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Forensic Entomology
Determining Time of Death In Buried Homicide Victims Using Insect Succession

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TECHNICAL REPORT
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EXECUTIVE SUMMARY

Research to establish a database of insect succession on buried carrion, in two geographic locations in British Columbia, was carried out starting June 1995. Exhumations took place at two weeks, six weeks, and three months after death at the Malcolm-Knapp Research Forest in the Vancouver Region and at the Alex Fraser Research Forest in the Cariboo Region. A predictable sequence of insect succession occurs on buried carcasses which is different from the succession found on above ground carcasses. This can be used to determine an elapsed time since death in homicide cases. This research is immediately valuable in analyzing cases currently pending, as well as future cases.

SOMMAIRE

La recherche en vue d'établir une base de données des insectes qui se succèdent sur des nécrophores enterrés s'est effectuée dans deux regions de la Colombie-Britannique à compter de juin 1995. Deux semaines, six semaines et trois mois suivant la mort, on a procédé à l'exhumation de carcasses au centre Malcolm-Knapp Research Forest, prés de Vancouver, et au centre Alex Fraser Research Forest, dans la region de Cariboo. On a observe une sequence prévisible des insectes se succédant sur les carcasses enterrées différente de celle des carcasses laissées au sol. Ces observations peuvent être utilisées pour determiner le temps écoulé entre la mort d'une personne et la découverte du corps dans les cas d'homicides. Les résultats de cette recherche peuvent servir dès maintenant pour l'analyse de cas en suspens ainsi que pour ceux 8 venir.

FORENSIC ENTOMOLOGY - DETERMINING TIME OF DEATH IN BURIED HOMICIDE VICTIMS USING INSECT SUCCESSION.

TECHNICAL REPORT
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ABSTRACT

Research to establish a database of insect succession on buried carrion, in two geographic locations in B.C. was carried out starting June 1995. Exhumations took place at two weeks, six weeks, and three months after death at the Malcolm-Knapp Research Forest in the Vancouver Region and at the Alex Fraser Research Forest in the Cariboo Region. A predictable sequence of insect succession occurs on buried carcasses which is different from the succession found on above ground carcasses. This can be used to determine an elapsed time since death in homicide cases. This research is immediately valuable in analyzing cases currently pending, as well as future cases.

ABSTRACT (non-technical)

Forensic entomology is the study of insects associated with a homicide victim. Insects colonize a body in a predictable sequence. This sequence is different if the body is buried, or not, and depending on what geographic area it is in. This is used to determine the postmortem interval. Research was conducted starting in June 1995, using buried pigs as human model, to establish a database of insect succession for burial in the Vancouver and Cariboo Regions of British Columbia. This research is immediately valuable in analyzing cases currently pending, as well as future cases.

INTRODUCTION

Decomposing bodies support a rapidly changing ecosystem. After death, carrion go through rapid physical, chemical and biological changes, during the decomposition process. Each stage of decomposition is attractive to different species of arthropods (mostly insects), and these arthropods colonize the remains in a predictable sequence, so that an analysis of the arthropods on a human homicide victim weeks or months after death can lead to an accurate estimate of elapsed time since death. This information may be vital in a homicide investigation. Time of death is very important in focusing an investigation into the correct time frame, determining timeline prior to death, and may be of value in identifying the victim (Anderson and VanLaerhoven 1996).

The study of insects associated with a human body in order to determine time of death, or forensic entomology, is accepted in courts worldwide and has been used in homicide investigations in North America for over 15 years (Anderson and VanLaerhoven 1996; Anderson 1995; Catts and Goff 1992; Goff 1991; Goff and Flynn 1991; Goff ***et*** al. 1988; Goff and Odom 1987; Goff ***et*** al. 1986; Greenberg 1985). Insect evidence is the most accurate and often the only method of determining time of death when more than 72 hours have elapsed (Kashyap and Pillai 1989). During the first hours after death, normal pathology techniques are capable of providing a reasonable estimate of the postmortem interval, however these techniques become less precise over time and cannot be used after 72 hours has elapsed (Coe and Curran 1980; Van den Oever 1976). Consequently, there is frequently no scientific, defensible method of determining elapsed time since death in these cases, except for the correct understanding and analysis of the insect evidence. Insect evidence can be used from immediately after death until several years after death, and has been successfblly defended in court innumerable times.

A much needed database of arthropod succession for the coastal region of B.C. (Anderson and VanLaerhoven 1996; Dillon and Anderson 1995b) has been completed. This has been extended across B.C. this year (Dillon and Anderson in progress), and later, throughout the rest of Canada. This research has already been extremely valuable in several cases in B.C. and, had it not been available, detailed and defensible determinations of time of death could not have been made. This work will be of great value in all fbture

cases in this area. However, this work only involves exposed remains and as yet, no work has been done on buried remains in Canada.

In some death situations, the corpse is not directly exposed to insect attack, but is buried beneath soil and/or vegetation. This is a common scenario in homicide investigations as the perpetrator frequently attempts to hide the evidence of the crime by burial. Homicide victims may be found in a wide variety of situations, but are most commonly left in remote or concealed areas in an effort to prevent discovery. Hence, victims of such crimes are frequently not discovered for some time. This means that determining time of death is extremely difficult without insect evidence.

There have been many forensic cases in which the corpses were buried in a shallow grave, and have still been colonized by insects. It is believed that insects may be delayed in reaching the remains, but once attracted to the remains, will feed and develop normally and will colonize in a predictable sequence. However, this has not been experimentally studied in Canada until now.

Insect succession varies according to temperature, habitat and geographic location (Goff 1991; Goff and Flynn 1991; Goff et al. 1988; Goff and Odom 1987; Goff et al. 1986; Goddard and Lago 1985; Greenberg 1985; Denno and Cothran 1976; Payne 1965; Reed 1958). This is true for both above ground and buried carcasses (Smith 1986; Rodriguez and Bass 1985). To complicate matters further, the time required for the insects to locate the remains and the sequence of colonization, as well as the rate of decomposition is different for corpses under burial conditions compared to corpses found above ground (Smith 1986; Rodriguez and Bass 1985; Payne et al. 1968). This makes extrapolation of insect succession databases from other habitats and geographic locations extremely precarious. Until 1995, no experimental research on insect succession on buried corpses had ever been done anywhere in Canada. In fact, there have been no published scientifically valid experimental research on insect succession on buried corpses which accurately mimic a homicide scenario anywhere in the United States or the rest of the world.

OBJECTIVES

The main objective of this research was to establish a database of insect succession on buried bodies in both the Vancouver Region of British Columbia and the Cariboo Region of British Columbia. In order to achieve this objective, the insect succession and rate of decomposition was compared on pigs ***(Sus scrofa*** L.) buried immediately, buried after 48 hours of exposure, buried then disturbed, and above ground pig carcasses in both the Cariboo Region and the Vancouver Region of British Columbia for a 12 month period beginning June 1995.

As well, other questions are also being examined through the course of this research. Changes that occur in soil density during the burial and decomposition process were examined via subsurface radar technology in collaboration with the R.C.M.P. Changes that occur in bone during the decomposition process are being studied in collaboration with researchers in England.

RESEARCH MODEL

Pigs ***(Sus scrofa*** L.) are excellent models for human decomposition studies as they are omnivores, with a digestion very similar to that of humans, are relatively hairless and have skin so similar to our own that it can be used in human skin grafts. A 23 kg pig is equivalent in weight to an average human adult male torso, which is the main site of insect colonization (Catts and Goff 1992).

RESEARCH AREAS

The experiment was located in two different geographical regions of B.C., the Vancouver Region and the Cariboo Region (Figure 1). The Vancouver Region consists of several biogeoclimatic zones including the Coastal Western Hemlock and Coastal Douglas-Fir Biogeoclimatic Zones, which are from approximately sea level to 1700 m above sea level, with monthly temperature ranges between -6 to 19°C and total annual precipitation between 107 and 3225 mm. This wet, cool climate is characterized by such tree species as ***Tsuga heterophylla*** (Western Hemlock), ***Pseudotsuga menziesii v. menziesii*** (Douglas-Fir) and ***Thuga plicata*** (Western Red Cedar). The Cariboo Region

also includes several biogeoclimatic zones, however only one was studied in this experiment. The Sub-Boreal Spruce Biogeoclimatic Zone, which ranges from approximately sea level to 1400 m above sea level, with monthly temperature ranges between -15 to 17°C and total annual precipitation between 189 and 1383 mm. This drier, more extreme climate is characterized by such tree species as ***Picea engelmannii*** x ***glauca*** (Engelmann / White Spruce Hybrid), ***Pseudotsuga menziesii v. glauca*** (Douglas-Fir), ***Pinus contorta*** var. ***latifolia*** (Lodgepole Pine) and ***Populus tremuloides*** (Trembling Aspen).

The majority of the work was carried out in the Vancouver Region since most buried cases are found here. Less extensive work was done in the Cariboo Region in conjunction with extensive exposed carcass experiments which were conducted at the same time (Dillon and Anderson in progress).

The research sites were located in the Alex Fraser Research Forest, Gavin Lake Block (Figure 2,3) just outside of Williams Lake in the Cariboo Region, and in the Malcom-Knapp Research Forest (Figure 4,5) in Maple Ridge in the Vancouver Region where exposed carcass experiments were previously conducted in 1994. Both areas were chosen on the basis of soil cover, and vegetation (Figure 6 - 8) so that they would be representative of the biogeoclimatic zones in which they were situated.

Both areas were chosen to avoid most of the public areas of the forests. The Alex Fraser Research Forest is open to the public, however only the occasional hunter was seen in the area. Although there was limited public access to the research area in the Malcolm-Knapp Research Forest, hikers were often seen on the access road to the area. Since the pig carcasses could possibly attract black bears in the Malcolm-Knapp Research Forest and both black and grizzly bears in the Alex Fraser Research Forest, bear hazard warning signs (Figure 9) were placed in both research forests so that possible bear-people interactions might be minimized.

Since the danger of attracting large carnivores applied to myself as well, I took several precautions. Graves were chosen to be close to the access roads. I carried a chemical bear repellent (Phazer® for Bears Aerosol Repellent 400 g), as well as a loud

whistle or air horn. While in the Malcolm-Knapp Research Forest, I carried a two-way radio with which I could contact the forest staff in case any trouble arose.

SITE PREPARATION

Two weeks before carcass placement, pitfall traps were placed to determine the natural fauna of the areas. Pitfall traps consist of 250mL glass jars which were placed into the ground so that the lip of the jar was level with the ground (Figure 10). Any ground crawling insects crossing the lip fell into the jar and was not able to escape, as a small amount of soapy water was placed in the bottom. Traps were placed at each carcass site and in three control sites with no carcass, at least 15 m fi-om the carcass sites. Once the carcasses were buried, the pitfall traps were placed in the soil above the carcasses to trap a sample of the insects attracted to or leaving the remains. The control traps remained at a distance from the carcasses to determine seasonal change of naturally occurring insect fauna in that area.

Graves were dug by hand, with shovels (Figure 11), for each carcass (except above ground control carcasses) and were large enough to accommodate the carcass (Figure 12). The graves were designed so that once the body was in place, the upper surface of it lay approximately 30 cm below the surface since this is a common depth for most of the forensic entomology cases involving buried bodies so far. Most homicide victims are not buried deeply. All graves were at least 15 m away fi-om the next grave or above ground carcass, so that olfactory orientation of insects to each carcass was independent (Figure 13 - 14).

EXPERIMENTAL CARCASSES

In both regions, the pigs were divided into three treatments.

In the Vancouver Region:

Treatment one consisted of 15 pigs that were buried immediately. These pigs were exhumed at two weeks after death, six weeks after death, and three months after death. Two more exhumations are scheduled to take place at nine months and twelve months after death. Three pigs were exhumed each time.

Treatment two consisted of nine pigs that were buried after 48 hours of exposure to insect colonization above ground (Figure 15). This was done to simulate the common homicide scenario of a delayed burial, since many killers don't dispose of the body immediately. These pigs were exhumed at two weeks after death, six weeks after death, and three months after death. Three pigs were exhumed each time.

Treatment three (or the control carcasses) consisted of three pigs that were left above ground for the duration of the experiment. These pigs were examined at the same time as the other pigs in treatments one and two.

In the Cariboo Region:

Treatment one consisted of 12 pigs that were buried immediately. These pigs were exhumed at two weeks after death, six weeks after death, and three months after death. One more exhumation is scheduled to take place at twelve months after death. Three pigs were exhumed each time.

Treatment two consisted of three pigs from treatment one. The three pigs exhumed at two weeks after death were re-buried after sampling in order to determine what the effect of disturbance was. Perpetrators return to the scene for many reasons; they dropped their wallet, want to check that its still there, or they had so much fun the first time that they want to relive it. These pigs were exhumed at six weeks after death and compared to pigs from treatment one exhumed at six weeks after death.

Treatment three (or the control carcasses) consisted of three pigs that were left above ground for the duration of the experiment. These pigs were examined at the same time as the other pigs in treatments one and two were exhumed

EXPERIMENTAL DESIGN

A 15 cm pin gun (Figure 16) was used to kill all the pigs. The carcasses were shot a second time after death, in the side of the thorax using a .22" caliber low velocity bullet to allow insertion of temperature probes.

Each pig was clothed, as clothing has been found to have an effect on insect succession (Dillon and Anderson 1995b). Each carcass was identically clothed with

human clothing. This included undergarments, T-shirt, blouse, shorts and socks, to simulate close fitting and loose clothing as well as layering (Figure 12).

A freshly killed pig carcass was carried to (Figure 17) and placed in each of the graves within hours of death. Each grave was filled with soil so that the grave was level with the ground and disguised by local vegetation (Figure 18, 19).

Exposed carcasses were protected fiom large scavenger attack by wire mesh (4"x2", 12.5 gauge) affixed to the ground over the entire carcass (Figure 16). This is wide enough to freely allow insect, etc. access, but is narrow enough to prevent a predator such as a bear fiom getting a paw into the cage to grab the carcass. Buried carcasses were protected by a large mesh grid placed over the grave after burial and staked down (Figure 21).

Insect development is temperature dependent; ***i.e.***, the normal metabolic rate increases with increased temperature, which results in a faster rate of development, so that the variation in temperature of the carcasses below ground must be determined. Carcass temperatures in above ground experiments become greatly elevated above ambient temperatures (Dillon and Anderson in progress; Anderson and VanLaerhoven 1996; Catts and Haskell 1990). This has a dramatic effect on insect development, and must be taken into account when determining time of death based on insect development. However, no work has been done to determine carcass temperatures below ground, which may be quite different from temperatures in above ground carcasses as many airborne bacteria are excluded by burial (Smith 1986). Therefore, carcass, soil and ambient temperature were monitored throughout the experiment using dataloggers.

In two buried carcasses within each research area, the last two to be disinterred, a temperature probe was inserted into the bullet hole on the thorax. One probe was connected to a datalogger (Figure 22) (SmartReader 1®, Young Environmental Systems, Richmond, B.C.) and recorded the internal carcass temperature every 30 minutes. The datalogger itself was placed in the soil surrounding the carcass and measured the soil temperature every 30 minutes for comparison with the carcass temperature. The second probe on the second buried carcass was connected to a different datalogger (Hobo®, Hoskins Scientific, Vancouver, B.C.) and measured the internal carcass temperature every

90 minutes. Placing the probes in the last carcasses to be disinterred ensured that temperature data was recorded for the entire 12 months. Unfortunately, the longest time period that the SmartReader 1® will record is every 30 minutes, but the Hobo® has a much smaller memory capacity than the SmartReader 1®. In order for the Hobo® to record the same number of days as the SmartReader 1®, it was set to record temperature every 90 minutes, instead of every 30 minutes.

Just as in two buried carcasses, a temperature probe was inserted into the bullet hole on the thorax of two above ground control carcasses within each research area. One probe was connected to a datalogger (SmartReader 1®, Young Environmental Systems, Richmond, B.C.) and recorded the internal carcass temperature every 30 minutes. The datalogger itself was placed on the ground slightly away from the carcass and measured the ambient air temperature every 30 minutes for comparison with the carcass temperature. The second probe on the second above ground control carcass was connected to a different datalogger (Hobo® , Hoskins Scientific, Vancouver, B.C.) and measured the internal carcass temperature every 90 minutes.

Biomass loss can be used as an indicator of the rate of decomposition. This was measured by weighing the carcasses. Each carcass was weighed both at the time of placement and at each exhumation. Carcasses were placed on a mesh platform and weighed using a 150 lb scale on a pulley system (Figure 23).

Each carcass site was identified by the use of plastic coated identification cards (Figure 24). Each site was labeled as to year, research area, treatment/ exhumation time and replicate number. For example 95-LM-2wk-1 indicated the year of the experiment (1995), the research area (Lower Mainland in Vancouver Region), the treatment/ exhumation time (two weeks after death) and the replicate number (pig 1).

