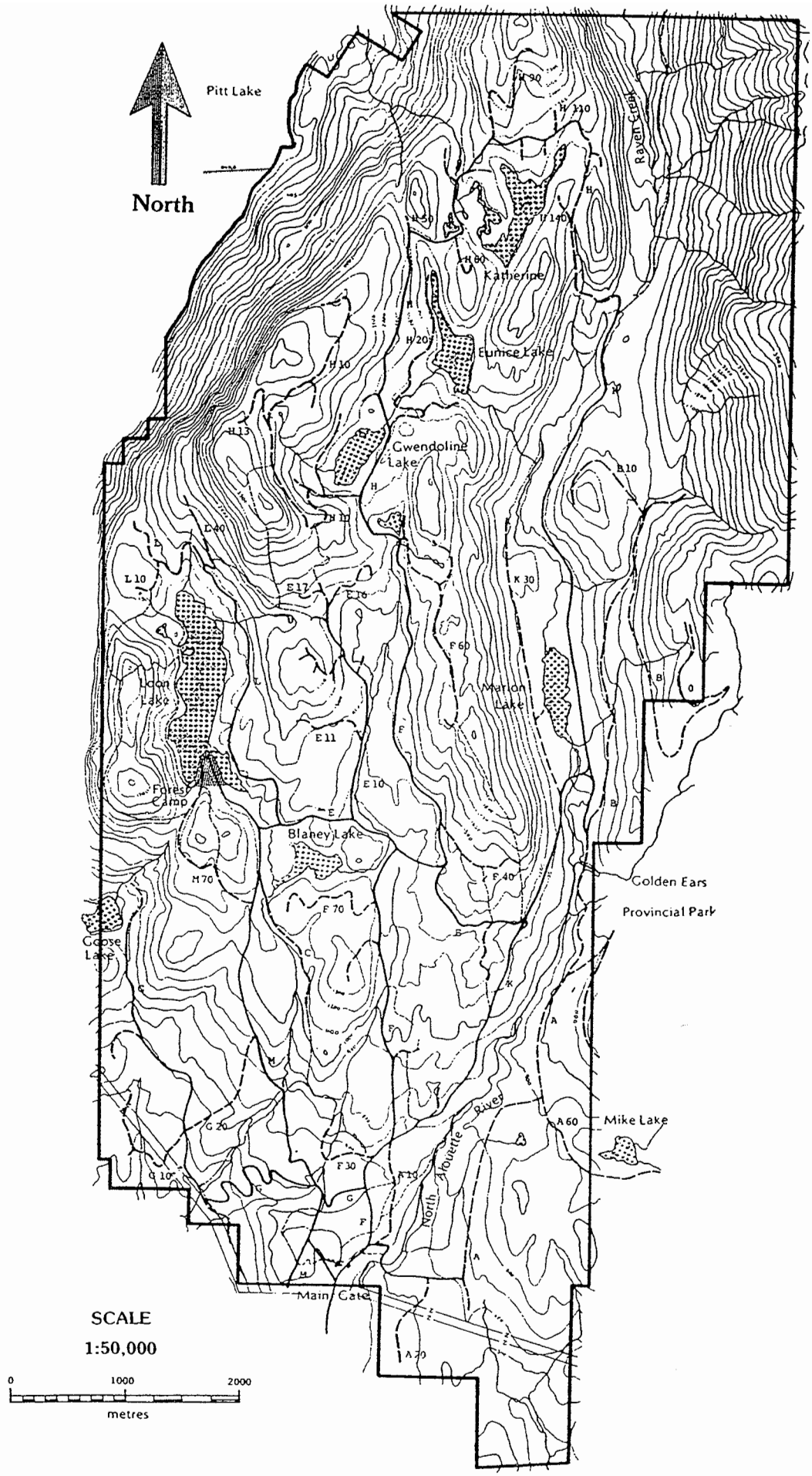


Map 1 U.B.C. Malcolm Knapp Research Forest

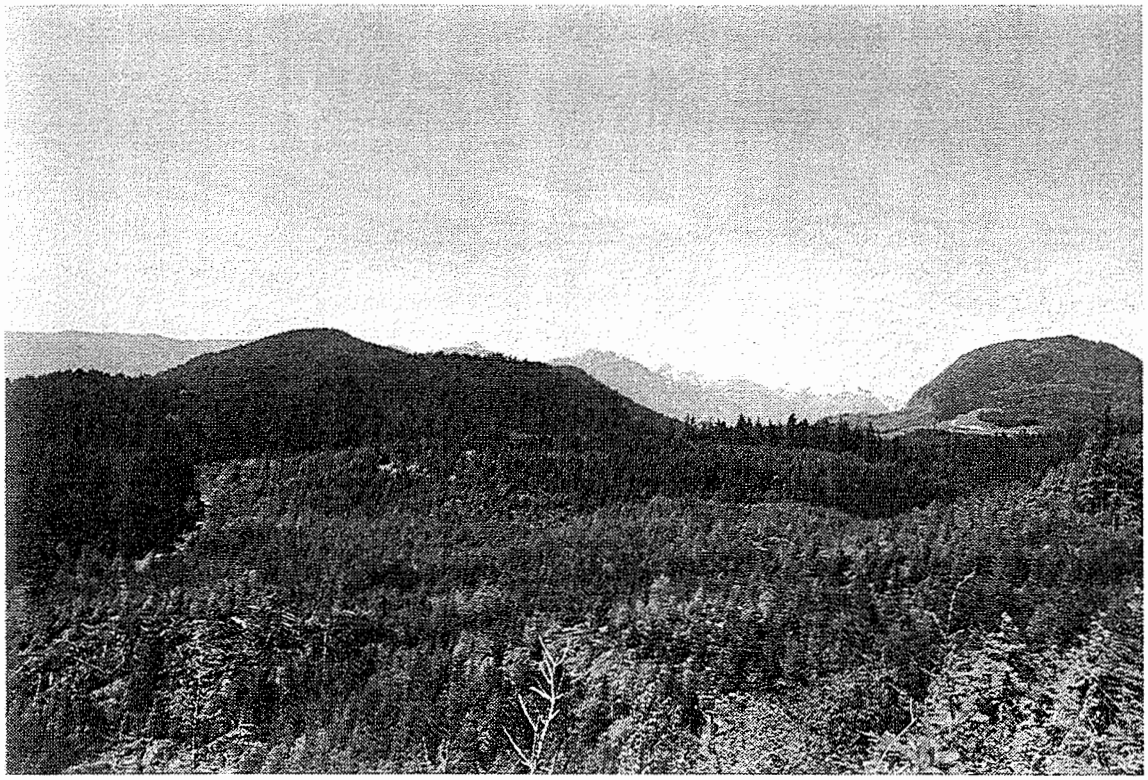


Figure 1 Photo: U.B.C. Malcolm Knapp Research Forest

Figure 2 Photo: Research Facilities

Figure 3 Photo: Bear Hazard Warning Sign

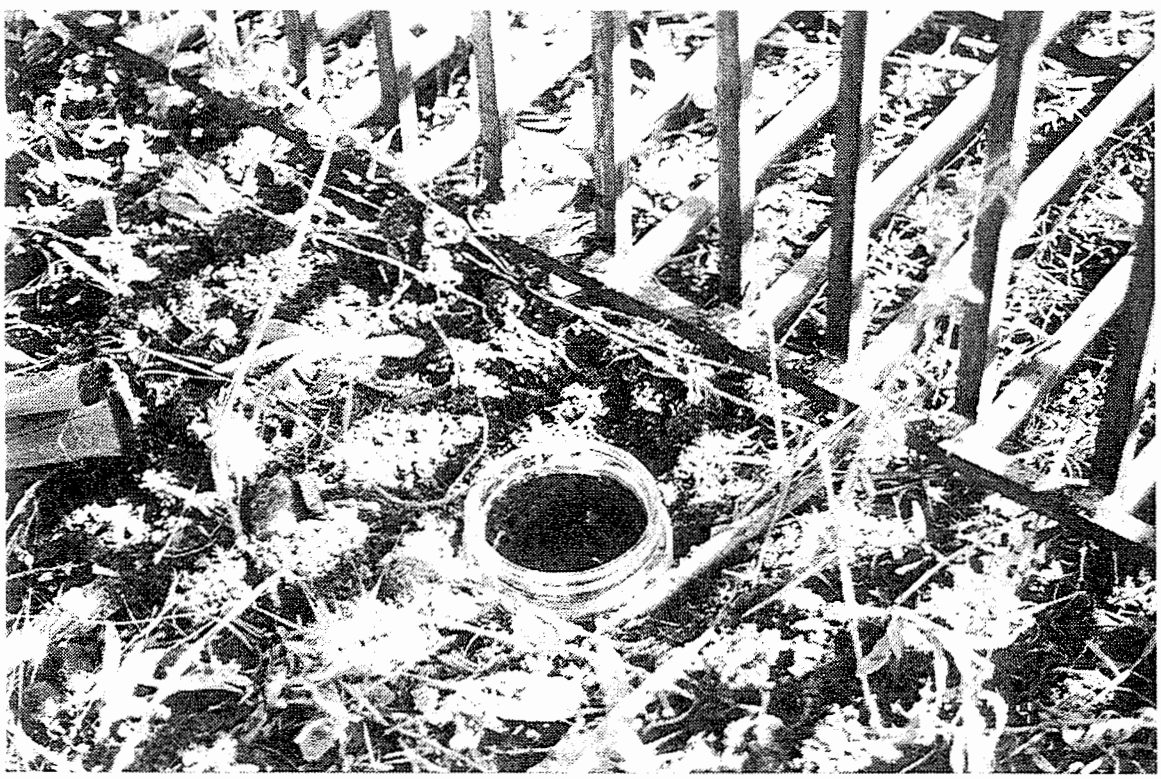


Figure 4 Photo: Pitfall Trap

Figure 5 Photo: Steel Barred Cages

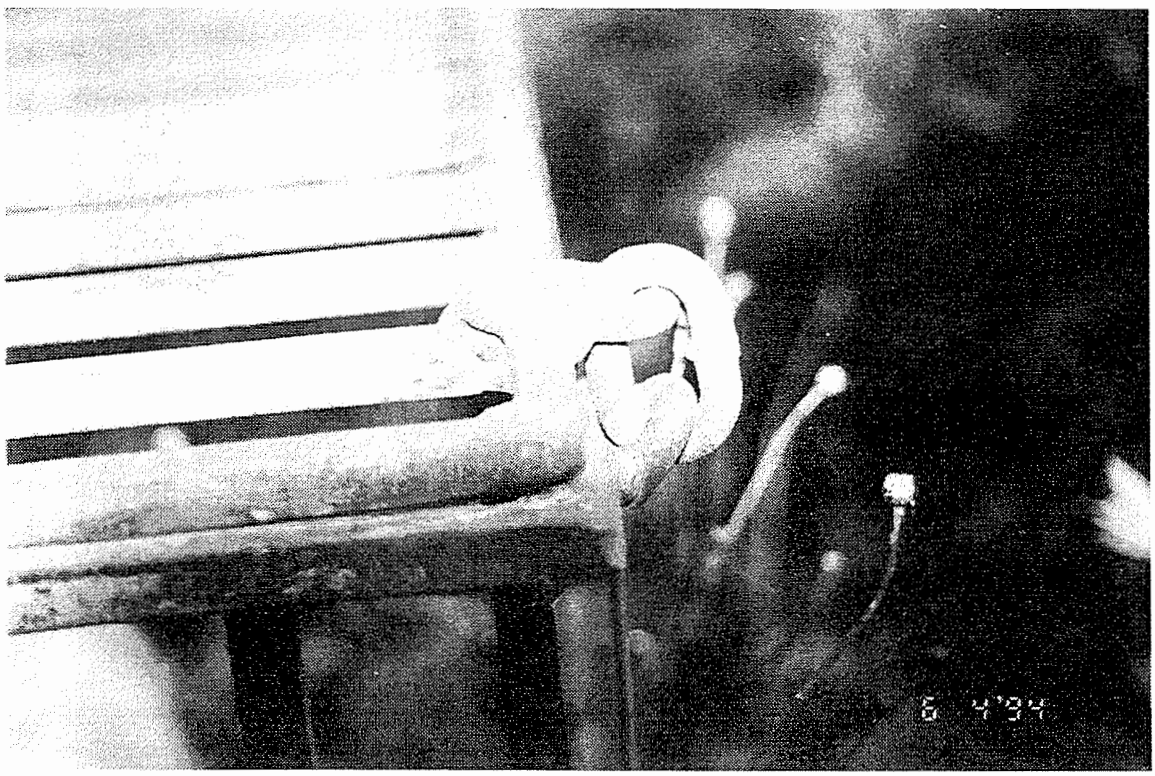