The use of replicate numbers of pigs and temperature probes and the use of control pigs and pitfall traps minimizes the effect of variation that can occur during experimentation, allowing the results of these experiments to be defensible in both the scientific and legal communities.

SAMPLING METHODS

Pitfall trap collection provides a sample of the soil fauna associated with the graves as well as the natural fauna in the research area. The contents of the pitfall traps were separated from the soapy water by the use of a small tea strainer. The insects from each trap were then placed in a separate sterile urine analysis vial with 70 % ethanol to preserve them for identification in the lab. The soapy water was then replaced in each pitfall trap.

The buried carcasses were exhumed carefully, in the manner of crime scene investigations (Figure 25,26), and examined for insects. The exhumation consisted of three stages: data recording, on-site collection, and field morgue collection.

Stage one methods:

Data recording was done using extensive photography (Figure 27) during all stages of the exhumations, and written notes of all observations. A grid was laid out before the actual excavation began (Figure 28). The grid covered a total area of $1m^2$ with each individual quadrant being 50 cm^2 Spatial relationships between recovered insect evidence was recorded between the four quadrants.

Stage two methods:

Collection of evidence began with careful removal of surface plant growth (Figure 29). It was then examined by hand for insect evidence. Next, soil was removed systematically (Figure 30), one quadrant at a time moving from the outermost to the innermost area (Skinner and Lazenby 1983). Soil was examined by hand for insect evidence (Figure 31).

When the entire corpse was exposed, more photographs were taken and notes made, then the carcass was lifted out and moved away from the grave using a mesh platform.

Soil in the bottom of the grave was examined by hand and sampled for insect evidence.

Stage three methods:

Insect evidence was collected using forceps or gloved fingers. Half of the larval Diptera were preserved in 70% ethanol, while the rest were kept alive to be reared to adulthood in the lab. Rearing larval Diptera to adulthood facilitates identification. All

adult Diptera and all stages of other orders of insects were labeled and preserved in 70% ethanol for later identification back at the lab at Simon Fraser University. Preserved specimens were placed in black screw cap vials, while living specimens were placed in sterile urine analysis vials with some beef liver and lid consisting of a paper towel held down by an elastic.

All larval Calliphoridae and Sarcophagidae were examined later in the lab under a binocular microscope to determine instar by number of spiracular slits (Smith 1986). Insects were identified using recognized insect keys, and with reference to our extensive reference collection. Specimens that are difficult to identify will be sent to Biosystematics Research Centre in Ottawa, for formal identification and to provide voucher specimens for our reference collection.

As well, pictures were taken throughout the examination. All areas of the clothing and carcass were examined and sampled for insect evidence.

When the examination was complete, the carcass was placed in a plastic bag (Figure 32) for disposal by incineration at the animal care facilities at S.F.U.

Above ground control carcasses were sampled on each exhumation day as described for the buried carcasses, however on a lesser scale as above-ground succession can be determined from the database previously established.

TEMPERATURE

Since insect development is temperature dependent, the influence of soil on the ambient temperature of a buried body is tremendous. While bodies above ground are influenced by the ambient air temperature, the action of maggot masses is capable of increasing the internal temperature of a carcass up to 40 °C (Figure 33), although this fluctuates considerably during a 24 hour period (Anderson and VanLaerhoven 1996). This acts to speed up insect development, therefore, knowing the temperature is a prerequisite to determining how long it has taken an insect to reach a certain developmental stage. Since this is how an elapsed time since death is estimated in the early stages of decomposition, temperature is an important factor which must be determined.

However, the soil acts as a temperature sink. There is much less fluctuation in temperature within the soil than there is in ambient air temperature (Figure 33,34), especially as depth within the soil increases (Rodriguez and Bass 1985; Wallwork 1976; Wallwork 1970; Kevan 1968). Soil temperature also tends to be lower than that of the ambient air temperature
(Figure 33). Soil restricts the movement of Dipteran larvae to the carcasses and therefore maggot masses were not formed. They still reached the carcasses, just not in the same huge numbers as was found seen in above ground carcasses (Figure 35). Without the influence of maggot masses, the ambient temperature was not raised (Figure 33), so insect fauna develop at a slower rate than if they were generating heat through the action of a maggot mass.

These trends held true for carcasses in both study sites. A comparison between temperatures recorded from carcasses in the Vancouver Region and the Cariboo Region (Figure 36) showed no sudden large temperature spikes in buried pigs, which would have indicated maggot mass activity. This lack of maggot masses on buried carcasses was not anticipated at the beginning of this study.

DECOMPOSITION RATE

Without maggot mass activity to both increase the rate of development of the insects themselves, as well as to remove most of the carcass biomass, the rate of decomposition of buried carcasses is slowed considerably. A series of photographs taken at the time of each exhumation illustrates this quite convincingly. At the start of the study, above ground carcasses and buried carcasses were about 50 lbs each at the fresh stage of decomposition (Figure 37,38), however at two weeks after death, the above ground carcass has passed through fresh, bloat and is now well into active decay with a large maggot mass rapidly removing flesh (Figure 39,40). The buried carcass is just now entering the bloat stage (Figure 41). The only maggots in sight are a few second instar larvae in the mouth (Figure 42).

At the next exhumation time, six weeks after death, the above ground carcass has completed active decay and now is in the remains stage, with only skin and bone remaining

(Figure 43). However, the buried carcass is still somewhere between the bloat and active decay stage. Most of the biomass is still present (Figure 44), although the legs have begun to loosen and detach.

Three months after death, there is little left of the above ground carcass (Figure 45). The buried carcass has just entered active decay, with some caving of the abdomen, legs and head disarticulated (Figure 46).

At nine months after death, even the skin is almost completely gone, leaving only bits of clothing and bones as evidence of the above ground carcass (Figure 47). It will be interesting to discover the state of the buried remains at the next exhumation.

A quantitative comparison of biomass loss of all three treatments of carcasses at the Malcolm-Knapp Research Forest indicates that there is no difference in rate of biomass loss between carcasses buried immediately compared to carcasses buried after 48 hours (Figure 48). However, the comparison of the rate of biomass loss of buried carcasses to above ground or exposed carcasses in the shade in the spring of 1994 (Dillon and Anderson 1995b) indicates a much more rapid rate of loss in above ground carcasses compared to buried carcasses (Figure 48).

The slower rate of decomposition and decreased rate of biomass loss should serve to lengthen insect succession on buried carcasses.

INSECT SUCCESSION

Two Weeks After Death: Differences in succession were observed between above ground and burial, between the Vancouver and Cariboo Regions, and between disturbed and delayed burials. At the first exhumation, two weeks after death, the blowfly ***Phormia regina*** (Figures 49-54) was found in large masses on the above ground or exposed carcasses in both Vancouver and Cariboo Regions, however, it was not found on any buried carcasses at any time in the study. The blowfly ***Protophormia terraenovae*** was found exclusively on exposed carcasses in the Cariboo (Figure 52). There were no maggots found on either the pigs buried immediately or after 48 hours in the Vancouver Region. However, there was more diversity in the Coleopteran fauna on the carcasses

buried after 48 hours, than found on either the carcasses buried immediately, or the exposed carcasses in the Vancouver Region (Figures 49-51).

In the Cariboo Region, the two blowfly species ***Calliphora vomitoria*** and ***Lucilia illustris*** were only found on buried carcasses (Figure 52-54). It is interesting that there appears to be at least a two week lag before blow flies reached buried carcasses in Vancouver, however, they were present at the two week exhumation in the Cariboo. This is likely due to differences in soil composition, since soil in the Alex Fraser Research Forest has a considerable amount of clay particles. Once dug up, the particles are quite large, forming coarse fragments with larger spaces between them than what is found in the Malcolm-Knapp Research Forest soils. These larger spaces would allow easier access to the buried carcasses. The muscid ***Hydrotaea sp.*** was also found exclusively on buried carcasses, in both regions, however it first appeared on buried carcasses in the Cariboo (Figure 53). One adult ***Fannia sp.*** was found on a buried carcass in the Cariboo.

Six Weeks After Death: The blowfly Calliphora vomitoria was found only on carcasses buried after 48 hours in the Vancouver Region, but on all buried carcasses in the Cariboo (Figure 51). ***Fannia sp.*** was found on all carcasses in the Cariboo, but only on buried carcasses in Vancouver, until the three month exhumation when it was found also on exposed carcasses (Figure 49-54). The muscid ***Morellia*** sp. was found exclusively on buried carcasses in the Vancouver Region. Muscids were well represented on buried carcasses in the Vancouver Region at this period in the succession, with ***Morellia sp.***, ***Ophyra sp.*** and ***Hydrotaea sp.*** all present (Figure 50-51). ***Spheridium bipustulatum,*** a member of the Histeridae family, was found exclusively on above ground carcasses in both regions (Figure 49, 52). Another Coleopteran, from the Dermestidae family was found only on above ground carcasses, only in the Cariboo Region, as was a member of the Dipteran Piophilidae family (Figure 52).

Three Months After Death: No dermestids or piophilids have yet been observed on any buried carcasses in either site, or on the exposed carcasses in the Vancouver Region. Sphaeroceridae, whose pupal cases closely resemble those of the Piophilidae, were found only on carcasses in the Vancouver Region (Figure 49-51). Throughout the study, the ant ***Camponotuspennsylvanicus*** (Figure 55) and silphids ***Nicrophorus***

defodiens and ***Nicrophorus hybridus*** (Figure 56) have been seen on carcasses creating holes and carting maggots about.

SCAVENGERS

Although the carcasses were protected from large scavenger attack, the above ground carcasses in the Cariboo Region were eaten about 3 weeks after death (Figure 57). Fortunately, this study was run in conjunction with extensive above ground carcass research, so that results could be extrapolated (Dillon and Anderson in progress). Since the entire carcasses were taken, it is impossible to determine what the effect of large scavenger disturbance had on the insect succession. Smaller scavengers dug out and consumed part of two different buried carcasses in the Vancouver Region (Figure 58). Both carcasses will be exhumed in June 1996, when the effect of the scavenging may be determined by comparing the insect succession with the remaining intact carcass of that treatment.

SUB-SURFACE RADAR

In order to use the now established database of insect succession for buried homicide victims in Vancouver and Cariboo Regions of British Columbia, it is first necessary to find the grave. Sub-surface radar, or ground penetrating radar is a tool which may help accomplish this. Sound waves are sent into the ground and interpreted by a graphical display (Figure 59-60). Different densities of objects sent the sound waves back in certain patterns. Roots reflect differently than rocks, which are different from soil. Using this three dimensional map, it is possible to determine if the ground has been recently disturbed, possibly indicating a grave. This technique was tested over several of the graves in the Malcolm-Knapp Forest, however we do not have the results of the tests yet.

SOIL ECOSYSTEM

In any study of succession, the ecosystem plays a vital role. In the study of grave fauna, it is the interaction between the soil ecosystem and the carrion ecosystem that is of

importance. The soil ecosystem is complex, with many different interrelated components. Each is contingent on the other, in an interwoven web. Food webs within the system are complex and dynamic. Enter into this arena, the rapidly changing ecosystem supported by decomposing carrion. Climate, flora and fauna are all factors in this scheme, influencing the rate of decomposition and succession of organisms associated with each stage of decay. Since the soil ecosystem is based on the decomposition of organic matter, the decomposition of carrion is, but an extension of this process. Minor actors in the decomposition of humus, dead soil fauna, and the breakdown of parent material, rise to the fore during the relatively short period of time taken to decompose carrion.

Although the succession on carcasses is rapid, it is very complex. When the carcass is in a grave, instead of above the soil, another wrinkle is added to an already complex scenario. Soil impedes the ability of fauna to reach the carcass. Some may be able to burrow, while others are not. However, succession and decomposition still occur.

The ability to determine time since death in buried bodies requires the knowledge of succession patterns and the influence of different factors on this succession However, in order to understand faunal succession on carrion within the soil, the we must first understand what soil is and how it is formed.

SOIL FORMATION

Soil is the decomposition product of its parent material and organic material. Decomposition agents can be physical, chemical and biological. While physical and chemical agents play a major role in the decomposition of the parent material, leading to the formation of the mineral soil, the decomposition of organic material is mainly achieved through biological processes, with physical and chemical agents playing a minor role. Both the mineral soil and the organic material ultimately become intermingled as organo-mineral complexes, which characterizes mature soil. This gives the soil its characteristic texture, structure and pH (Wallwork 1970).

Physical processes exert mechanical effects on the parent material, resulting in progressively smaller particle sizes. Climatic conditions such as wind, water and temperature are capable of transforming large boulders into the smallest grains of sand,

given enough time. Water is especially destructive, and in the form of ice or frost, is capable of exerting an expansion force in the order of 150 ton/ft^2. Gravity is also capable of causing rock fragmentation and abrasion, as demonstrated by landslides. Gravity in combination with ice, such as in glaciers, is an incredibly powerful force, capable of both grinding down large rock, as well as transporting it long distances as is the case with glacial till (Wallwork 1970).

Physical processes expose more surface area to chemical degradation. Chemical decomposition reactions, of which oxidation, reduction, carbonation and hydrolysis are the most important, change the mineral composition of the parent material. Soluble minerals are released and may become bound with organic molecules or removed through leaching (Wallwork 1970).

In well-aerated, well-drained soils, oxidation occurs, whereas in poorly-aerated, poorly-drained wet soils, reduction occurs. This commonly occurs in different parts of a soil at the same time. It can result in the solubility of minerals in one area and their precipitation in another, thereby moving the minerals from one area and to another. Hydrolysis is also found in combination with other reactions, and aids the movement of minerals into the soil solution, where they become available to plants. In the later stages of decomposition, carbonation is common due to higher concentrations of CO_2, which are a result of the presence of organic material (Wallwork 1970).

Early colonizers such as lichens and mosses also play a role in the decomposition of the parent material, albeit a minor one compared to the above processes. They are capable of extracting minerals from the rock as well as causing chipping and flaking, thus increasing the surface area available to other processes. They form organic complexes which can result in the formation of secondary clay minerals and organo-clay complexes. This, plus the added organic material that they provide as they themselves decompose, helps establish a richer and more varied vegetation complex. This vegetation and the organic material derived from it plays an ever-increasing role in the soil's development (Wallwork 1970; Russell 1969).

Although the organic content of the embryonic soil is fairly low, thereby limiting the types of vegetation and soil fauna able to colonize it, it increases as the decomposition

products of both the parent material and the organic material intermingle and form complexes. As the process continues, the size of the soil particles and the spaces between them decrease, resulting in an increased capacity of the soil to retain moisture. The increased water-holding capacity, increased plant nutrients (from the decomposition of the parent material) and increased organic material allow the soil to support more diverse flora and fauna. Organic material rapidly accumulates at this stage. Soil depth is increased and distinct layers are formed (Wallwork 1970).

At this stage, the biological decomposition of organic material takes on added importance in the soil development. Fresh organic litter accumulates on the surface of the soil, providing food for a variety of organisms, which physically and chemically degrade the matter within themselves. This results in the production of humus, which is considered the first step in the decomposition of organic material (Burges 1967; Burges 1965; Handley 1954; Rome11 and Heiberg 1931) cited in (Wallwork 1970).

The second step consists of formation of clay-humus complexes. In the decomposition of the parent material and initial formation of the soil, it was important that the soil particles and therefore pore spaces between them, reach a size where the soil is capable of retaining enough moisture to support a richer flora and fauna. However, there is an optimum pore size and soil particle size required to maintain good aeration and drainage. Aggregations of particles to form crumbs increases the total pore space in the soil, thereby achieving this goal. These soil crumbs are formed by electro-chemical bonding and cementing (Russell 1969; Russell 1961).

The result is a characteristic soil profile formed by the influence of climate, vegetation, parent material and the activities of the soil flora and fauna (Wallwork 1970). The characteristics of various layers allow soils to be classified into different types.

SOIL TYPES

Choosing the criteria to use to define different soil types is a subject of much debate (Avery 1969), however, one possible method is a textural classification. In this, three types are recognized: clay (>.002 mm diameter soil particles), silt (.002-.02 mm) and sand (.02-2 mm). Another method is based on the degree of defined profiles. Zonal soils

have a well-defined profile, azonal soils lack a well-defined profile and intrazonal soils are intermediate, Examples of zonal soils are found in forest and grassland soils, whereas embryonic soils could be considered azonal and peat soils can be considered intrazonal soils. However, considering the variability found between forest and grassland soils, this classification may be simplistic (Wallwork 1970).

Still another method, based on the soil forming process, is possible. Four types of soil forming processes are used for this classification: calcification, podzolization, laterization and gleization. Calcification occurs in areas of moderate to low rainfall when the parent material is high in calcium carbonate. Insufficient water to leach the carbonate leads to the formation of a calcium horizon. Desert soils commonly have this layer near the soil surface, while some grasslands may have this layer lower down in the A horizon (Figure 61), depending on the amount of rainfall and therefore the amount of leaching (Wallwork 1970).

Podzolization occurs when iron and aluminum are leached from the A horizon and deposited in the B horizon, with iron accumulating slightly above the aluminum. Hardpan may develop in the B horizon due to the concentration of metallic ions. The result is little mixing of organic and mineral material, with an acidic humus layer (Russell 1961). Forest soils, of both evergreen or deciduous forests, and poorly-drained moorland result in this type of soil (Wallwork 1976; Wallwork 1970).

Laterization is confined to subtropical and tropical regions. It is characterized by intense chemical weathering of parent material and soil minerals. Soluble organic molecules are lost, while iron and aluminum remains. Fresh organic material is rapidly lost and therefore the humus layer is almost non-existent. Hardpan can form due to the concentration of metallic ions, and form a layer impervious to water, thus impeding drainage. Savannah soils are a product of this process (Wallwork 1976; Wallwork 1970).

Gleization occurs in areas of poor drainage. Oxygen is limited in the soil, leading to reducing conditions, which slows the breakdown of organic material into humus. Raw humus or peat is the result. Leaching is limited, however, if the soil is not permanently

waterlogged, iron may be precipitated into one layer forming ironpan (Wallwork 1970; Russell 1961).

Further classifications can be made on the basis of the humus type within a soil (Avery 1969; Howard 1969). Humus type is greatly influenced by the vegetation that originally supplies the organic material (Rome11 and Heiberg 1931; Hesselman 1926) cited in (Howard 1969). Muller (Muller 1884; Muller 1879) cited in (Howard 1969) first described two types, commonly found in forests. Mor humus is acidic, with three layers: a surface litter (L) layer, a fermentation (F) layer and a (H) humus layer below it. This layering is aided by the strong component of fungal decomposers which act to glue the litter into matted layers. This is usually found on sandy soils beneath conifers, and is associated with podzolization (Wallwork 1976; Wallwork 1970).

In contrast, mull humus is neutral or alkaline and lacks the distinct layering found in mor humus. Mull humus usually forms in soils with a rich calcium content. This favors earthworms which promote a greater mixing of organic and mineral material. The alkaline or neutral conditions also favor bacteria as the primary decomposers, as opposed to the fungi in rnor humus (Muller 1884; Muller 1879) cited in (Wallwork 1976; Wallwork 1970; Kevan 1968).

However, distinguishing between mull and mor is not always as easy in the field, therefore there is a third intermediate type. Moder humus has the distinct layers of the mor humus, and the fauna of the mull humus. This has sometimes been called "mull-like mor" (Wallwork 1970; Avery 1969; Kevan 1968; Kubiena 1955).

This classification is not restricted to forests. Grasslands can be classified as mull humus, while moorland and fens can be classified as an extreme form of mor humus or peat (Wallwork 1976 ; Wallwork 1970).

FACTORS AFFECTING SOIL FAUNA

It has already been noted that soil fauna play an intrinsic role in the soil formation and classification. Just as there are various factors affecting soil formation, several factors influence the abundance and distribution of soil fauna. These will influence not only which organisms are present in the soil, but also which organisms can take part in

the succession on carrion. Soil temperature is much less variable than air temperature (Figure 34). While the surface litter layer is influenced by daily fluctuations in air temperature, deeper layers tend to remain constant (Wallwork 1976; Wallwork 1970; Kevan 1968). Therefore, soil animals which prefer different temperature conditions (Madge 1961; Wallwork 1960) move vertically through the soil during a 24-hour cycle (Wallwork 1976; Tarras-Wahlberg 1961; Wallwork and Rodriguez 1961). Vegetation and topography are important in sheltering the soil, which, if left unprotected, would experience more extremes in temperature. This is why forest soils are more protected from seasonal extremes than grassland soils. Therefore, while forest carabid beetles are active throughout the year, grassland carabid beetles are inactive during the winter, and diurnal during the rest of the year (Wallwork 1970).

Soil moisture is an important factor influencing soil fauna. Some soil fauna, such as protozoans and nematodes, depend directly on free water, since they are primarily aquatic. Others depend on the relative humidity within the soil, since this influences how fast water is lost by living organisms. The distribution of many animals depends on the moisture profile within a soil (Wallwork 1970; Kevan 1968). With body fluids from the carrion present during the first stages of decomposition, moisture is not limiting and may actually be in excess.

Soil atmosphere is the water or air between particles of soil, and is influenced by particle size, pore size, rainfall, horizontal and vertical water movements, depth of the organic litter and the burrowing activities of soil animals. The amount of air present will determine the amount of oxygen available for metabolic activities of soil organisms. Also, since air flow is constricted by soil particles, high concentrations of carbon dioxide can build up (Wallwork 1970; Kevan 1968). This can inhibit soil fauna abundance and distribution.

Similar to air, the penetration of light into the soil is also variable. It depends on topography, vegetation, and soil type. Light is very important in the early stages of soil formation when only lichens and mosses are present, however, later in development, these give way to saprophytic organisms, for which light is not as essential (Kevan 1968). Just as temperature can influence the behavior of soil fauna, so can light. Day length can be an

important determinant of activity, diapause and mating. For example, mating behavior of the isopod ***Armadillidium vulgare*** is determined by day length (Wallwork 1970). It is difficult, however, to distinguish between effects of temperature, light and humidity, or whether they are acting in concert.

The pH of the soil is another factor which influences soil fauna, and therefore, the decomposition of organic material within the soil. Earthworms, slugs, millipedes and insect larvae are commonly found in large numbers within alkaline or neutral mull humus, whereas the more acidic mor humus houses mites and Collembola, and is unsuitable for the larger invertebrates (Wallwork 1976; Wallwork 1970; Kevan 1968; Satchel1 1955).

Soil structure and texture can affect soil fauna, especially burrowing soil fauna. It influences their ability to burrow successfully. If the soil is too compacted, they cannot penetrate it, however, if the soil is too fine, it may not retain the form of the burrow and the animals may die of asphyxiation. Non-burrowing animals are influenced by the size of the pores within a soil, which can control their movement through the soil (Kevan 1968). However, digging changes the soil structure and texture which may allow easier access for some insects. Since blowflies were able to reach carcasses buried in the Cariboo Region faster than in the Vancouver Region (Figure 52-54), even though soil in the Alex Fraser Research Forest is more compact than found in the Malcolm-Knapp Research Forest, we have assumed that the act of digging the graves changed the nature of the soil structure sufficiently to allow easier access to the bodies. Before this study, I had assumed that since the soils were more compacted in the Alex Fraser Research Forest, insects would be delayed much more than in the Malcolm-Knapp Research Forest. This illustrates the necessity of understanding not only the succession of insects, but also the associated ecosystem.

SOIL FAUNA ECOLOGY

In this study, the succession on carrion took place in the soil, by soil dwelling organisms. As in other ecosystems, the soil ecosystem consists of primary producers, primary consumers, secondary consumers, tertiary consumers and decomposers. Nutrients and energy cycle from one trophic level to another. The green plants, or

primary producers, supply dead and decaying leaves, h i t , woody stems and roots. Saprophytic animals in the soil, and phytophages or herbivores above the soil, are the primary consumers that feed on the organic material supplied by the primary producers. The carnivores, or secondary consumers use the primary consumers as prey. Larger carnivores, or tertiary consumers feed on the secondary consumers. The decomposers feed on dead and decaying organic matter from all levels of the food web, thus enabling the nutrients and energy to become available to the primary producers again. These levels are somewhat artificial, however. For example, a pseudoscorpion may be a secondary consumer when it feeds on Collembola, and a tertiary consumer when it feeds on other pseudoscorpions (Wallwork 1970).

The inter-relationshipsof soil fauna in the food chain allow some classification of soil fauna according to their feeding habits.

1. Carnivores can be divided into:

- predators, such as carabid, pselaphid, scydmaenid, staphylinid beetles, mesostigmatid and prostigmatid mites, spiders, harvestmen, pseudoscorpions, scorpion, sun-spiders, centipedes, nematodes and molluscs.
- and parasites, such as ichneumonids, staphylinid beetles, parasitic Diptera, nematodes (Wallwork 1970; Kevan 1968).

2. Phytophages such as molluscs, lepidopteran larvae, nematodes, symphylids, dipteran larvae, scarabaeid Coleoptera, Orthoptera, termites, beetle larvae and phthiracaroid mites (Wallwork 1970; Kevan 1968).
3. Saprophages such as lumbricids, enchytraeids, isopods, millipedes, hemiedaphic mites, Collembola and insects. Some of these are also coprophages (faecal-feeders), xylophages (wood-feeders) and necrophages (carrion-feeders). These have sometimes been referred to as scavengers, debris-feeders or detritivores (Wallwork 1970).
4. Microphytic-feeders which also includes many saprophytic mites and Collembola, as well as fungus-feeding ants, termites, dipteran Mycetophilidae, coleopteran Nitidulidae, nematodes, molluscs and protozoans (Wallwork 1970).
5. There are also those whose feeding habits include a variety of foods, making classification into one of the above groups meaningless, unless they are classed as

opportunistic. These are the nematodes, cryptostigmatid mites, Collembola, and the larvae of Diptera and Coleoptera (Wallwork 1970).

In discussing the inter-relationships and feeding habits of soil fauna, the presence and habitat preference of soil fauna must also be understood. Some soil fauna are only present in the soil to escape unfavorable conditions above the soil, as is the case with diapausing Coleoptera, Thysanoptera and Heteroptera. Other soil fauna spend their egg and larval stages in the soil, and leave the soil when they reach adulthood. Diptera larvae are important members of this group, as are Coleoptera and Lepidoptera larvae and pupae. Because they leave the soil as adults, they are sometimes classified as temporary or geophiles, while other soil fauna which never leave the soil are called permanent or geobionts (Jacot 1940). Examples of geobionts are protozoans, nematodes, annelids, myriapods, isopods, mites, Collembola, some insects and molluscs (Wallwork 1976; Wallwork 1970; Kevan 1968).

Since soil can be characterized as having different layers, with differing properties, it is sensible to use this sort of classification to discuss habitat preferences of soil fauna. Ecologists have defined three zones: the hemiedaphon (surface organic layers), the euedaphon (mineral soil) and the epigeon (vegetation layer above soil surface). There are a variety of microhabitats within these zones, which vary due to soil type, vegetation type and geography. However, the largest variable of concern to soil fauna is soil moisture. Since there is more variability of this within the hemiedaphon than in the other two zones, the hemiedaphon has been further divided according to moisture content. Various hemiedaphic soil arthropods have been defined as being hydrophiles (living on the surface of free water), mesophiles (living in moist organic litter), and xerophiles (living in drier sites, such as moss, lichens and tree bark) (Klima 1956; Varga 1956; Strenzke 1953) cited in (Wallwork 1970; Kevan 1968; Tarras-Wahlberg 1961).

Within the fauna of the epigeon are many species which are only temporary dwellers, such as many phytophagous insects. There is however, overlap between epigeon and hemiedaphon fauna, as some species move into the soil for a short period of time. As well, many species such as isopods, molluscs, arachnids and Collembola move out of the

hemiedaphon and into the aerial vegetation during their seasonal or diurnal migrations. There are also movements of soil fauna between the hemiedaphon and the euedaphon, which makes classification of soil fauna based on stratigraphical relationships difficult (Wallwork 1970).

Assemblages of soil fauna can be described for different soil types. In the mull humus of lowland grasslands, earthworms and bacteria are extremely common and very important in the formation of the humus. There are also Acari, Collembola (Wallwork 1976; Wallwork 1970; Wood 1966; Salt et al. 1948), Coleoptera, Diptera, Thysanura, and to a lesser degree Diplopoda, Chilopoda, Symphyla and Protura (Wallwork 1970; Salt et al. 1948). Contrast this with the composition in mor humus of forests, which consists of Acari, Collembola, Diptera larvae and other insect larvae, and carnivorous staphylinid beetles, carabid beetles, centipedes, spiders, and pseudoscorpions (Bornebusch 1930) cited in (Wallwork 1976). As well, earthworms are rare in mor humus and fungi take over the role of bacteria (Wallwork 1970).

Coleopteran Soil Fauna: Within the Coleopteran soil fauna, three types of feeding habits are represented. The most common are the carnivorous Carabids and the predatory and saprophytic Staphylinids (Wallwork 1976; Kevan 1968). Other families included the predatory Cicindelidae, Histeridae and Elateridae. The Elateridae are also phytophagous on wood. Both the Histeridae and the Elateridae are found in decaying wood and twigs (Wallwork 1970; Kevan 1968). As well, there are the predacious Pselaphidae, Scydmaenidae, Cantharoidea, Cleroidea and Cucujoidea (Raw 1967). Decomposition of organic material by litter-feeding or carrion-feeding is common in the larvae of Passalidae, Lucanidae, Elateridae, Scarabidae, Silphidae, Nitidulidae, Ptiliidae and Tenebrionidae (Wallwork 1976; Kevan 1968). Histeridae also has carrion-feeding species within its family (Kevan 1968).

Habitat preference is noticeable within different families of Coleoptera. The phytophagous larvae of Elateridae, Scarabidae, Curculionidae and the carnivorous larvae of the Cicindelidae, Cantharidae, Meloidae, Cleridae, Staphylinidae and Lampyridae are classed as geophiles, spending their immature stages within the soil and leaving the soil as

adults (Wallwork 1970; Kevan 1968). Both adults and larvae of various families often have modifications for burrowing in the soil (Kevan 1968).

Within the family Carabidae, distinct habitats are associated with feeding habits. Predatory carabids are found in woodlands, while saprophytic and phytophagous carabids are more common in open fields (Wallwork 1970). For example, carnivorous ***Nebria brevicollis, Notiophilus substriatus*** and ***Notiophilus rufipes*** are found mostly in woodlands, while ***Notiophilus biguttatus*** is restricted to forests and ***Notiophilus palustris*** is restricted to grasslands (Wallwork 1976; Greenslade 1964). ***Feronia madida*** which feeds on carrion, is found in both habitats (Wallwork 1976; Williams 1959).

Within the Scarabaeidae, Coprinae, Aphodiinae, Geotrupinae and Troginae, the adults and larvae feed on carrion and dung, while living underneath it in burrow systems that they construct (Wallwork 1976; Ritcher 1958).

Various habitat preferences are also seen with the family Elateridae. Larvae of ***Agriotes lineatus, A. obscurus*** and ***Athous niger*** prefer heavy soils such as loam or clay loam, while ***Selatosomus aeneus*** is restricted to sandy loam, ***Limonius aeruginosus*** favors light textured soils and ***Corymbites sjaelandias*** is restricted to peat (Wallwork 1970; Nadvornyj 1968).

Dipteran soil fauna: While the Coleoptera are one of the most important insect orders of soil fauna, Diptera are a close second in moist habitats. Diptera larvae are very important contributors to the soil community (Wallwork 1970). There are a large number of families represented in the soil fauna, too many to list, however a few important ones are the Tipulidae, Bibionidae, Mycetophilidae, Sciaridae, Chironomidae, Ceratopognidae, Psychodidae, Tabanidae, Asilidae, Empididae, Stratiomyidae, Rhagionidae, Therevidae, Phoridae, Syriphidae, Borboridae, Sepsidae, Scatophagidae, Muscidae, Calliphoridae, and Sarcophagidae (Brauns 1954) cited in (Wallwork 1970).

Moisture and food limit the distribution of soil Diptera. Ceratopogonidae and Tabanidae are virtually subaquatic, while others such as Syrphidae can withstand considerable drought (Kevan 1968). Cyclorrhapha, Scatophagidae, Borboridae, Sepsidae and Muscidae are commonly found on carrion and dung (Wallwork 1976). Calliphorids and Sarcophagids are early successional species on decaying carrion (Anderson and

VanLaerhoven 1996 ;Wallwork 1970; Kevan 1968). Some members of the families Tachiniidae, Phoridae and Calliphoridae are parasitic on earthworms and molluscs (Kevan 1968; Raw 1967). *Fannia canicularis* L. is another larva in the soil (Peterson 1951), found on carrion in later stages of succession (Anderson and VanLaerhoven 1996). Most dipteran larvae are not able to burrow effectively, so depend on existing spaces or passage though decomposing vegetable substrate (Kevan 1968).

Carrion Fauna: Various studies have been done to determine the arthropod succession on carcasses in different geographic areas, since climate has a direct effect on arthropod distribution. However, most of these studies have used various different animals (Anderson and VanLaerhoven 1996; Early and Goff 1987; Abell et *al.* 1982; Braack 1981; Jiron and Cartin 1981; Coe 1978; Putman 1978; Denno and Cothran 1976; Smith 1975; Cornaby 1974; Payne 1965; Reed 1958; Bornemissza 1957).