Figure 6 Photo: Hinge on Cage

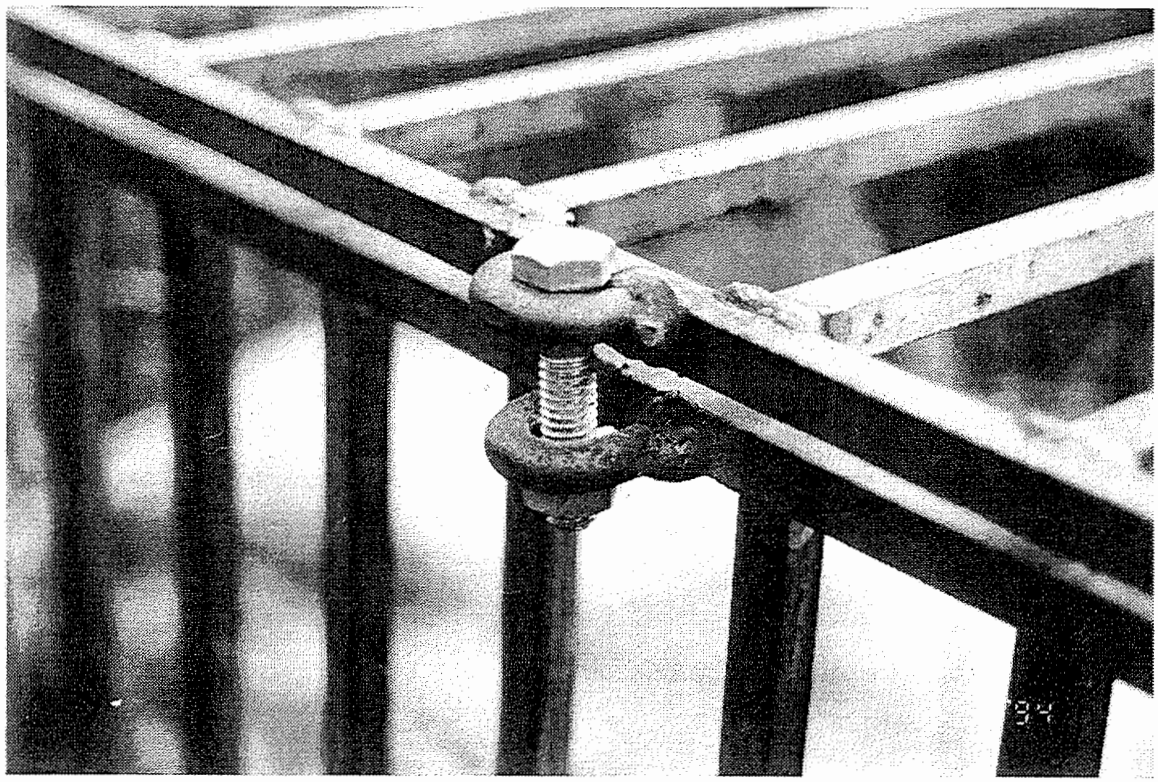


Figure 7 Photo: Locking Mechanism on Cage

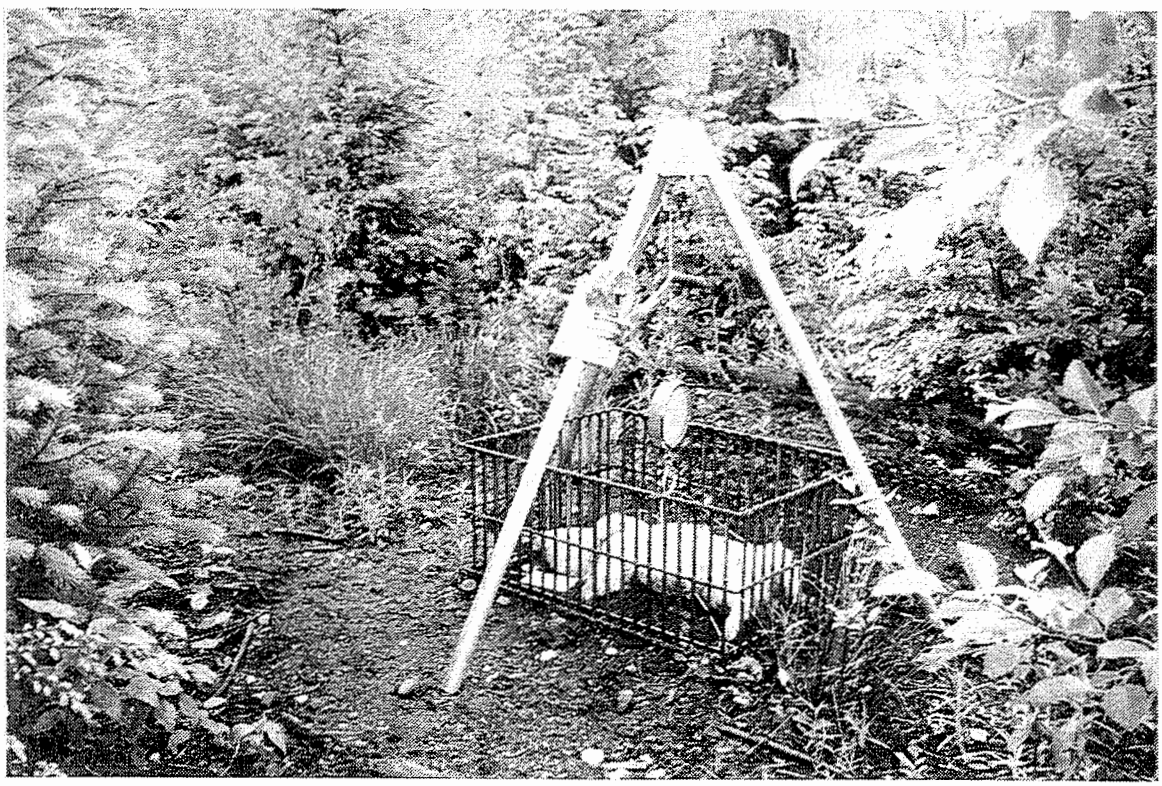


Figure 8 Photo: Weighing Platform

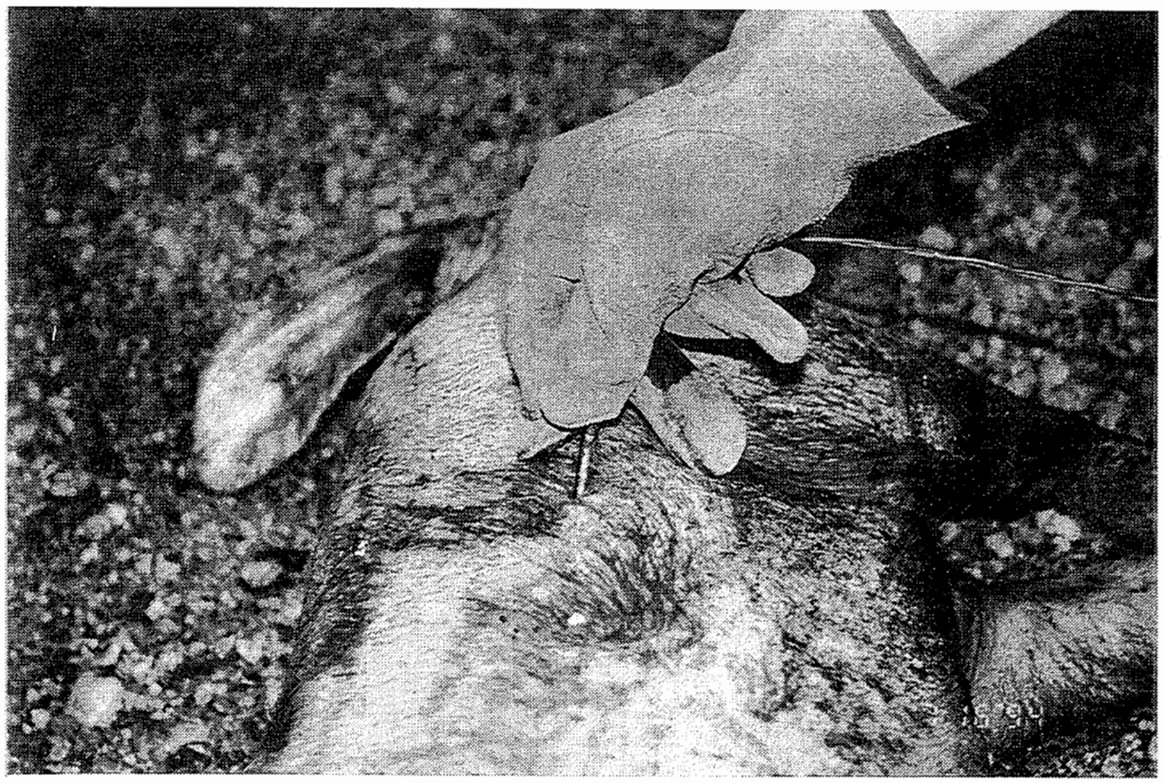


Figure 9 Photo: Temperature Probes inserted into Control Carcass

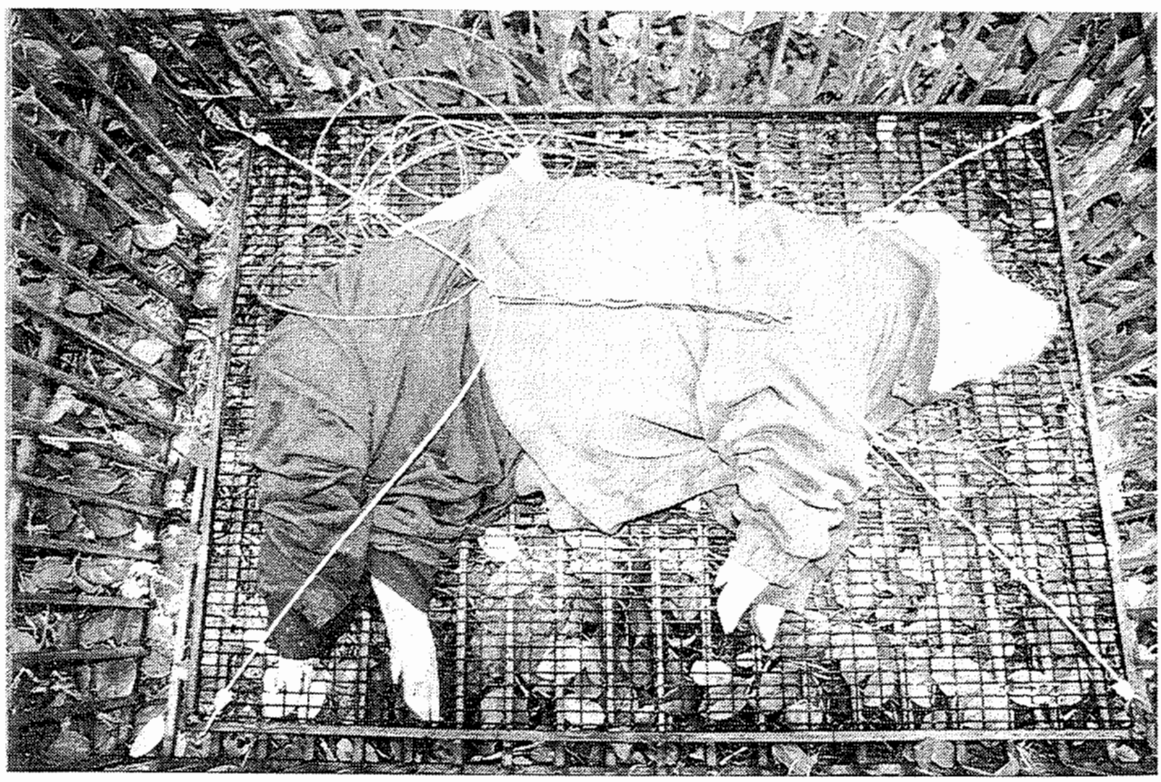


Figure 10 Photo: Clothed Carcass