Very little has been done with human carcasses. Some case studies have been done (Anderson 1995), however only one experimental above ground study has been done by Rodriquez and Bass (Rodriguez and Bass 1983). Unfortunately, there are many problems in the experimental design of the study. Due to the difficulty in obtaining human carcasses for decomposition trials, only one cadaver was used at a time, so no control cadavers or replicates were included. Four carcasses were used, however, each was placed at a different time of the year, when insect populations fluctuate and do not remain constant throughout the year. It is impossible, statistically or otherwise, to make conclusions of insect succession based on only one carcass. Another problem is that the cadavers were not placed far enough apart from each other. The facility in which the experiment was performed contains many bodies in various stages of decay, therefore the olfactory orientation of the insects to the bodies was not independent. Also, each carcass was sampled, and with no unsampled carcasses, it is impossible to determine whether or not sampling affected the insect succession. As well, all the carcasses were naked. This is not a problem if the purpose is to examine insect succession alone. However, the purpose of this study was to examine insect succession in order to determine the elapsed time since death in homicide cases. Since most homicide victims are clothed or have clothing associated with them, and clothing effects the insect succession by providing shelter and

absorbing body fluid, thus lengthening the insect succession (Dillon and Anderson 1995a), this study fails to approximate the appropriate conditions for a homicide victim.

One further problem with the study by Rodriquez and Bass (Rodriguez and Bass 1983) is that the insects were only identified to family. Since different insect species within a family may have very different habitat and feeding preferences, identification to genera is necessary, and to species preferable. Keeping this in mind, their results were as follows: During the fresh stage, Calliphorids and Muscids were common. At the onset of the bloat stage, Silphids, Staphylinids and Histerids and Sarcophagids were present in addition to the Calliphorids and Muscids. During the decay stage, Nitidulids were also present. In the final stage, the dry stage, only Nitidulids, Staphylinids, Dermestids, Clerids and Scarabaeids were present (Rodriguez and Bass 1983).

All these above ground studies have one ecological fact in common; there are a succession of arthropods species on decomposing carcasses. This occurs on the carcass. The soil fauna below the carcass also goes through a succession of species. Numerous factors influence soil fauna, as previously discussed. When these conditions change due to the influence of carcass decomposition, so does the soil fauna composition. Soil moisture is greatly increased as fluids from the body seep into the soil. Soil pH changes as organic molecules enter the soil. Ammonia, a by-product of decomposition, is produced in high quantities, changing the pH of the soil. Light is decreased, while temperature may increase due to maggot mass activity. The usual soil fauna such as Collembola and many Acari, disappear from under the carcass, but can still be found 40 cm away. Plant growth beneath the carcass also ceases, with all the vegetation dying, however, plants nearby show improved growth over a period of time as the products of decomposition become incorporated into the humus layer and are available as nutrients. Over a year later, typical soil fauna for that soil type begins to return to its previous assemblage of species (Bornemissza 1957).

Grave Fauna: As this study has now shown, there is definitely a difference between the succession on above ground bodies compared to buried bodies. The ability of carrion soil fauna, such as Coleoptera or Diptera, to burrow successfully to reach their food source depends on soil structure and texture. If the soil is too compacted, they

cannot penetrate it, however, if the soil is too fine, it may not retain the form of the burrow and the animals may die of asphyxiation. The act of burying a body may decrease compaction as seemed to be the case in the Alex Fraser Research Forest. Some Diptera, such as those from the genera ***Calliphora*** and Lucilia (Fuller 1932), and those in the family Phoridae (Nuorteva 1977; Lundt 1964) are capable of burrowing while other Diptera are influenced by the size of the pores within a soil, which can control their movement through the soil (Kevan 1968). This has lead to some erroneous conclusions, however. Nuorteva (Nuorteva 1977) states that the presence of blowfly larvae and Piophilid larvae on a buried body indicates that the body was kept unburied for a portion of time. This is contradicted by evidence from other studies (Lord et al. 1992; Gilbert and Bass 1967; Fuller 1932) as well as data from this study.

Until now, experimental studies on the insect succession on buried carcasses was lacking. There was one study on buried pigs by Payne (Payne et al. 1968). However, this study used a board frame, with a lid and soil on top, in a pit 50-100 cm deep. This is an unrealistic scenario for homicides. Buried homicide victims are not in coffins. The method that they used influences the ability of insects to reach the carcasses.

Many more studies have been done on surface carcasses, however, one notable study has been done using buried human cadavers (Rodriguez and Bass 1985). This is the only experimental study using buried human cadavers. Other studies have been done using human bodies exhumed from actual homicide cases, or from anthropological studies (Megnin 1894) cited in (Lord et al. 1992; Nuorteva 1977; Stafford 1971; Leclercq 1969; Gilbert and Bass 1967; Lundt 1964; Motter 1898). Unfortunately, the study by Rodriquez and Bass suffers many of the same problems as the previous study (Rodriguez and Bass 1983). Due to the difficulty in obtaining human carcasses for decomposition trials, there were no control carcasses, nor was there any replication. Six carcasses were used, however, each was buried at a different time of the year, when insect populations fluctuate and do not remain constant throughout the year. It is impossible to make conclusions of insect succession based on only one carcass. Since they did not use control above ground carcasses, the only comparison that they had was the data from their previous study, in a different year. They had nothing available for direct comparison of

succession rates. Two of the bodies were missing their brains and internal organs. Gut fauna is responsible for large changes in the decomposition, such as bloat. Without the internal organs, the decomposition pattern would be completely different. As well, some bodies were clothed, while others were not. Since clothing affects the insect succession by providing shelter and absorbing body fluid, thus lengthening the insect succession, all the bodies should have been clothed in the same manner. The bodies were also buried at different depths and only 5ft apart. Since many insects have excellent olfactory senses, this is unlikely to be far enough apart for them to distinguish the bodies as separate, rather than as a mass grave. There were also many other bodies present in the facility where the study was performed, which would provide further stimuli for the olfactory senses of the insects. Also, since different depths will change the ability of different insects to reach the bodies, there will be little between-body comparisons possible. One final problem with this study was that they exhumed the bodies, then reburied them and exhumed them again. Since they had no control bodies, they were unable to determine the effects of uncovering the bodies. Insects that were not able to burrow down to the body could have been introduced during the exhumation. Unfortunately, our study did not have a sufficiently large sample size to show this effect, but it has been used in cases in the United States to determine times of disturbance as well as elapsed time since death (Anderson) .

Again, they did not identify the insect species past family. Even then, the only results mentioned are the presence of Calliphorids, Sarcophagids, Scarabiaeids and Staphylinids. No other insects were mentioned, nor were times of appearance given for the families that were mentioned (Rodriguez and Bass 1985).

Decomposition studies worldwide have used a variety of different carcass types and sizes including cats (Early and Goff 1987), dogs (Jiron and Cartin 1981; Reed 1958), guinea pigs (Bornemissza 1957), mice (Putman 1978), foxes (Smith 1975; Easton 1966); lizards and toads (Cornaby 1974); turtles (Abell et al. 1982), rabbits (Denno and Cothran 1976), elephants (Coe 1978), impala (Braack 1981) and humans (Rodriguez and Bass 1983). Carcass type and size can have an effect on decomposition rate and insect succession. Denno and Cothran (Denno and Cothran 1975) found that carcass size had a direct relation to fly populations, and work by Hewadikaram and Goff

(Hewadikaram and Goff 1991) supported this, but also indicated that there were no size-related differences between 8.4 kg and 15.1 kg pig carcasses with respect to composition of the insect fauna or patterns of succession. It might be expected that small carcasses would decompose more rapidly than larger carcasses, but because the larger carcass attracted more flies, it supported a larger number of maggots, so decomposition, was actually faster in the larger carcass, due to maggot removal of body material (Hewadikaram and Goff 1991). However, extremely small carcasses such as those of lizards and toads (Cornaby 1974) and shrews, mice and other small rodents (Payne 1965) have been reported to decompose very quickly, with no marked stages of decomposition. Coat type may also have an effect on the insects attracted to the body. Human bodies are obviously the ideal research material, but it is not usually possible to obtain large numbers of human bodies at one time, so studies using such carcasses have invariably had only one replicate (Rodriguez and Bass 1985; Rodriguez and Bass 1983). Therefore, 22 kg pigs have been recommended as suitable human models for decomposition (Catts and Goff 1992). Pigs (*Sus scrofa* L.) are omnivores, with a digestion very similar to that of humans, are relatively hairless and have skin so similar to our own that it can be used in human skin grafts. A 23 kg pig is equivalent in weight to an average adult male torso, which is the main site of insect colonization (Catts and Goff 1992). Studies here have been related to actual human cases of known time of death, and the pig model appears to relate well to human cases. In the absence of statistically sound buried human cadaver research, non-human models must be used. Only by the use of a non-human model will the problems inherent in human carcass research be solved. Therefore, by using pigs in burial experiments, a much needed database of insect succession for burial has been established for the Vancouver and Cariboo Regions of British Columbia.

CONCLUSION

Burial has a distinct insect succession pattern from that which occurs on above ground bodies. It is different in different geographic areas, just as above ground succession is different in different areas. Only by an understanding of this succession can an accurate elapsed time since death be determined. However, this requires both the

knowledge of the successional sequence as well as the ecosystem interactions. This research is immediately valuable in analyzing cases currently pending, as well as future cases.

ACKNOWLEDGMENTS

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REFERENCES

Abell, D.H., Wasti, S.S. and Hartmann, G. 1982. Saprophagous arthropod fauna associated with turtle carrion, Appl. Entomol. Zool., 17: 301-307.

Anderson, G.S, Assistant Professor, Department of Biological Sciences, Simon Fraser University, Burnaby , B.C. .

Anderson, G.S, 1995, The use of insects in death investigations: an analysis of forensic entomology in British Columbia over a five year period. Can. Soc. Forensic Sci. J., 28(4): 277-292.

Anderson, G.S. and VanLaerhoven, S.L. 1996. Initial Studies on Insect Succession on Carrion in Southwestern British Columbia. J. For. Sci., in press.

Avery, B.W., 1969. Problems of Soil Classification. In: J.G. Sheals (Editor), The Soil Ecosystem. A symposium. The Systematics Association, London, pp. 9-18.

Bornebusch, C.H. 1930. The fauna of forest soil. Forst. ForsVaes Danm., 11: 1-224.

Bornemissza, G.F. 1957. An analysis of arthropod succession in carrion and the effect of its decomposition on the soil fauna. Aust. J. Zool., 5: 1-12.

Braack, L.E.O. 1981. Visitation patterns of principal species of the insect complex at carcasses in the Kruger National Park. Koedoe, 24: 33-49.

Brauns, A. 1954. Untersuchungen zur angewandten Bodenbiologie; Bd. I. Terricole Dipterenlarven, Musterschmidt, Gottingen.

Burges, N.A., 1965. Biological processes in the decomposition of organic matter. In: D.V.C.E G Hallsworth (Editor), Experimental Pedology, pp. 189-98.

Burges, N.A., 1967. The decomposition of organic matter in the soil. In: F.R. N A Burges (Editor), Soil Biology, pp. 479-92.

Catts, E.P. and Goff, M.L. 1992. Forensic entomology in criminal investigations. Ann. Rev. Entomol., 37: 253-272.

Catts, E.P. and Haskell, N.H. 1990. Entomology and death: a procedural guide. Joyce's Print Shop, Inc., Clemson, SC., 182 pp.

Coe, J.I. and Curran, W.J., 1980. Definition and time of death. In: W.J. Curran, A.L. McGarry and C.S. Petty (Editors), Modern Legal Psychiatry and Forensic Science. F.A. Davis Co., Phil., pp. 1310 pp.

Coe, M. 1978. The decomposition of elephant carcasses in the Tsavo (East) National Park, Kenya. J. Arid Environs., 1: 71-86.

Cornaby, B.W. 1974. Carrion reduction by animals in contrasting environments. Biotropica, 6: 51-63.

Denno, R.F. and Cothran, W.R. 1976. Competitive interaction and ecological strategies of sarcophagid and calliphorid flies inhabiting rabbit carrion. Annals of the Entomological Society of America, 69: 109-113.

Denno, R.I. and Cothran, W.R. 1975. Niche relationship of a guild of necrophagous flies. Annals of the Entomological Society of America, 68: 741-754.

Dillon, L.C. and Anderson, G.S. 1995a. Development of a database of insect succession on carrion in Coastal British Columbia in order to determine time of death., American Academy of Forensic Sciences, Seatle, Washington.

Dillon, L.C. and Anderson, G.S. 1995b. TR-05-95 Forensic Entomology The use of Insects in Death Investigations to Determine Elapsed Time Since Death. Canadian Police Research Centre, 38 pp.

Dillon, L.C. and Anderson, G.S. in progress. Development of a database of insect succession on carrion in British Columbia in order to determine time of death. .

Early, M. and Goff, M.L. 1987. Arthropod succession patterns in exposed carrion on the island of O'ahu, Hawai'i. J. Med. Entomol., 23: 520-531.

Easton, A.M. 1966. The Coleoptera of a dead fox ***(Vulpes vulpes* L.);** including two species new to Britain. Entomologists Monthly Mag, 102: 205-210.

Fuller, M.E. 1932. The effect of carcass burial on blowflies. J. Coun. Sci. Ind. Res., 5: 162-164.

Gilbert, B.M. and Bass, W.M. 1967. Seasonal dating of burials from the presence of fly pupae. American Antiquity, 32: 534-535.

Goddard, J. and Lago, P.K. 1985. Notes on blowfly (Diptera : Calliphoridae) succesion on carrion in Northern Mississippi. Journal of Entomological Science, 20: 3 12-317.

Goff, M.L. 1991. Comparison of insect species associated with decomposing remains recovered inside dwellings and outdoors on the island of Oahu, Hawaii. J. For. Sci., 36: 748-753.

Goff, M.L. and Flynn, M.M. 1991. Determination of postmortem interval by arthropod succession: A case study from the Hawaiian islands. J. For. Sci., 36: 607-614.

Goff, M.L. and Odom, C.B. 1987. Forensic entomology in the Hawaiian Islands, U.S.A. Three case studies. Am. J. For. Med. Path., 8: 45-50.

Goff, M.L., Odum, C.B. and Early, M. 1986. Estimation of postmortem interval by entomological techniques : a case study from Oahu, Hawaii. Bull. Soc. Vector. Ecol., 11: 242-246.

Goff, M.L., Omori, A.I. and Gunatilake, K. 1988. Estimation of postmortem interval by arthropod succession. Three case studies from the Hawaiian Islands. Am. J. For. Med. Path., 9: 220-225.

Greenberg, B. 1985. Forensic entomology : case studies. Bulletin Entomological Society of America, 3 l(4): 25-28.

Greenslade, P.J.M. 1964. The distribution, dispersal and size of a population of *Nebria* brevicollis (F.) with comparitive studies on three other Carabidae. J. Anim. Ecol., 33: 311-33.

Handley, W.R.C. 1954. Mull and Mor formation in relation to forest soils. Bull. For. Commn. Lond., 23: 115.

Hesselman, H. 1926. Studier over barrskogens humustacke, dess egenskaper och beroende av skogsvarden. Meddn St. SkogsforsAnst., 22: 169-552.

Hewadikaram, K. and Goff, M. 1991. Effect of carcass size on rate of decomposition and arthropod succession patterns. Am J Forensic Med Path, 12: 235-240.

Howard, P.J.A., 1969. The Classification of Humus Types in Relation to Soil Ecosystems. In: J.G. Sheals (Editor), The Soil Ecosystem. A symposium. The Systematics Association, London, pp. 4 1-54.

Jacot, A.P. 1940. The fauna of the soil. Quart. Rev. Biol., 15: 28-58.

Jiron, L.F. and Cartin, V.M. 1981. Insect succesion in the decomposition of a mammal in Costa Rica. New York Entomol. Soc., 89: 158-165.

Kashyap, V.K. and Pillai, V.V. 1989. Efficacy of entomological method in estimation of postmortem interval: a comparative analysis. Forensic Sci. Int., 40(3): 245-250.

Kevan, D.K.M. 1968. Soil Animals. H.F.&G. Witherby Ltd., London.

Klima, J. 1956. Strukturklassen und Lebensformen der Oribatiden (Acari). Oikos, 7: 227-42.

Kubiena, W.L., 1955. Animal activity in soils as a decisive factor in establishment of humus forms. In: D.K. Kevan (Editor), Soil Zoology, pp. 73-82.

Leclercq, M. 1969. Entomolgical Parasitology : Entomology and legal medicine. Pergamon Press, Oxford.

Lord, W.D., Adkins, T.R. and Catts, E.P. 1992. The use of ***Synthesiomyis nudesita*** (Van Der Wulp (Diptera: Muscidae) and ***Calliphora vicina*** (Robineau-Desvoidy) (Diptera: Calliphoridae) to estimate the time of death of a body buried under a house. J. Agric. Entomol., 9(4): 227-235.

Lundt, H. 1964. Ecological observations about the invasion of insects into carcasses buried in soil. Pedobiologia, 4: 158.

Madge, D.S. 1961. "Preferred temperatures" of land arthropods. Nature, London, 190: 106-7.

Megnin, P. 1894. Faune des Cadavres. Application de l' Entomologie a la Medicine Legale. Encyclopedie Sci. Aide- Memoire., Paris.

Motter, M.G. 1898. A contribution to the study of the fauna of the grave - a study of 150 disinterrments, with some additional observations. J. N.Y. Entomol. Soc., 6: 201-231.

Muller, P.E. 1879. Studier over Skovjord, som Bidrag ti1 Skovdyrkningens Theori. I. Om Bogemuld og Bogemor paa Sand og Ler. Tidsskr. Skovbr., **3:** 1-124.

Muller, P.E. 1884. idem II Om Muld og Mor i Egeskove og paa Heder. Tidsskr. Skovbr., 7: 1-232.

Nadvornyj, V.G. 1968. Wireworms (Coleoptera, Elateridae) of the Smolensk region, their distribution and incidence in different soil types. Pedobiologia, 8: 296-305.

Nuorteva, P., 1977. Sarcosaprophagous insects as forensic indicators. In: Tedeschi (Editor), Forensic Medicine : A study in trauma and environmental hazards. W.B. Saunders Co., pp. 1072-1095.

Payne, J.A. 1965. A summer carrion study of the baby pig ***Sus Scrofa*** Linnaeus. Ecology, 46: 592-602.

Payne, J.A., King, E.W. and Beinhart, G. 1968. Arthropod succession and decomposition of buried pigs. Nature, 219: 1180-1181.

Peterson, A. 1951. Larvae of insects. Part I I Lithoprint. Edwards, Ann Arbor, 416 pp.

Putman, R.J. 1978. The role of carrion-frequenting arthropods in the decay process. Ecol. Entomol., 3: 133-139.

Raw, F., 1967. Arthropoda (except Acari and Collembola). In: N.A. Burges and F. Raw (Editors), Soil Biology, pp. 323-62.

Reed, H.B. 1958. A study of dog carcass communities in Tennessee with special reference to the insects. The American Midland Naturalist, 59: 213-245.

Ritcher, P.O. 1958. Biology of Scarabaeidae. A. Rev. Ent., 3: 311-34.

Rodriguez, W.C. and Bass, W.M. 1983. Insect activity and its relationship to decay rates of human cadavers in East Tennessee. J. For. Sci., 28: 423-432.

Rodriguez, W.C. and Bass, W.M. 1985. Decomposition of buried bodies and methods that may aid in their location. J. For. Sci., 30: 836-852.

Romell, L.G. and Heiberg, S.O. 1931. Types of humus layer in the forests of northeastern United States. Ecology, 12: 567-608.

Russell, E.J. 1961. Soil conditions and plant growth. Longmans, London, 688 pp.

Russell, E.W., 1969. The Soil Environment. In: J.G. Sheals (Editor), The Soil Ecosystem. A symposium. The Systematics Association, London, pp. 1-8.

Salt, G., Hollick, F.S.J., Raw, F. and Brian, M.V. 1948. The arthropod population of pasture soil. Anim. Ecol., 17: 139-50.

Satchell, J.E., 1955. Some aspects of earthworm ecology. In: D.K.M. Kevan (Editor), Soil Zoology. H.F.&G. Witherby Ltd., London, pp. 180-201.

Skinner, M. and Lazenby, R.A. 1983. Found! Human Remains. Archeology Press, Simon Fraser University, Burnaby, B.C.

Smith, K.G.V. 1975. The faunal succession of insects and other invertebrates on a dead fox. Entomological Gazette, 26: 277.

Smith, K.G.V. 1986. A manual of forensic entomology. Trustees of The British Musem (Nat. Hist.) and Cornell University Press, London, 205 pp.

Stafford, F. 1971, Insects of a medieval burial. Science and Anthropology, 7: 6-10.

Strenzke, K. 1953. Untersuchungen uber die Tiergemeinschaften des Bodens: Die Oribatiden und ihre Synusien in den Boden Norddeutschlands. Zoologica, 37: 1-167.

Tarras-Wahlberg, N. 1961. The Oribatei of a central Swedish bog and their environment. Oikos, suppl. 4: 56.

Van den Oever, R. 1976. A review of the literature as to the present possibilities and limitations in estimating the time of death. Med. Sci. Law, 16: 269-276.

Varga, L. 1956. Biologie du Sol, Rapports du VI Congres International de la Science du Sol, Paris, pp. 231-235.

Wallwork, J.A. 1960. Observations on the behaviour of some oribatid mites in experimentally-controlled temperature gradients. Proceeding of the Zoological Society of London, 135: 619-29.

Wallwork, J.A. 1970. Ecology of Soil Animals. McGraw-Hill Publishing Co. Ltd., London, 283 pp.

Wallwork, J.A. 1976. The Distribution and Diverstiy of Soil Fauna. Academic Press Inc., New York, 355 pp.

Wallwork, J.A. and Rodriguez, J.G. 1961. Ecological studies on oribatid mites with particular reference to their role as intermediate hosts of anoplocephalid cestodes. J. econ. ent., 54: 701-5.

Williams, G. 1959. Seasonal and diurnal activity of Carabidae, with particular reference to *Nebria, Notiophilus* and Feronia. J. Anim. Ecol., 28: 309-30.

Wood, T.G. 1966. The fauna of grassland soils with special reference to Acari and Collembola. Proc. N. Z. ecol. Soc., 13: 79-85.

LIST OF FIGURE HEADINGS:

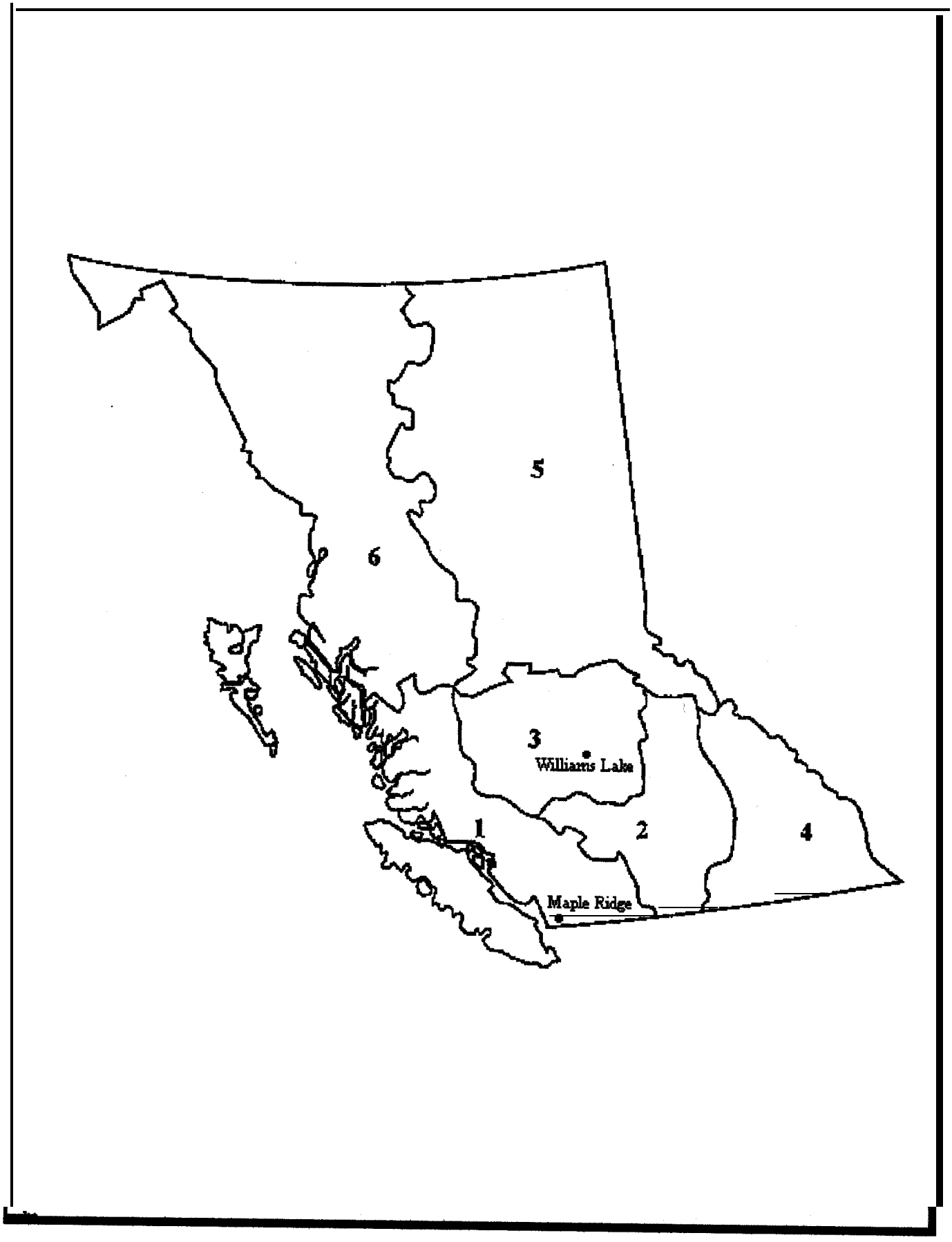

Figure 1 Forest Regions of British Columbia

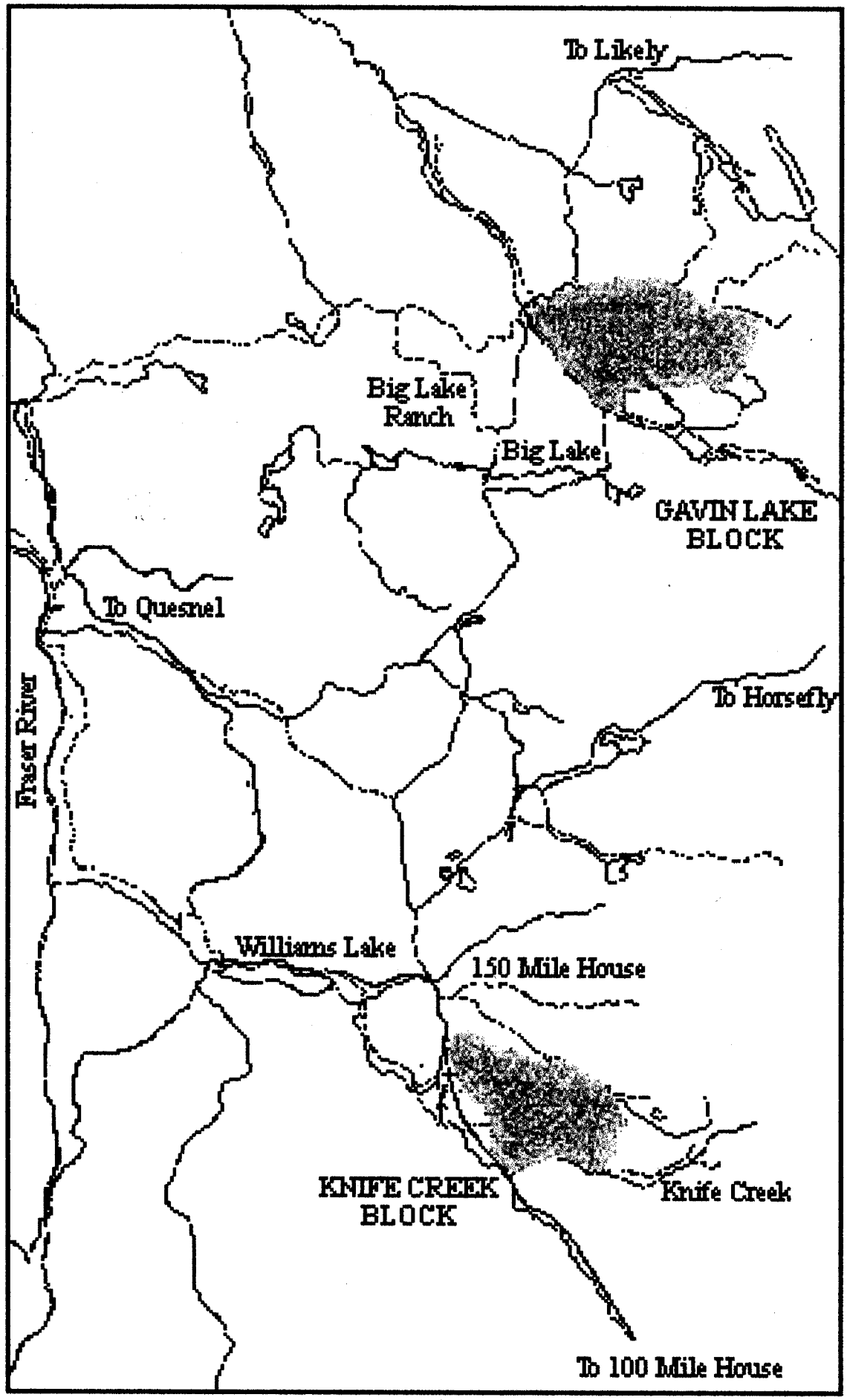

Figure 2 Alex Fraser Research Forest

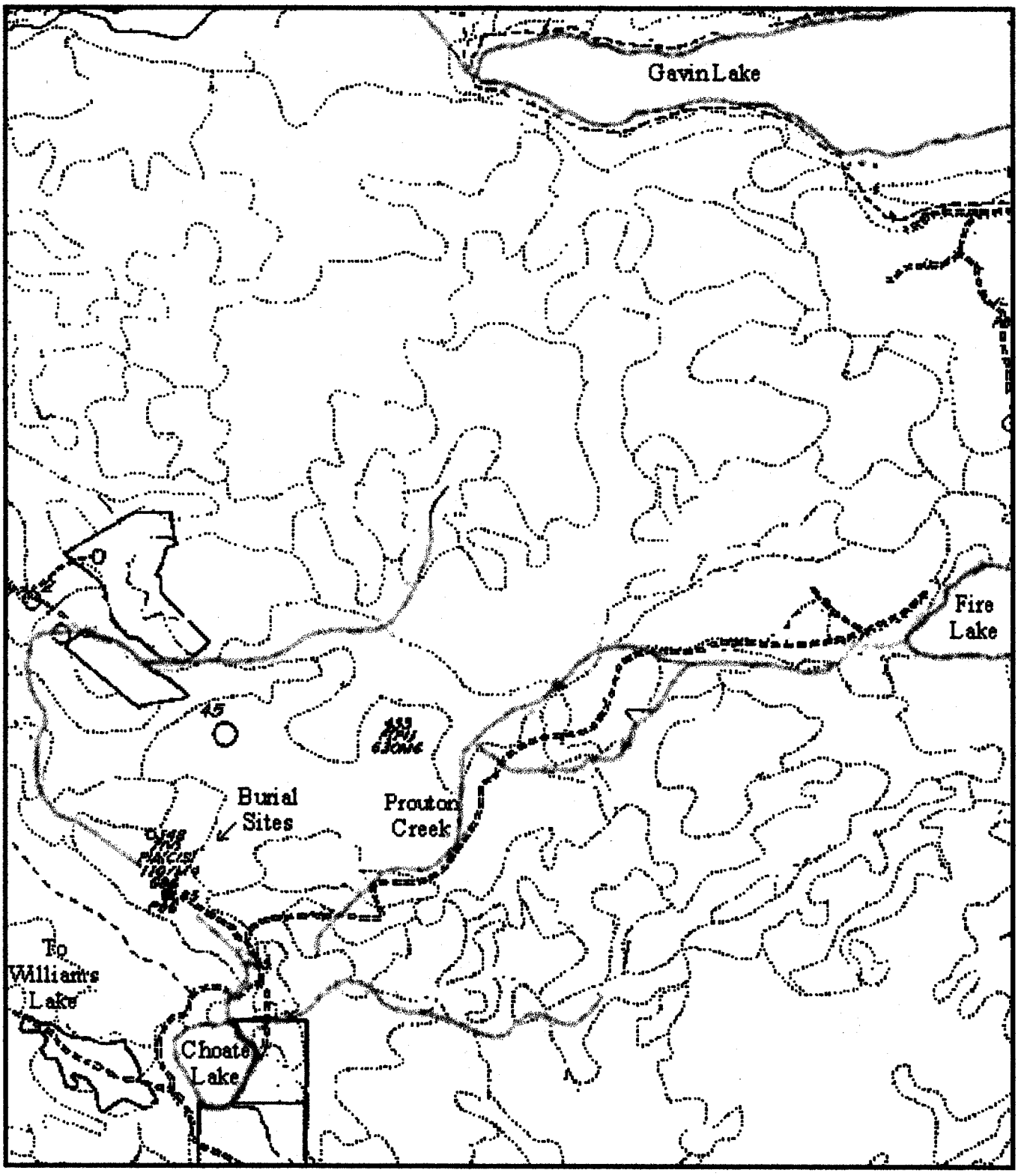

Figure 3 Gavin Lake Block

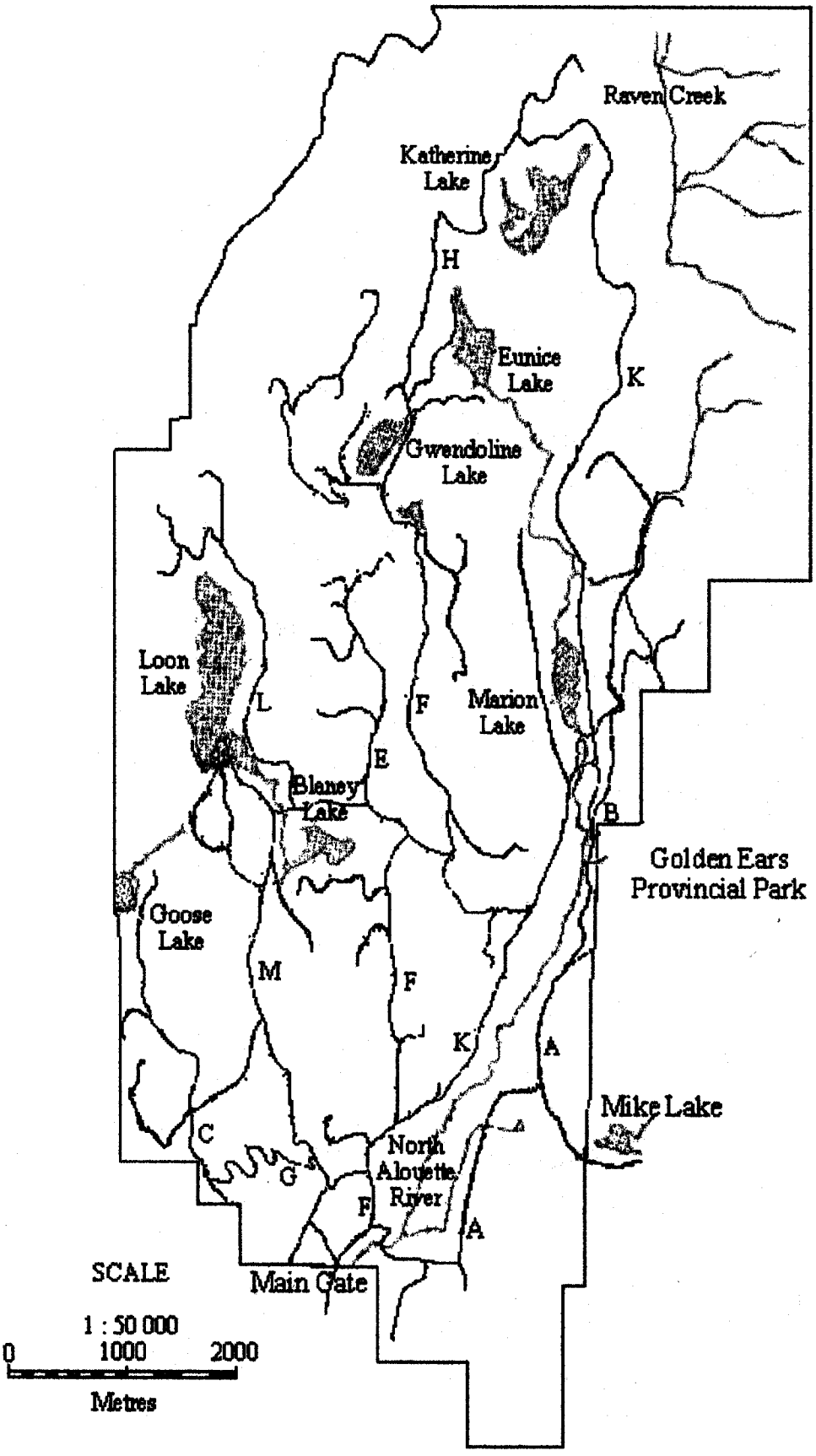

Figure 4 Malcolm-Knap Research Forest

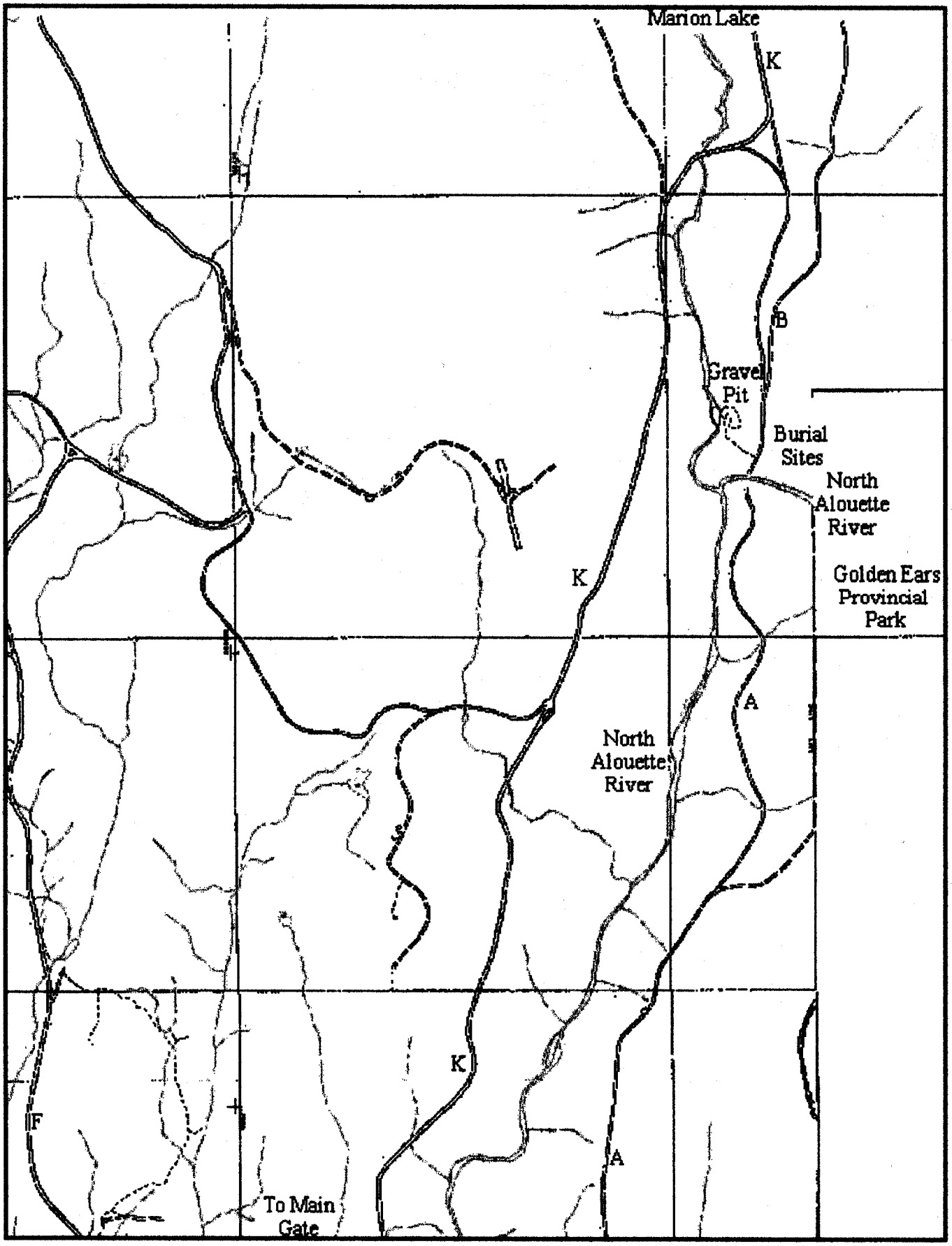

Figure 5 Central East Section of Malcolm-Knap Research Forest

Figure 6 Interior Forest Vegetation in Coastal Western Hemlock Biogeoclimatic Zone

Figure 7 Golden Ears Provincial Park

Figure 8 Interior Forest Vegetation in Sub-Boreal Spruce Biogeoclimatic Zone

Figure 9 Bear Hazard Warning Sign

Figure 10 Pitfall Trap

Figure 11 Digging Graves

Figure 12 Pig in Grave

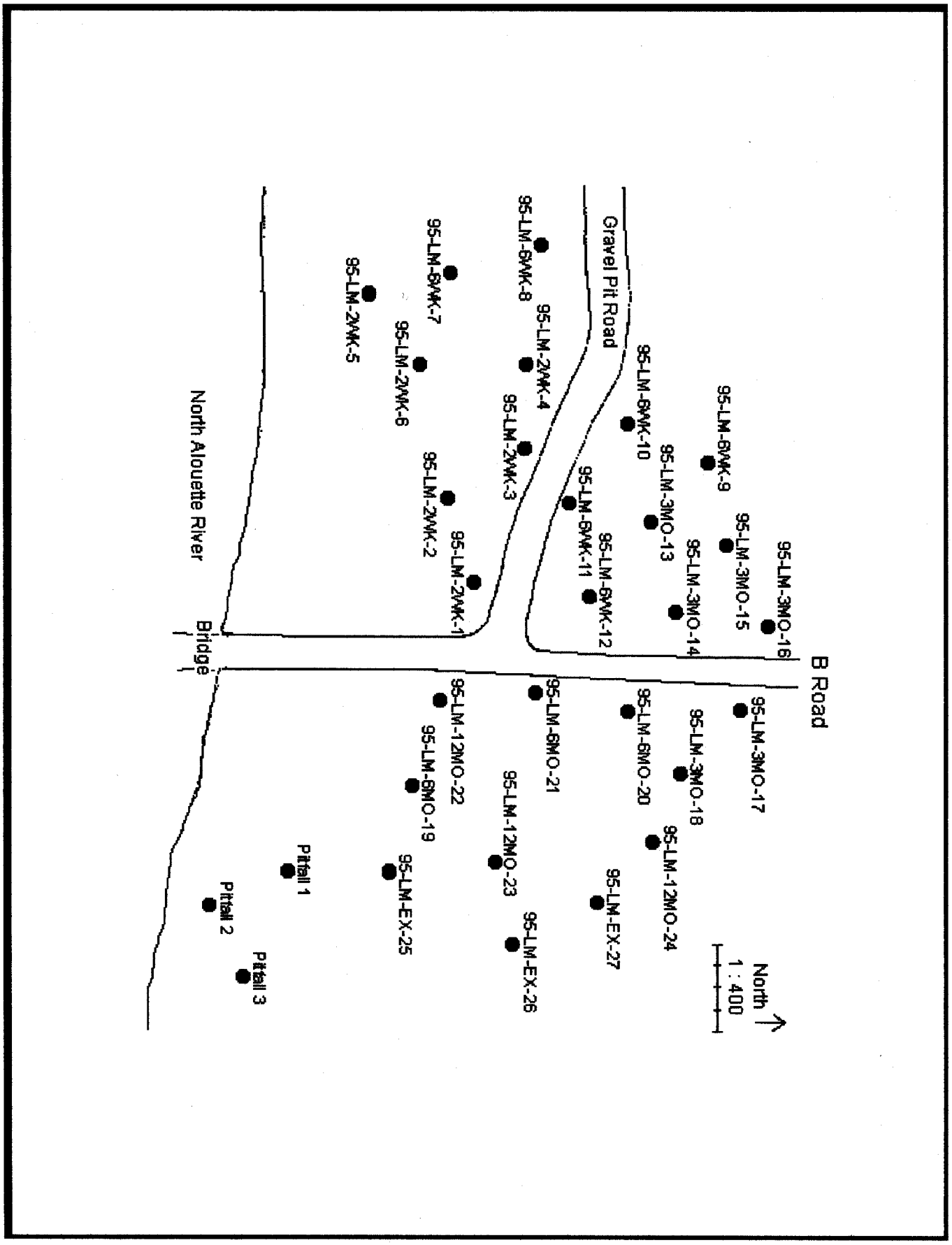

Figure 13 Map of Individual Carcass Sites in Malcolm-Knap Research Forest

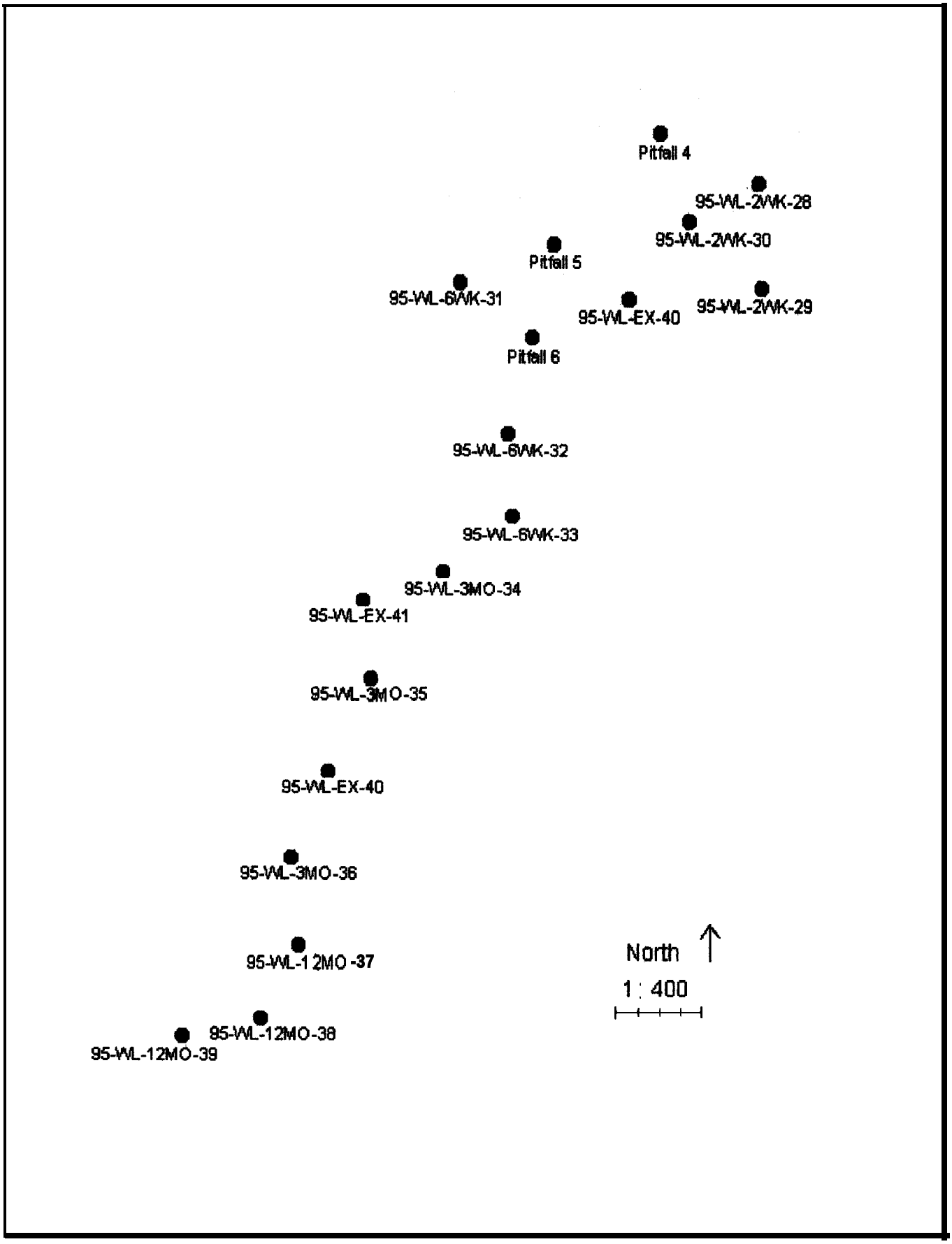

Figure 14 Map of Individual Carcass Sites in Atex Fraser Research Forest

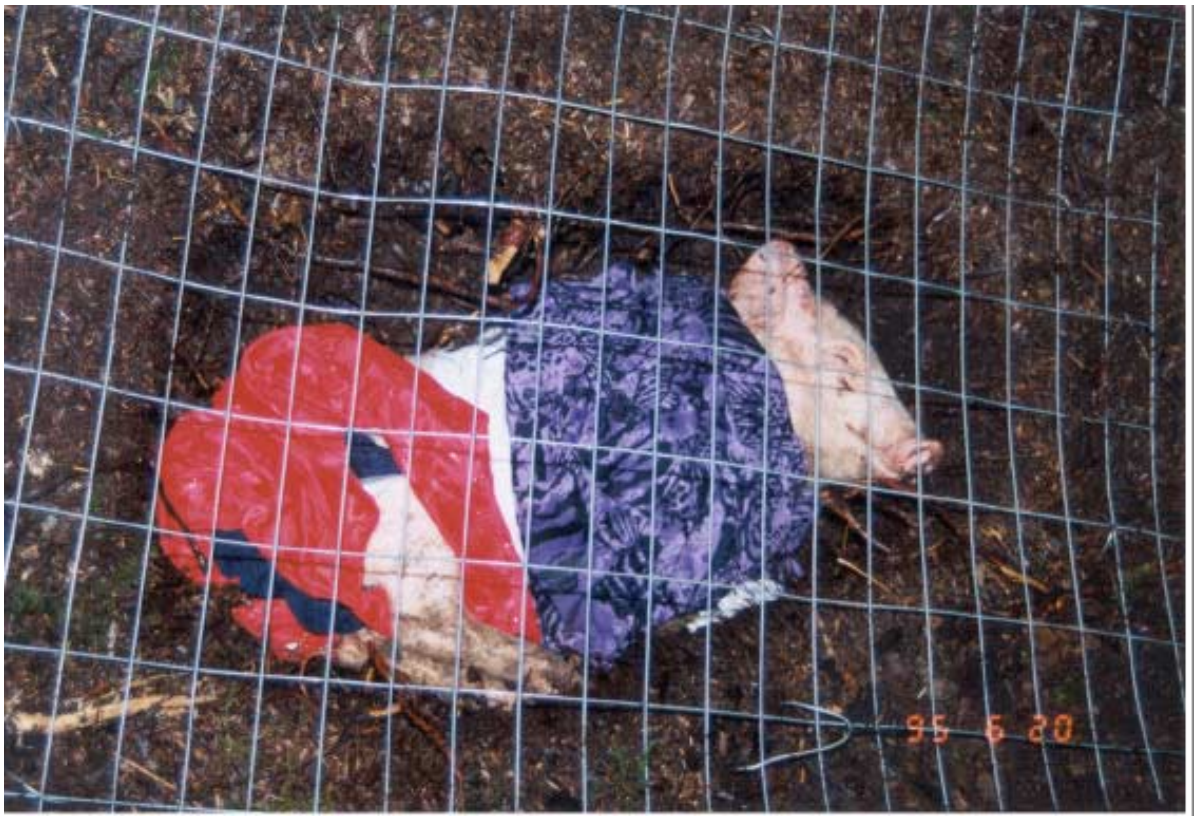

Figure 15 Pig Exposed for 48 hours to Insect Colonization

Figure 16 Pin Gun Used to Kill Pigs

Figure 17　Carrying Pigs Out to Grave Sites

Figure 18 Site Before Disturbance (Grave Digging)