FIGURE 11: TEMPERATURE RANGE OF SHADE CARCASSES DURING SPRING 1994

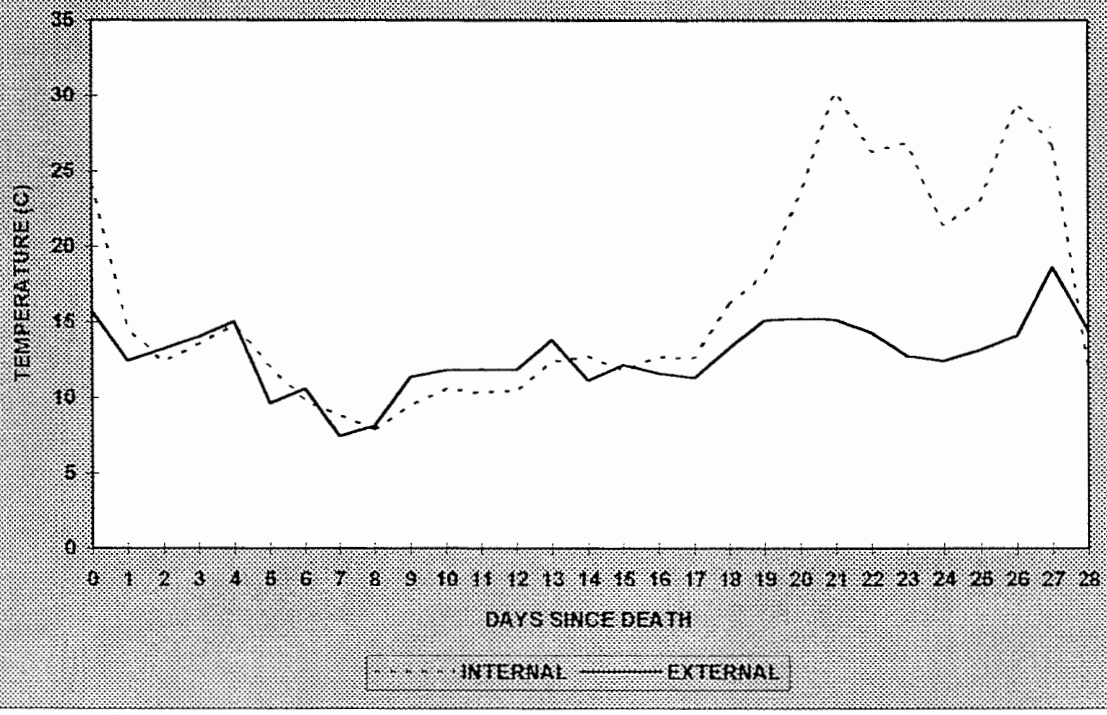


FIGURE 12: TEMPERATURE RANGE OF SUN CARCASS DURING SPRING 1994

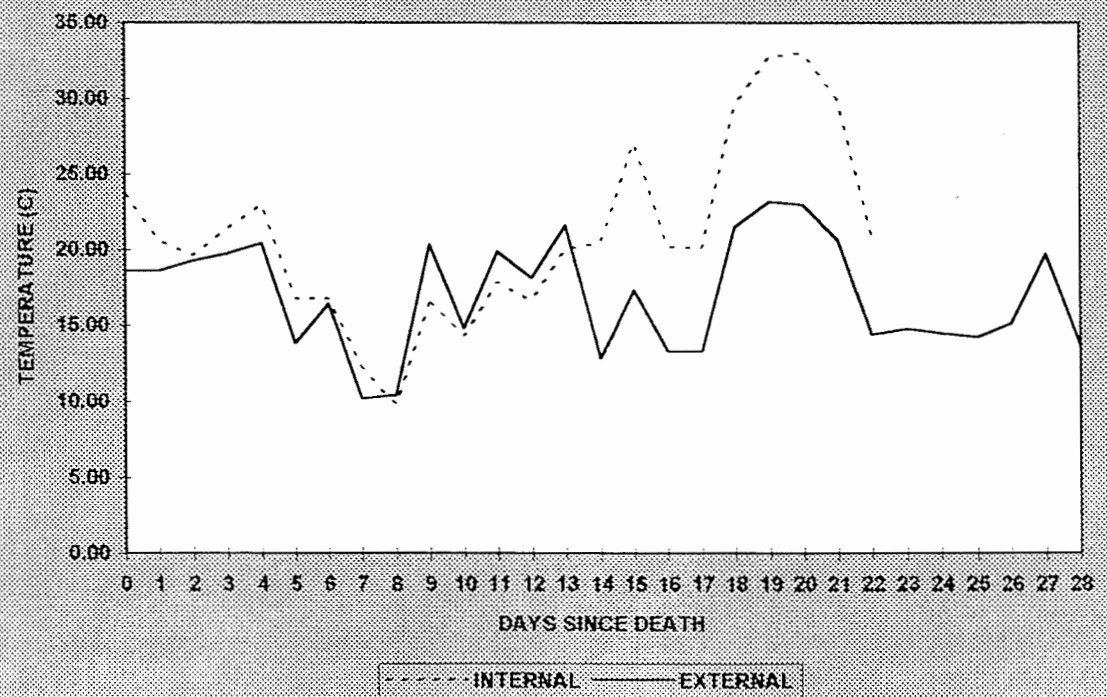


FIGURE 13: TEMPERATURE RANGES OF SHADE CARCASSES DURING SUMMER 1994

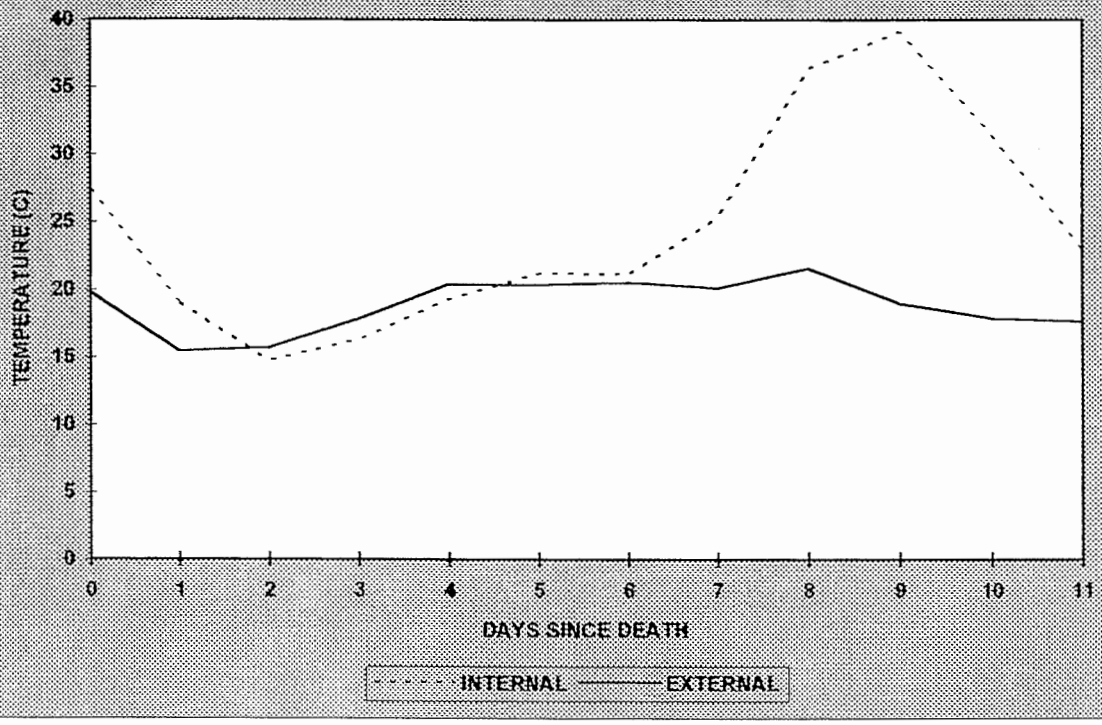


FIGURE 14: TEMPERATURE RANGE OF SUN CARCASSES DURING SUMMER 1994

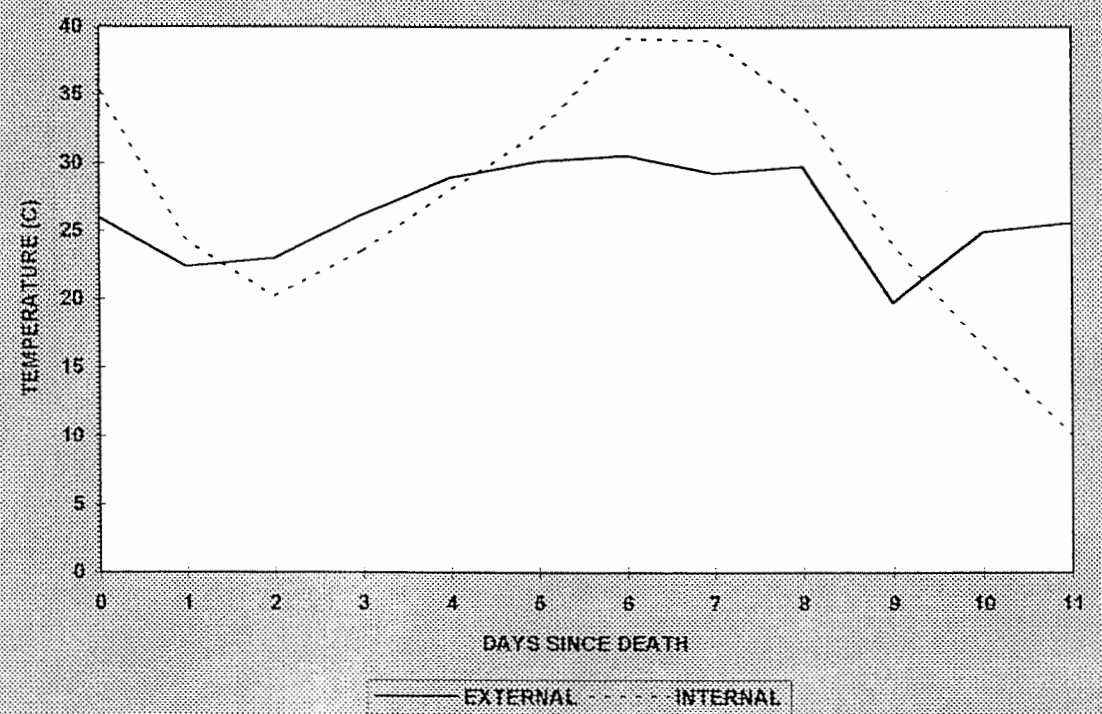


FIGURE 15: TEMPERATURE RANGES OF SHADE CARCASS DURING FALL 1994

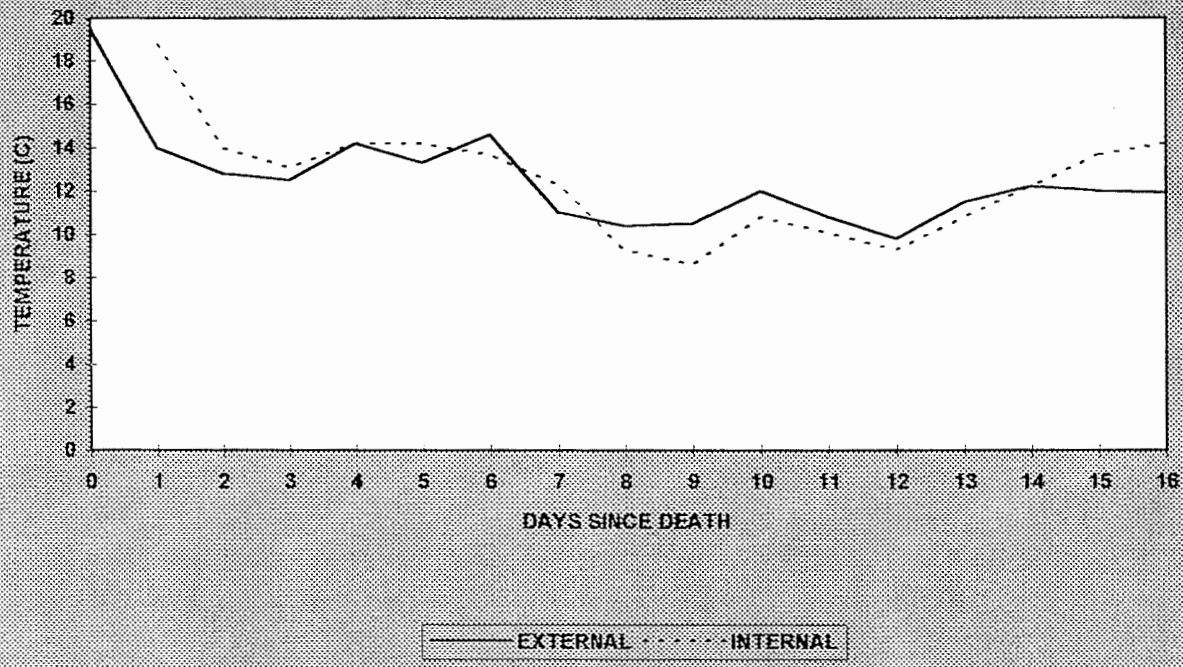


FIGURE 16: TEMPERATURE RANGES OF SUN CARCASS DURING FALL 1994

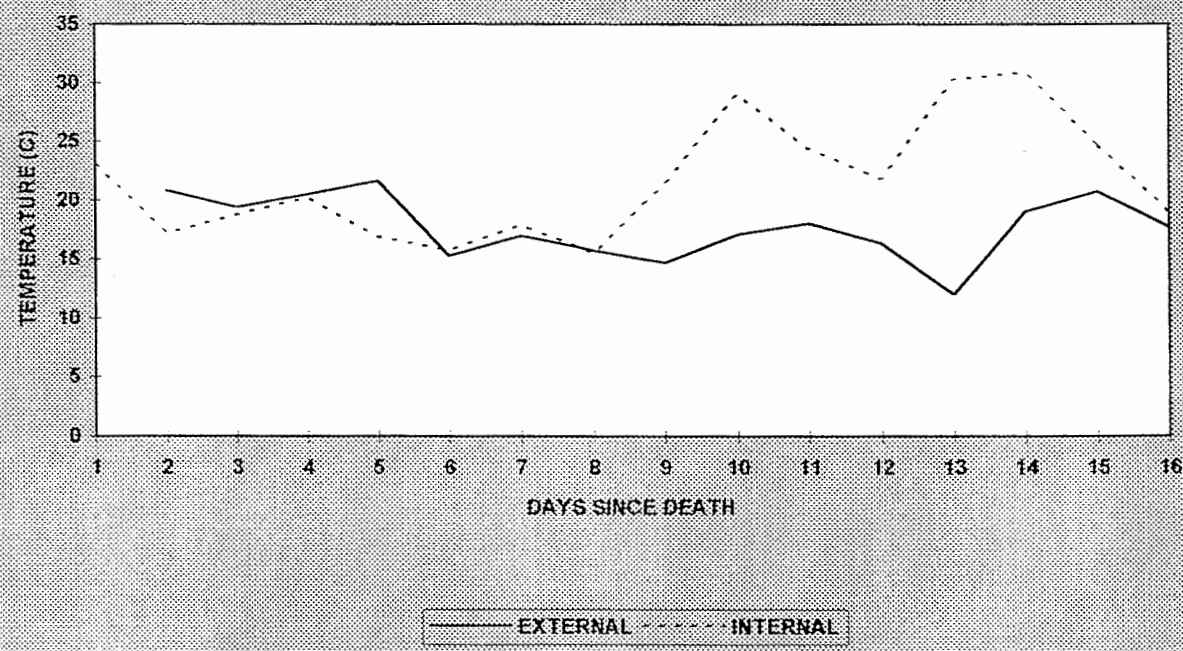


FIGURE 17: RATE OF BIOMASS LOSS IN SUN VS SHADE DURING THE SPRING EXPERIMENT

(NOTE: SUN CARCASSES = 94-1-1, 94-1-2, 94-1-3; SHADE CARCASSES = 94-1-7, 94-1-9, 94-1-10)