Figure 19 Site After Grave Filled

Figure 20 Exposed Pig

Figure 21 Site Protected from Scavengers

Figure 22 Smart Reader Datalogger

Figure 23 Weighing Pigs

Figure 24 ID Card

Figure 25 Creation of a Safe Zone

Figure 26 Marking off the Area

Figure 27 Making a Photographic Record

Figure 28 Gridding the Area

Figure 29 Removing all Surface Vegetation

Figures 30 & 31 Removing Soil by Hand for Insect Evidence

Figure 32 Removing the Body

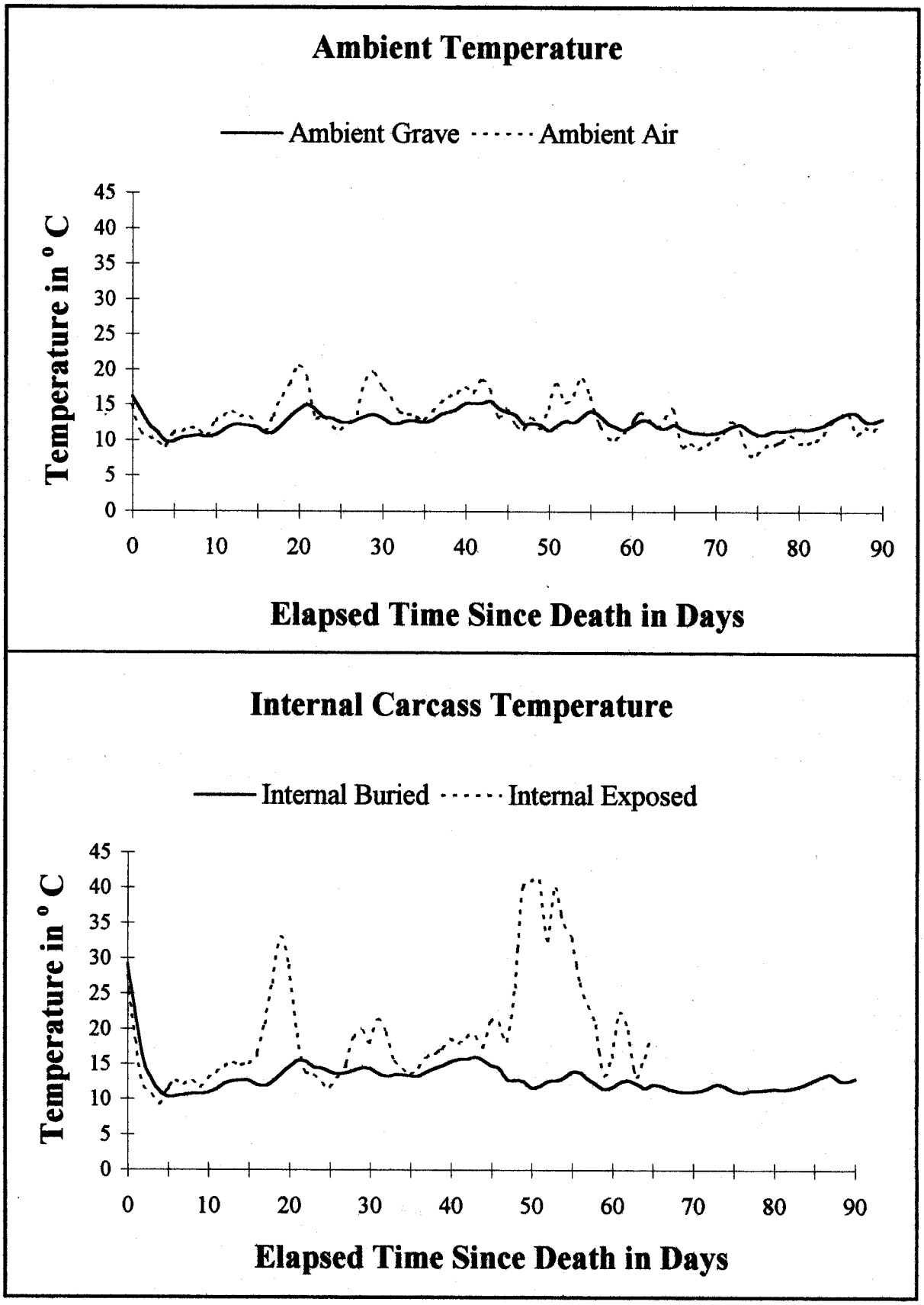

Figure 33 Ambient and Internal Temperatures of Carcasses in Cariboo Region

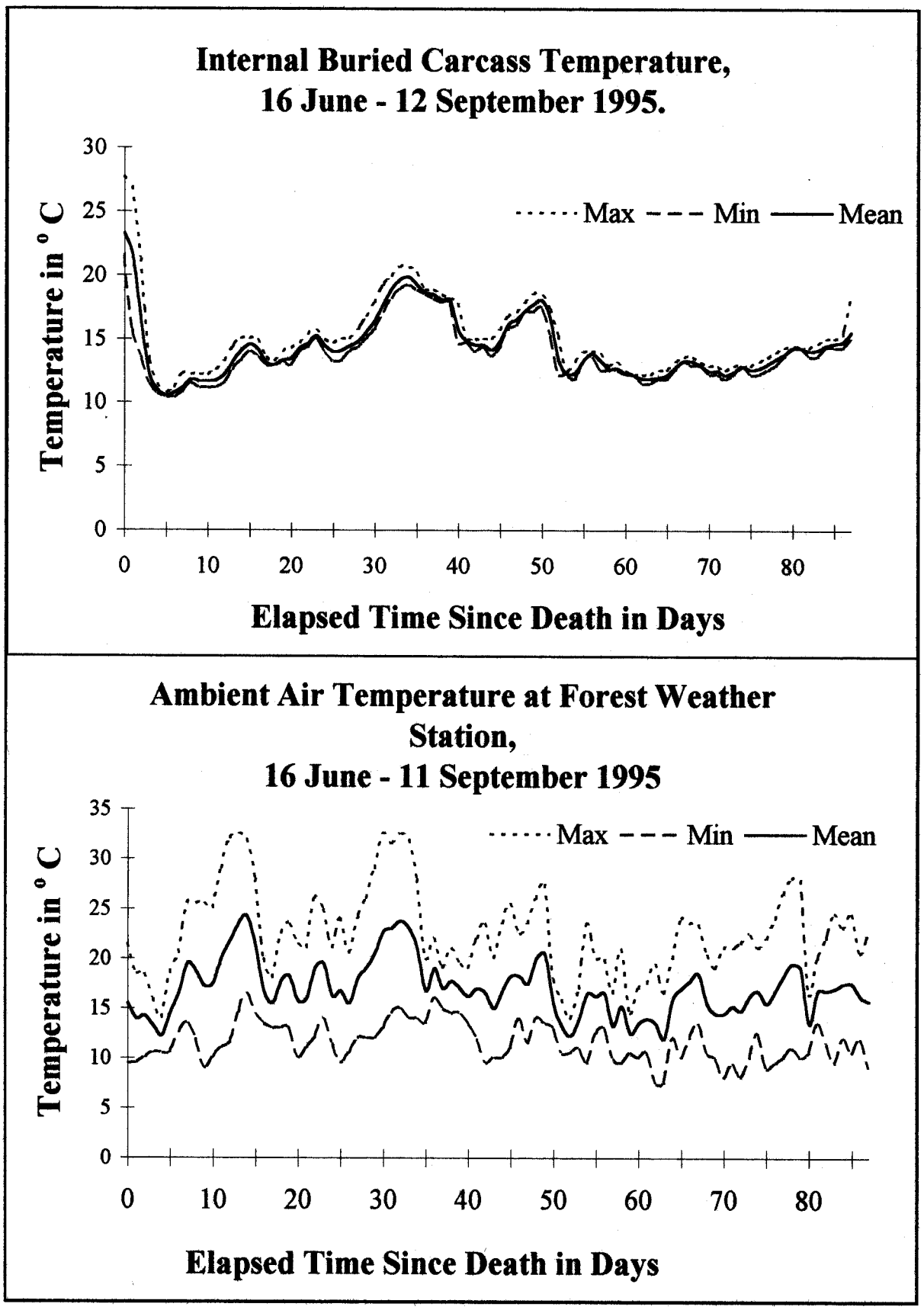

Figure 34 Comparison of Internal Carcass and Ambient Air Temperature in Vancouver Region