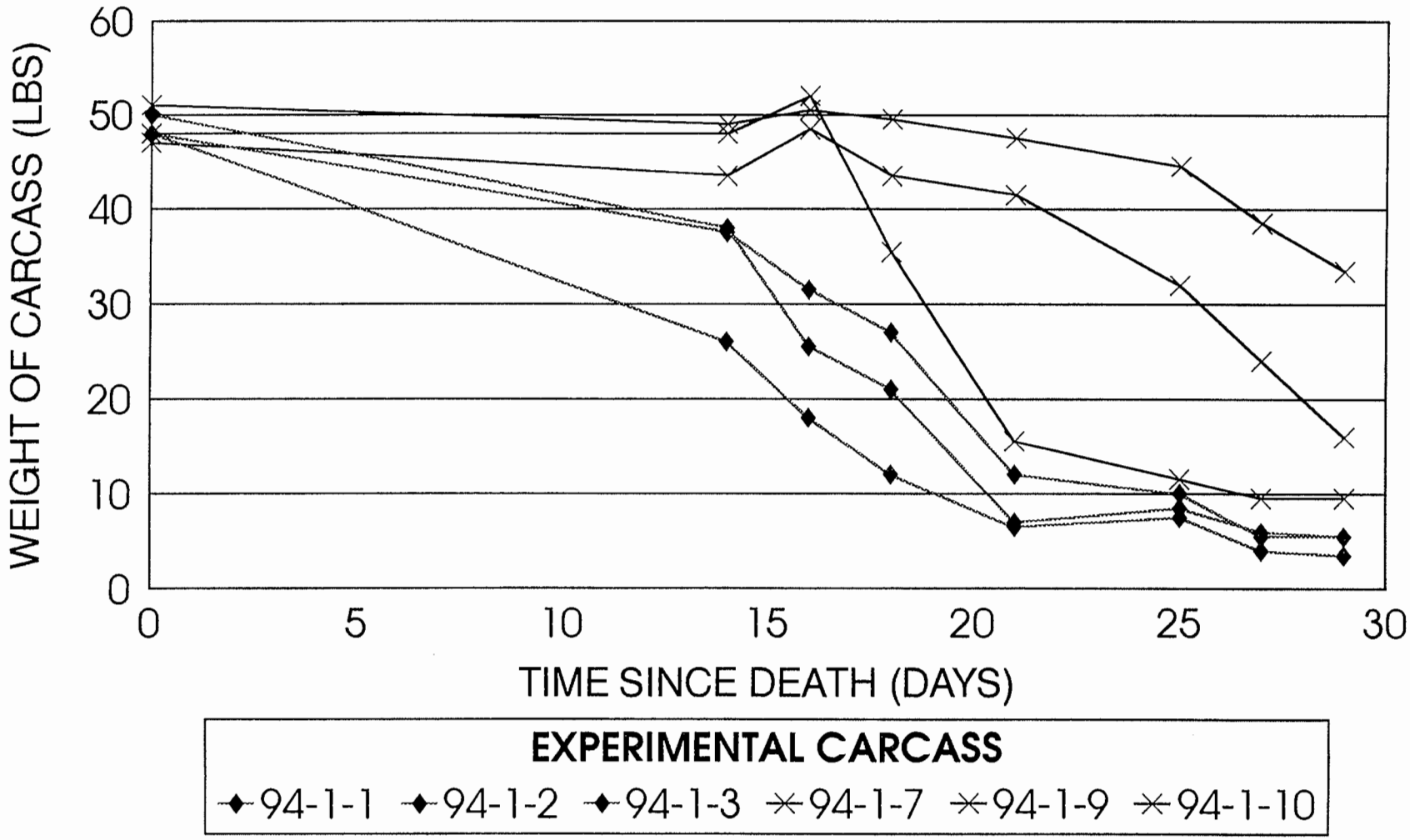


Figure 17 Weight Loss for Sun and Shade Carcasses, Spring Experiment

FIGURE 18: RATE OF WEIGHT LOSS IN SUN VS SHADE DURING THE SUMMER EXPERIMENT

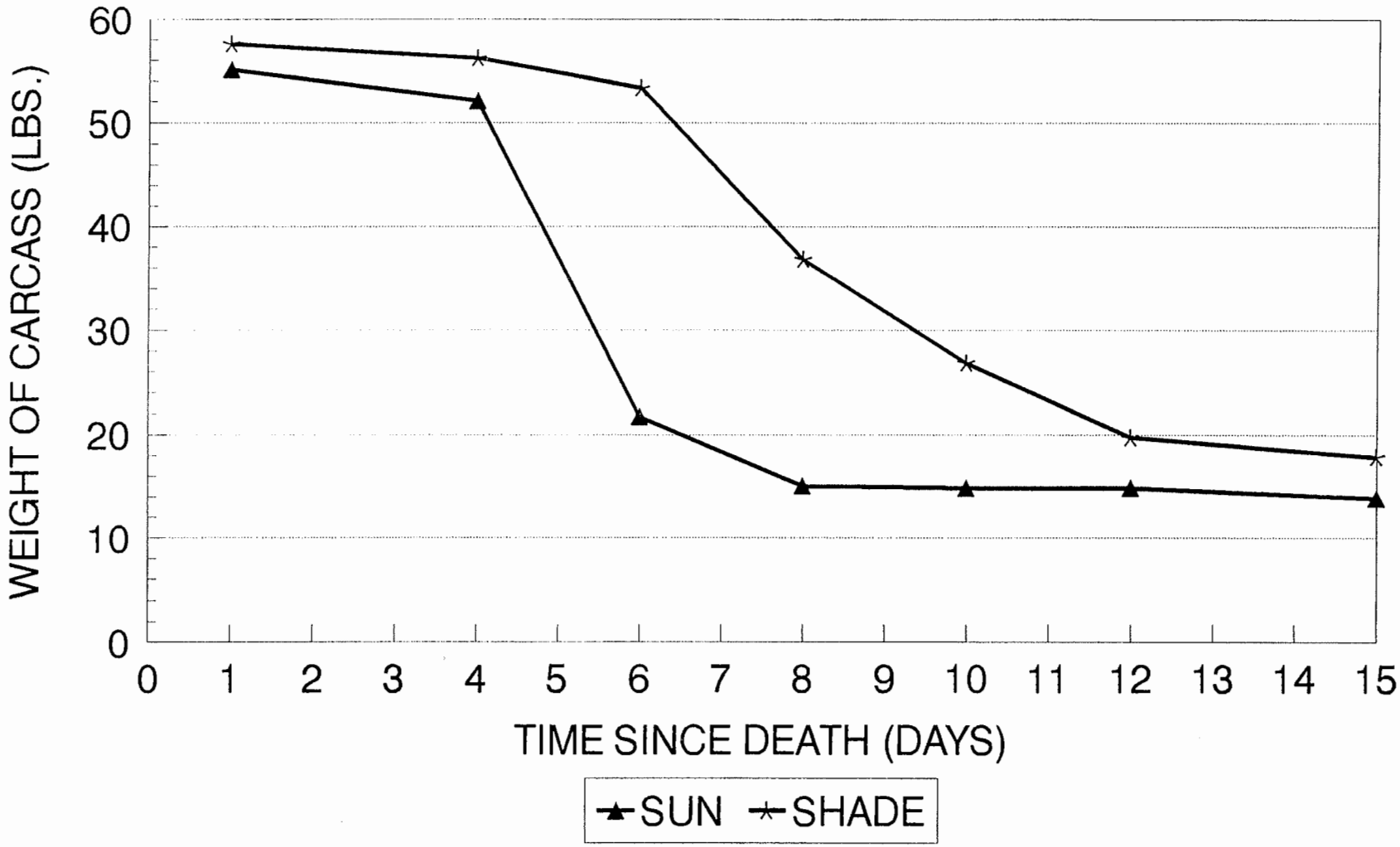


Figure 18 Weight Loss for Sun and Shade Carcasses, Summer Experiment

FIGURE 19: RATE OF WEIGHT LOSS IN SUN VS SHADE DURING THE FALL EXPERIMENT

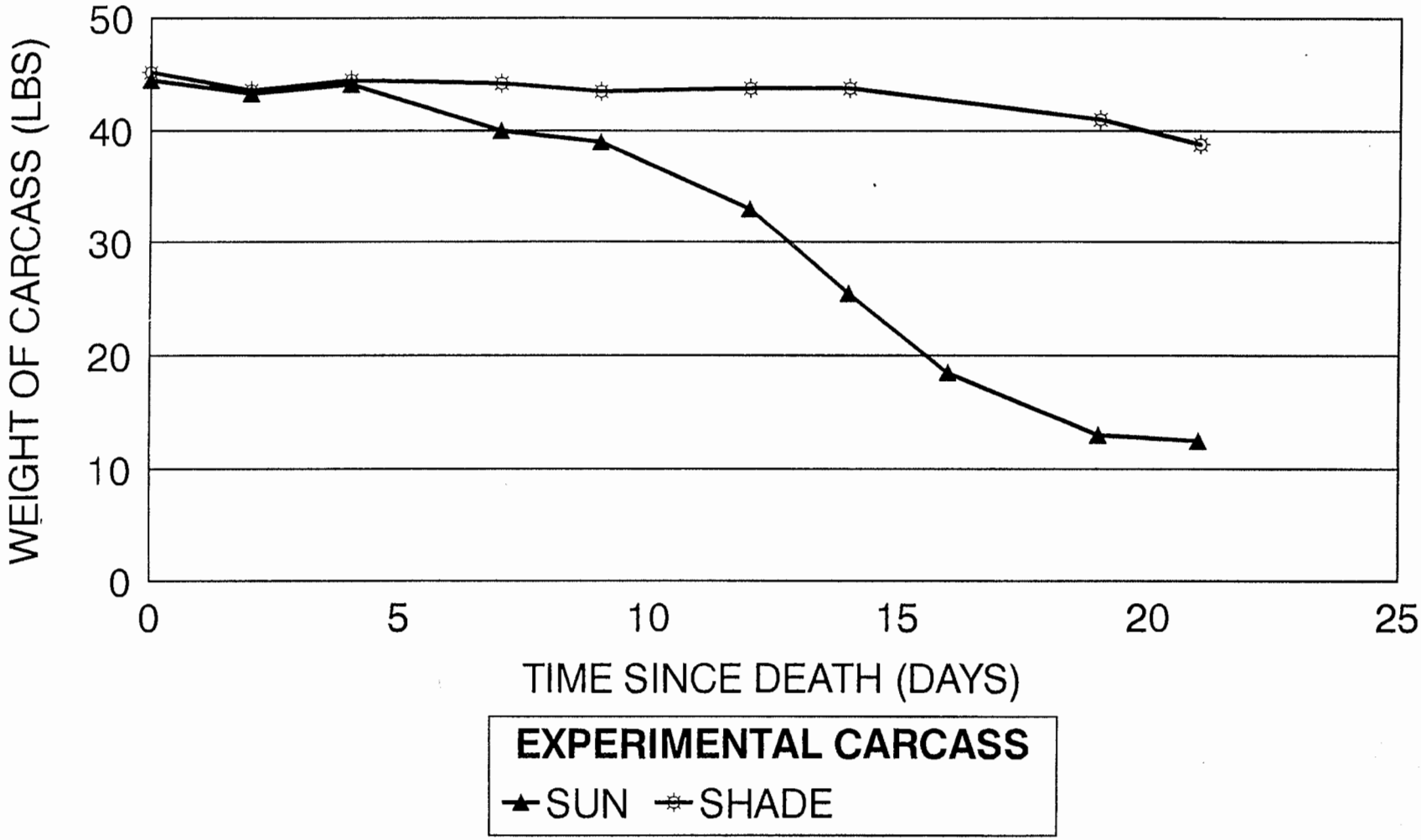
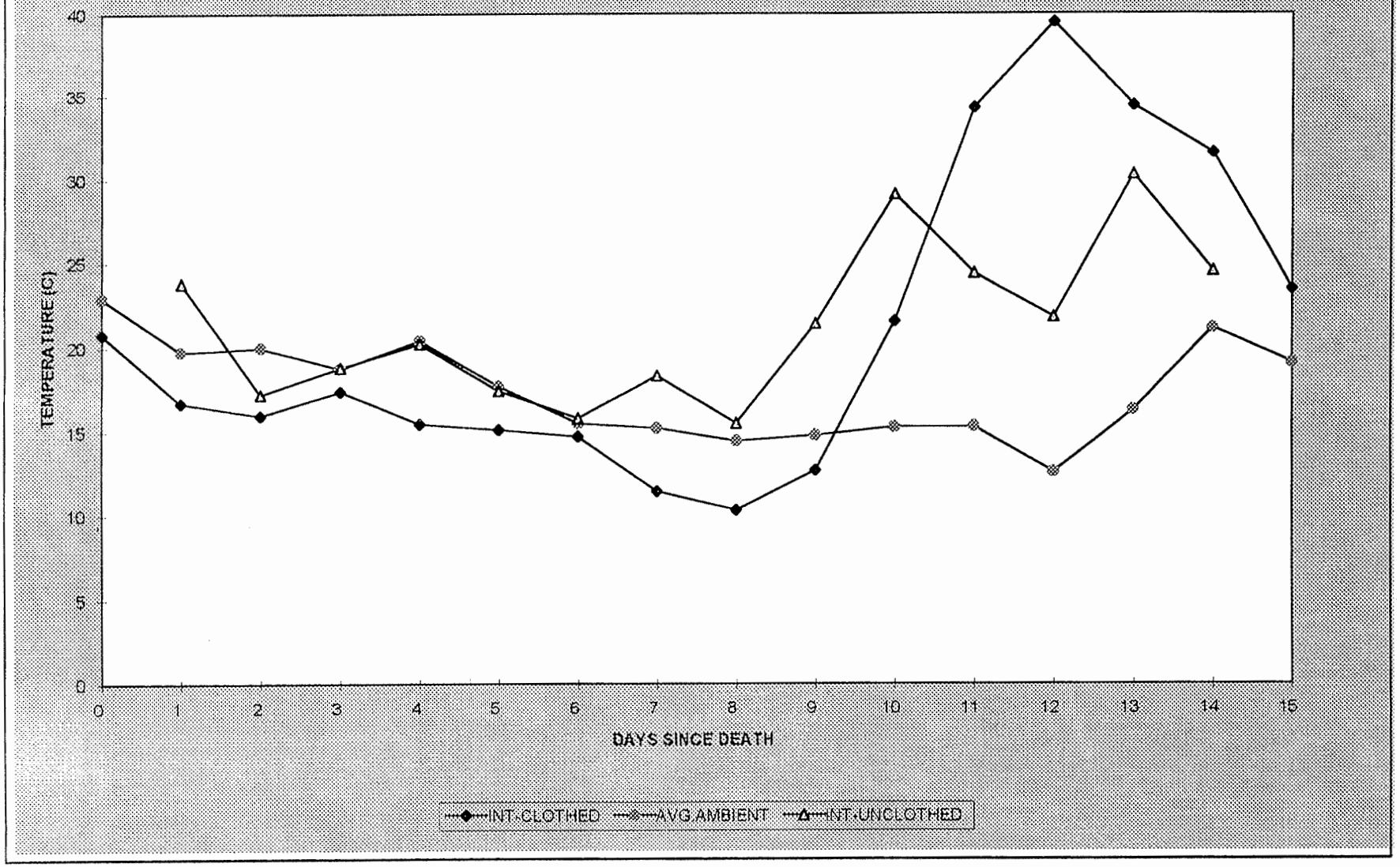