Figure 35 Maggot Masses

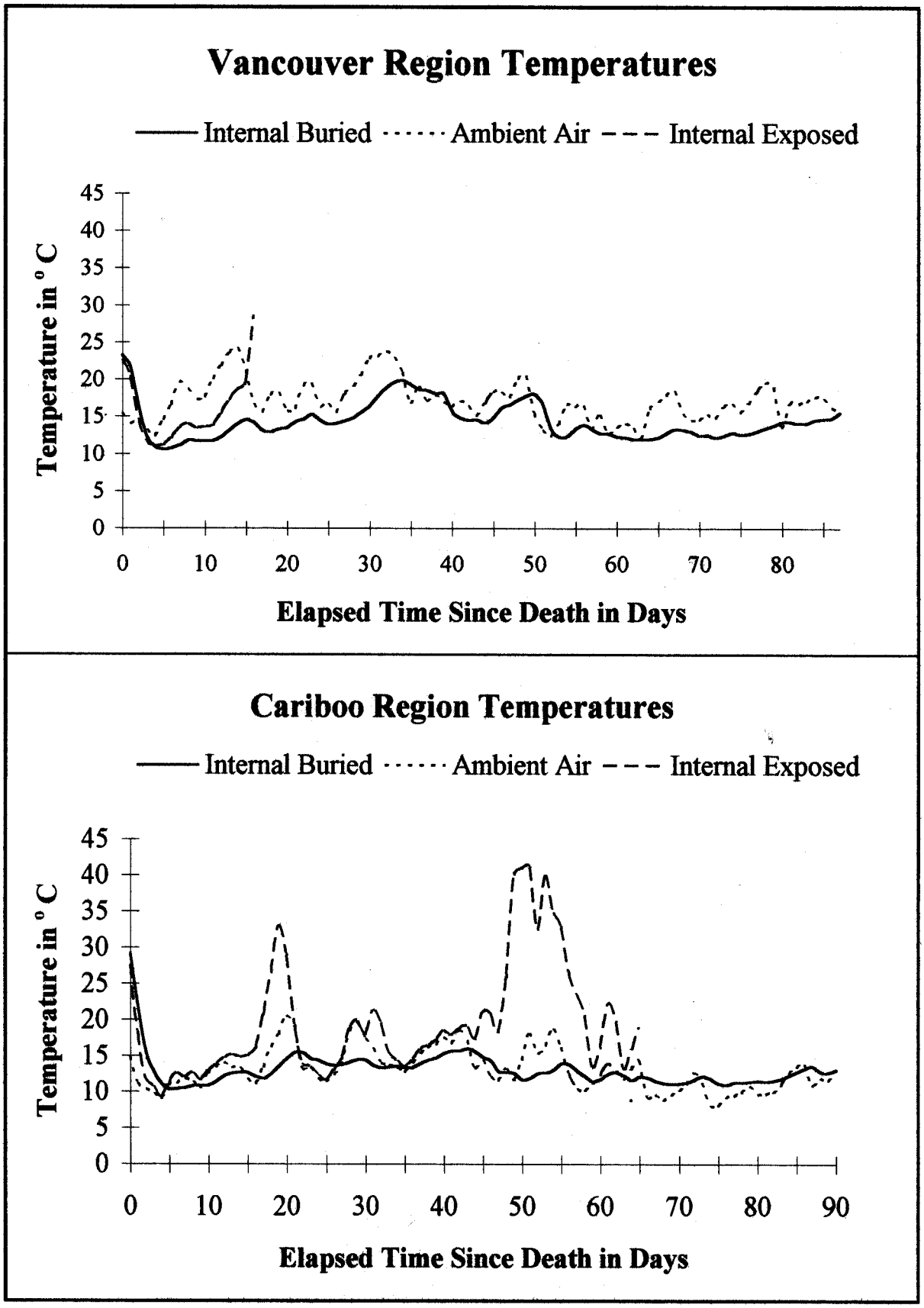

Figure 36 Summary of Vancouver and Cariboo Region Carcass Temperatures

Figure 37 Burial Pig on Day of Death

Figure 38 Exposed Pig on Day of Death

Figure 39 & 40 Exposed Pig; 2 Weeks After Death

Figure 41 Burial Pig; 2 Weeks After Death

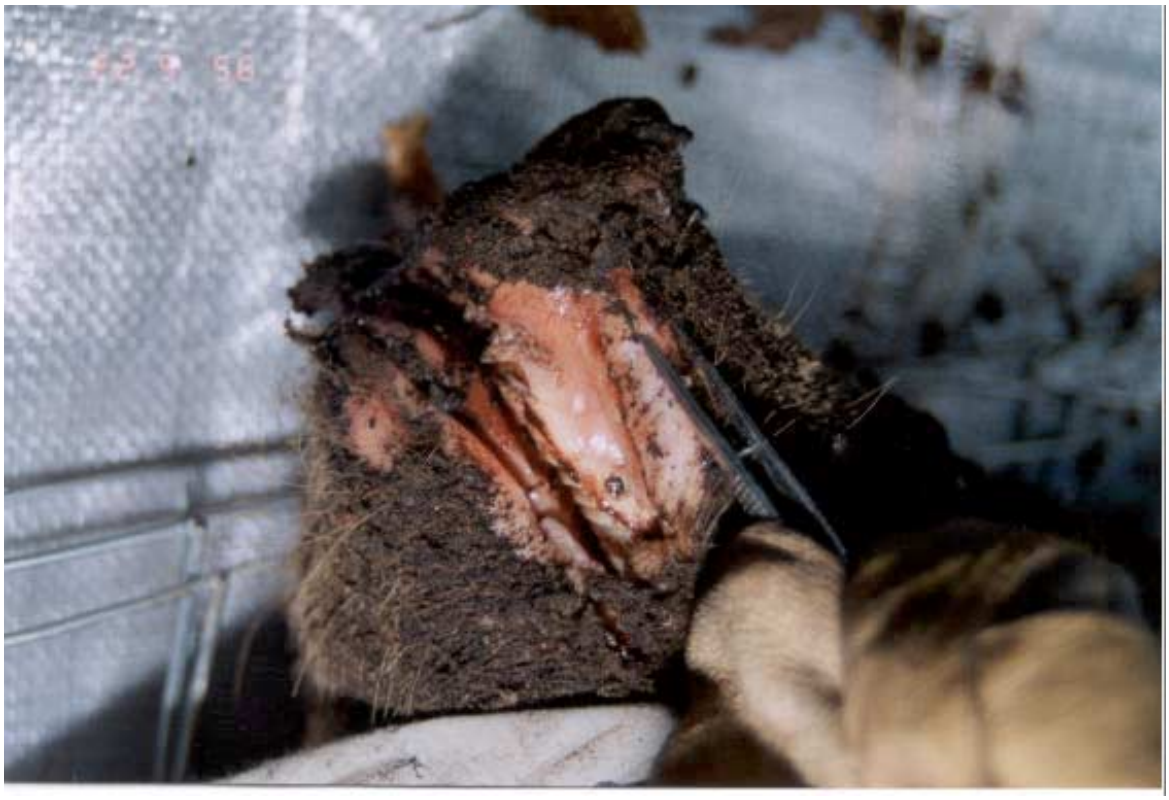

Figure 42 Burial Pig, Maggots in Mouth

Figure 43 Exposed Pig, 6 Weeks After Death

Figure 44 Burial Pig, 6 Weeks After Death

Figure 45 Exposed Pig, 3 Months After Death

Figure 46 Burial Pig, 3 Months After Death

Figure 47 Exposed Pig, 9 Months After Death

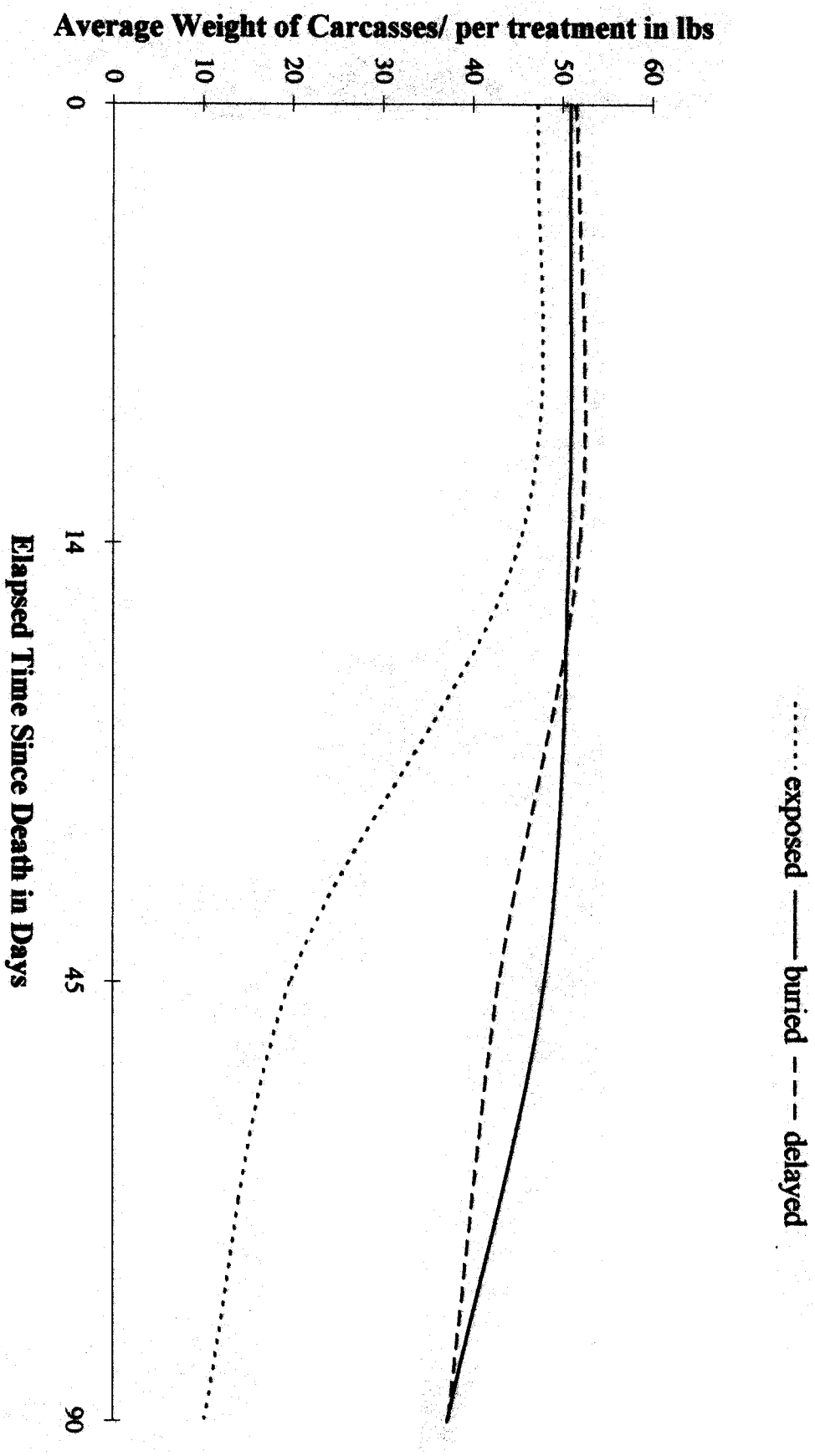

Figure 48 Biomass Loss of Carcasses in Vancouver Region

Above Ground Carcasses			Elapsed Time Since Death in Days		
Order	Insect Family	Species	14	45	90
Diptera	Calliphoridae	*Calliphora vomitoria*			
		Lucilia illustris			
		Phormia regina			
		Protophormia terraenovae			
	Fannidae	*Fannia sp.*			
	Heleomyzidae				
	Muscidae	*Hydrotaea sp.*			
		Morellia sp.			
		Ophyra sp.			
	Phoridae	*Megaselia sp.*			
	Sphaeroceridae				
Coleoptera	Carabidae				
	Dermestidae				
	Elateridae				
	Histeridae	*Sphaeridium bipustulatum*			
	Leiodidae				
	Staphylinidae	*Ortholestes cingulatus*			
		Creophilus maxillosus			
		unknown sp.			
	Silphidae	*Nicrophorus defodiens*			
		Nicrophorus hybridus			
Hymenoptera	Formicidae	*Camponotus pennsylvanicus*			
		unknown sp.			

Relative Abundance:

Sparse Common Numerous

Figure 49 Insect Succession Database for Exposed Pigs in Vancouver Region

Carcasses Buried Immediately			Elapsed Time Since Death in Days		
Order	Insect Family	Species	14	45	90
Diptera	Calliphoridae	*Calliphora vomitoria*			
		Lucilia illustris			
		Phormia regina			
		Protophormia terraenovae			
	Fannidae	*Fannia sp.*			
	Heleomyzidae				
	Muscidae	*Hydrotaea sp.*			
		Morellia sp.			
		Ophyra sp.			
	Phoridae	*Megaselia sp.*			
	Sphaeroceridae				
Coleoptera	Carabidae				
	Dermestidae				
	Elateridae				
	Histeridae	*Sphaeridium bipustulatum*			
	Leiodidae				
	Staphylinidae	*Ortholestes cingulatus*			
		Creophilus maxillosus			
		unknown sp.			
	Silphidae	*Nicrophorus defodiens*			
		Nicrophorus hybridus			
Hymenoptera	Formicidae	*Camponotus pennsylvanicus*			
		unknown sp.			

Relative Abundance:

Sparse Common Numerous

Figure 50 Insect Succession Database for Buried Pigs in Vancouver Region

Carcasses Buried After 48 Hrs			Elapsed Time Since Death in Days		
Order	Insect Family	Species	14	45	90
Diptera	Calliphoridae	*Calliphora vomitoria*			
		Lucilia illustris			
		Phormia regina			
		Protophormia terraenovae			
	Fannidae	*Fannia sp.*			
	Heleomyzidae				
	Muscidae	*Hydrotaea sp.*			
		Morellia sp.			
		Ophyra sp.			
	Phoridae	*Megaselia sp.*			
	Sphaeroceridae				
Coleoptera	Carabidae				
	Dermestidae				
	Elateridae				
	Histeridae	*Sphaeridium bipustulatum*			
	Leiodidae				
	Staphylinidae	*Ortholestes cingulatus*			
		Creophilus maxillosus			
		unknown sp.			
	Silphidae	*Nicrophorus defodiens*			
		Nicrophorus hybridus			
Hymenoptera	Formicidae	*Camponotus pennsylvanicus*			
		unknown sp.			

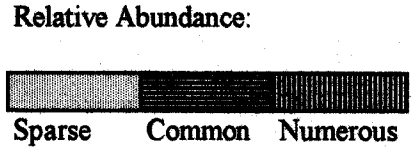

Figure 51 Insect Succession Database for Buried after 48 hr Pigs in Vancouver Region

Above Ground Carcasses			Elapsed Time Since Death in Days		
Order	Insect Family	Species	14	47 *	75 *
Diptera	Calliphoridae	*Calliphora vomitoria*			
		Lucilia illustris			
		Phormia regina			
		Protophormia terraenovae			
	Fannidae	*Fannia sp.*			
	Piophilidae	unknown sp.			
	Muscidae	*Hydrotaea sp.*			
		Morellia sp.			
		Ophyra sp.			
	Phoridae	*Megaselia sp.*			
	Sphaeroceridae				
Coleoptera	Carabidae				
	Dermestidae				
	Elateridae				
	Histeridae	*Sphaeridium bipustulatum*			
	Leiodidae				
	Staphylinidae	*Ortholestes cingulatus*			
		Creophilus maxillosus			
		unknown sp.			
	Silphidae	*Nicrophorus defodiens*			
		Nicrophorus hybridus			
Hymenoptera	Formicidae	*Camponotus pennsylvanicus*			
		unknown sp.			

* Dillon and Anderson CPRC March 1996 Technical Report

Figure 52 Insect Succession Database for Exposed Pigs in Cariboo Region

Buried Carcasses			Elapsed Time Since Death in Days		
	Insect				
Order	Family	Species	14	45	90
Diptera	Calliphoridae	*Calliphora vomitoria*			
		Lucilia illustris			
		Phormia regina			
		Protophormia terraenovae			
	Fannidae	*Fannia sp.*			
	Heleomyzidae				
	Muscidae	*Hydrotaea sp.*			
		Morellia sp.			
		Ophyra sp.			
	Phoridae	*Megaselia sp.*			
	Sphaeroceridae				
Coleoptera	Carabidae				
	Dermestidae				
	Elateridae				
	Histeridae	*Sphaeridium bipustulatum*			
	Leiodidae				
	Staphylinidae	*Ortholestes cingulatus*			
		Creophilus maxillosus			
		unknown sp.			
	Silphidae	*Nicrophorus defodiens*			
		Nicrophorus hybridus			
Hymenoptera	Formicidae	*Camponotus pennsylvanicus*			
		unknown sp.			

Relative Abundance:

Sparse Common Numerous

Figure 53 Insect Succession Database for Buried Pigs in Cariboo Region

Disturbed Carcasses			Elapsed Time Since Death in Days
Order	Insect Family	Species	45
Diptera	Calliphoridae	*Calliphora vomitoria*	
		Lucilia illustris	
		Phormia regina	
		Protophormia terraenovae	
	Fannidae	*Fannia sp.*	
	Heleomyzidae		
	Muscidae	*Hydrotaea sp.*	
		Morellia sp.	
		Ophyra sp.	
	Phoridae	*Megaselia sp.*	
	Sphaeroceridae		
Coleoptera	Carabidae		
	Dermestidae		
	Elateridae		
	Histeridae	*Sphaeridium bipustulatum*	
	Leiodidae		
	Staphylinidae	*Ortholestes cingulatus*	
		Creophilus maxillosus	
		unknown sp.	
	Silphidae	*Nicrophorus defodiens*	
		Nicrophorus hybridus	
Hymenoptera	Formicidae	*Camponotus pennsylvanicus*	
		unknown sp.	

Relative Abundance:

Sparse Common Numerous

Figure 54 Insect Succession Database for Disturbed Buried Pigs in Cariboo Region

Figure 55 Silphidae

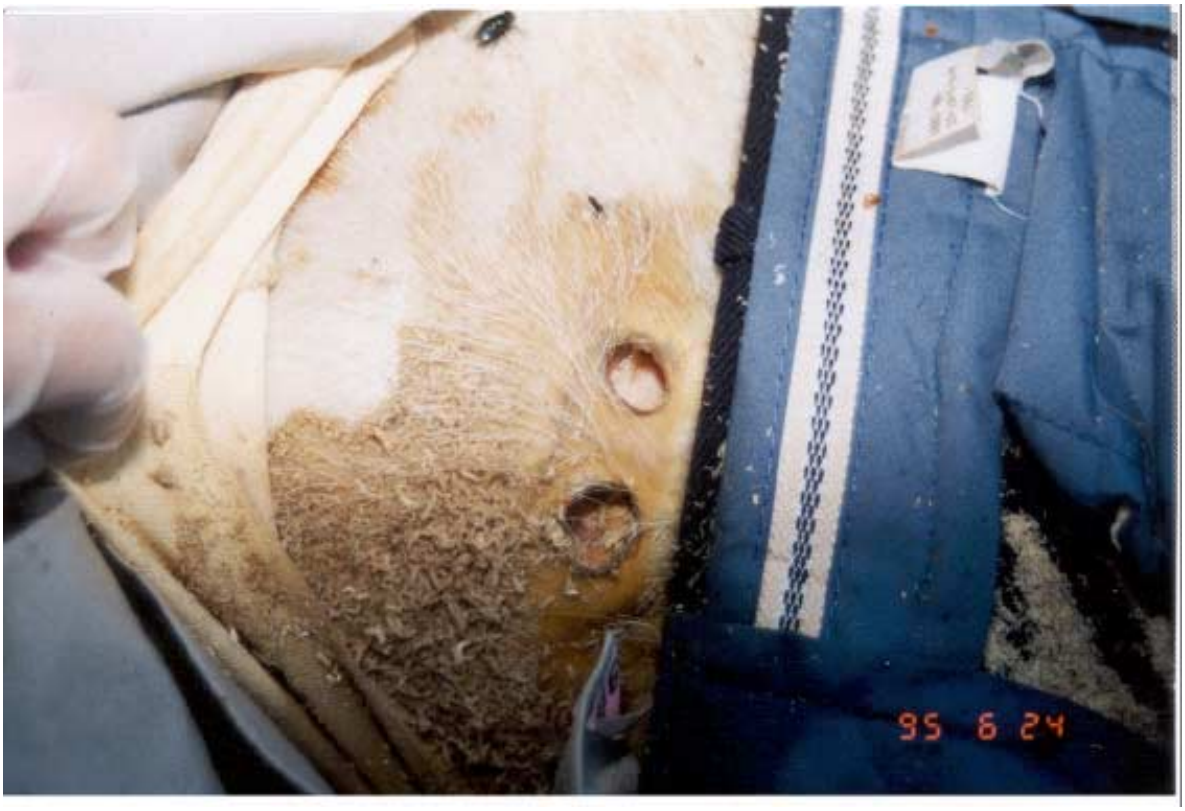

Figure 56 Ant Damage

Figure 57 Large Scavenger Damage

Figure 58 Small Scavenger Damage

Figure 59 Sub-surface Radar

Figure 60 Sub-surface Radar Recording Device

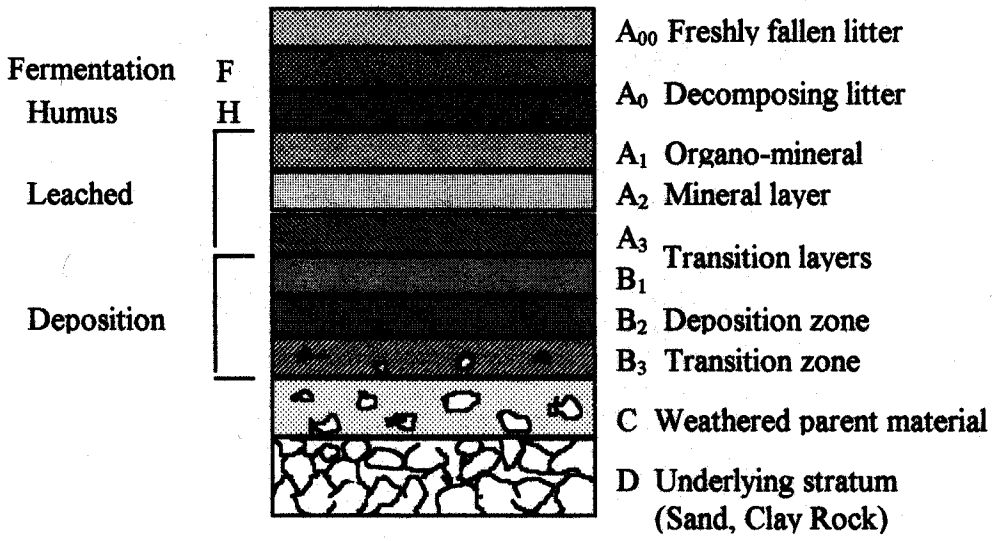

Figure 61 Soil Layers and Horizons