Figure 19 Weight Loss for Sun and Shade Carcasses, Fall Experiment

Figure 20 Photo: Diptera Eggs underneath Clothing on Clothed Carcasses

FIGURE 21: TEMPERATURE RANGE OF CLOTHED VERSUS UNCLOTHED CARCASSES IN SUN HABITAT (FALL EXPERIMENT)



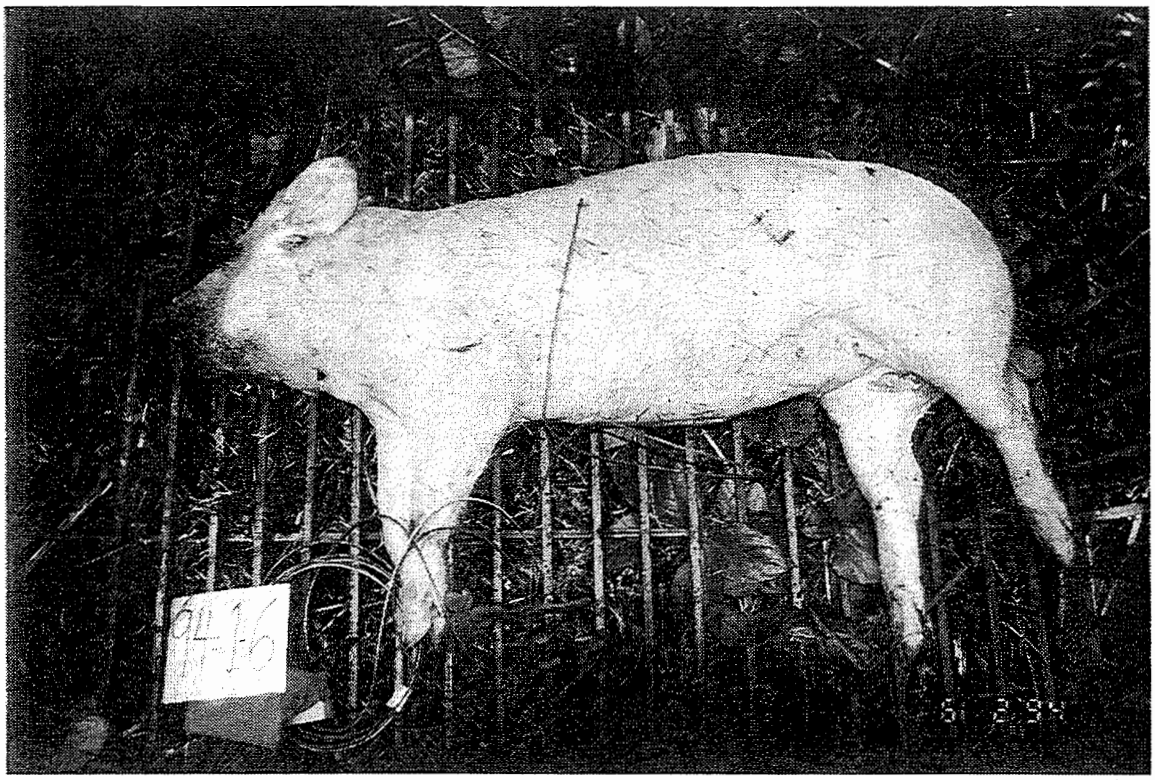


Figure 26 Photos: Shrew Chewed and Unchewed Carcasses, Fall Experiment

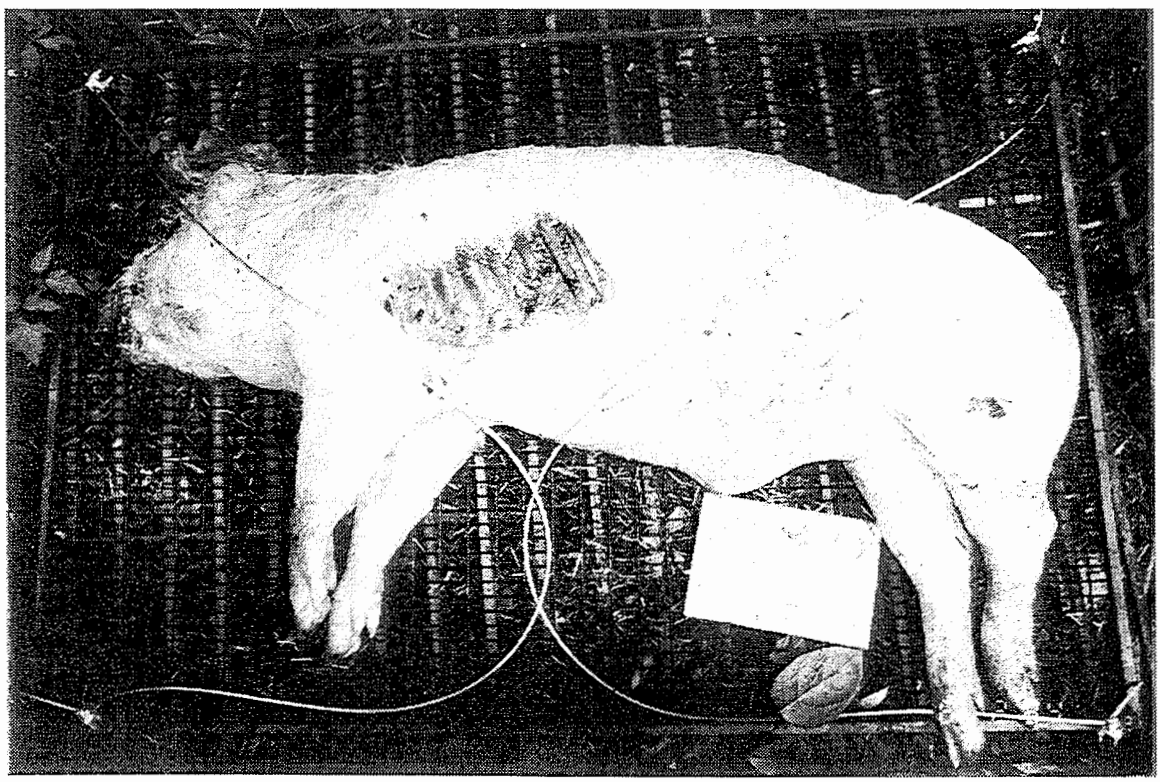


Figure 27 Photos: Shrew Chewed and Unchewed Carcasses, Fall Experiment

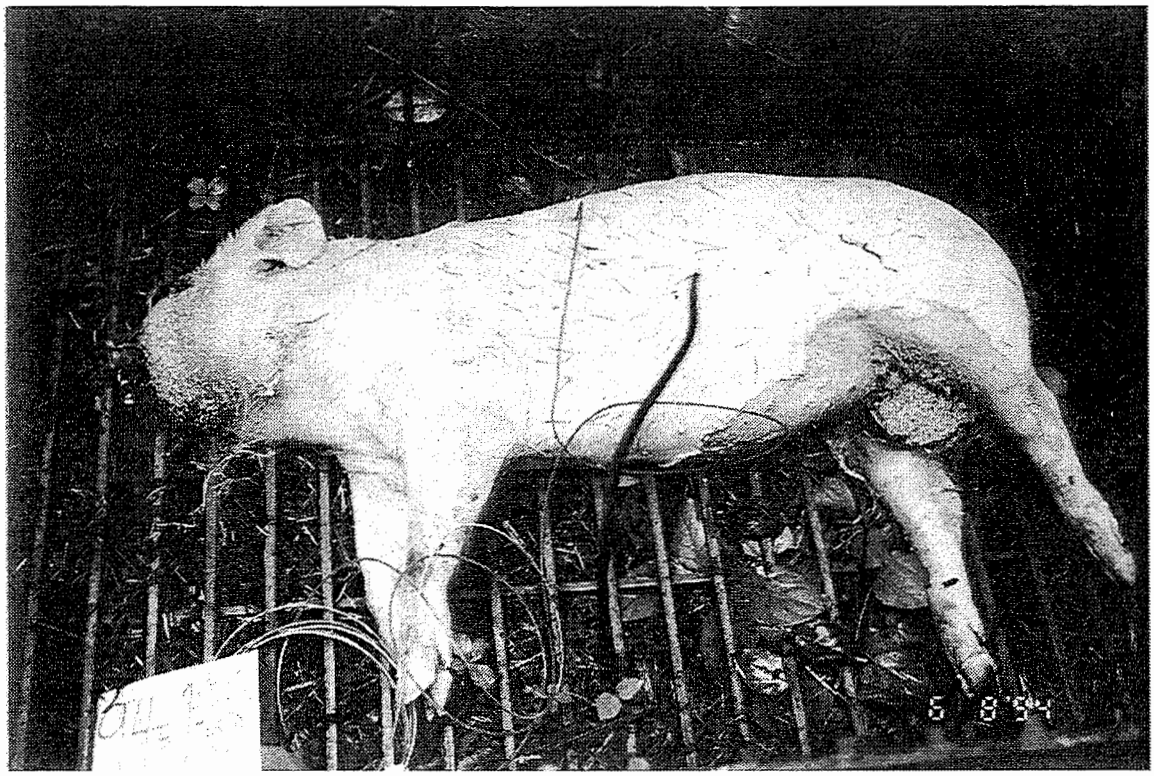


Figure 28 Photos: Shrew Chewed and Unchewed Carcasses, Fall Experiment

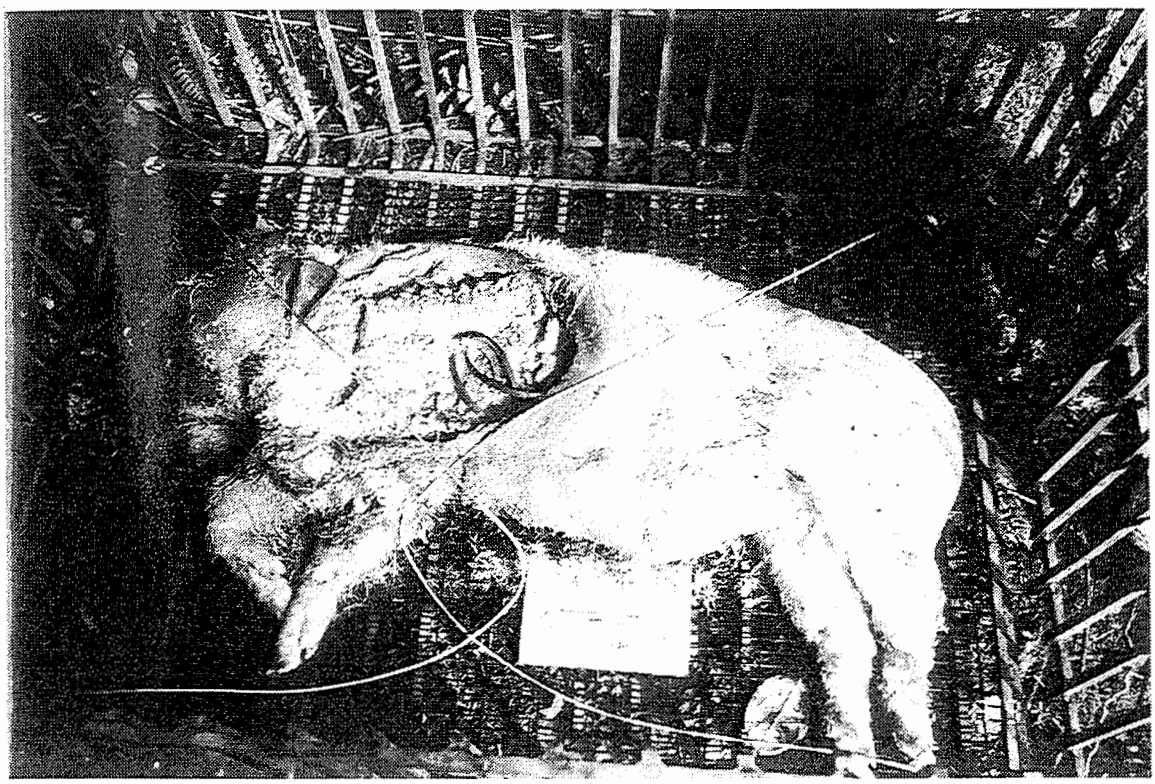


Figure 29 Photos: Shrew Chewed and Unchewed Carcasses, Fall Experiment

TABLE TWO: ARTHROPOD SUCCESSION OVER TIME IN THE SUN HABITAT; SPRING EXPERIMENT

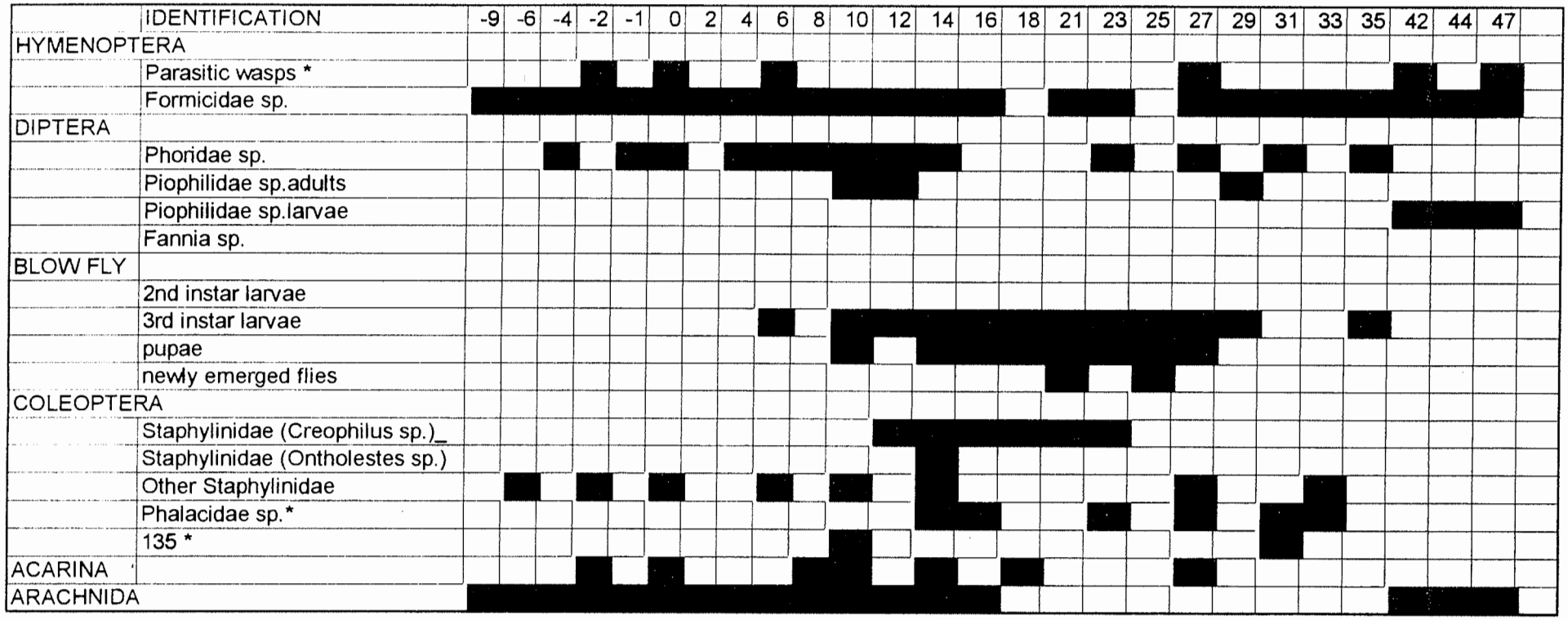


Table 2 Arthropod Succession on Sun Carcass, Spring Experiment

NOTE: This table represents only a few insect species observed and collected on sun carcasses. The presence of an insect is indicated by a blackened cell in the above graph. * = further identification required.