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Estimating the Postmortem Interval in Freshwater Environments

Billie Lee Seet
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Billie Lee Seet entitled "Estimating the Postmortem Interval in Freshwater Environments." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Anthropology.

Lee Meadows Jantz, Major Professor

We have read this thesis and recommend its acceptance:

Walter Klippel, Richard Jantz

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Acceptance for the Council:

_____Anne Mayhew___________
Vice Chancellor and Dean of
Graduate Studies

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Estimating the Postmortem Interval in Freshwater Environments

A Thesis
Presented for the
Master of Arts
Degree
The University of Tennessee, Knoxville

Billie Lee Seet
August 2005

Dedication

This thesis is dedicated to my grandparents, Mary Lou and David William Hess.

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Abstract

Forensic investigators often deal with human remains recovered from water. Estimating the time since death for bodies that have been submerged in water can be quite difficult because there is a lack of data on the subject. This preliminary study was intended to provide additional data through the use of record research. Autopsy reports containing cases in which human remains were recovered from bodies of freshwater were used. Thirty-one variables were collected from each report in a present/absent context. Nine of the variables were then used in logistic regression analyses in order to measure their relationship to time in water. Results from this research indicate that only three of the variables were significant and the time since death estimate can only be made in large time intervals. The three variables: purge, hair slippage, and marbling can narrow the postmortem interval to either 48 hours or less or greater than 48 hours.

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Chapter 1: Introduction

Anthropological interest in research concerning the estimation of time since death is a fairy new endeavor. It dates back to the early 1980s at the University of Tennessee when Dr. William Bass and his graduate students attempted to chronicle the process of decomposition and its relationship to insect activity. This project provided the first systematic documentation of the process of decay using human subjects rather than animal subjects (Bass and Rodriguez 1983). Results from this research used to estimate the postmortem interval have been useful to forensic investigators when trying to estimate the time elapsed since death. This early research spawned a new interest and new era of study in forensic anthropology.

Time since death research is of anthropological significance because of its important role in the identification of human remains. Long before time since death studies were being conducted, physical anthropologists were providing forensic assistance in investigations. In fact, research in the field of forensic anthropology dates back to 1878, when Thomas Dwight, M.D. published *The Identification of the Human Skeleton, a Medicolegal Study* (Pickering and Bachman 1997). Often, human bodies are recovered in advanced decompositional stages and crime scene investigators need specialists, such as anthropologists, to aid in identification.

The answers that anthropologists can provide help to limit a search in a forensic investigation quite dramatically. If an osteobiography and the time since death of a victim can be estimated then the list of potential victims and suspects can be narrowed down. This information is vital both to the authorities involved in a case as well as to the victim's family.

The process of decomposition is a highly sensitive process. There are many factors that affect it, the most common of these being temperature, humidity, scavengers, and trauma (Mann *et al.* 1990). Temperature is the most influential (Mann *et al.* 1990). It has the ability to either increase or decrease the speed of which decomposition occurs; extreme cold can even halt the process entirely (Mann *et al.* 1990). Humidity is also very important and works in concert with temperature and scavenging (Mann *et al.* 1990). When the temperature is warm or hot and the humidity is high, invertebrate scavenging is at its peak (Mann *et al.* 1990). If humidity is high during the colder months, scavenging is slowed (Mann *et al.* 1990). Low humidity has a similar effect as low temperature; invertebrate activity is slowed and decomposition can even discontinue (Mann *et al.* 1990). Vertebrate and invertebrate scavenging both lead to an increased rate of decomposition because the more scavenging that take place, the less remains there are to decompose. Lastly, trauma can influence decay because the odor released from open wounds acts to attract scavengers (Mann *et al.* 1990). It is important to note that while each of these factors can be influential independently, it is their coordinated effort that is important when deciphering the postmortem interval (Mann *et al.* 1990).

Most research done on the estimation of the postmortem interval has focused its interest on the process of decomposition in terrestrial environments. There are a large number of studies that document decay on land in many different seasons and under many different conditions. This research, although very important, leaves one forensic scenario open to questions. This scenario entails the decomposition of bodies that have been submerged in water. Forensic recoveries from bodies of water are quite common, but studies documenting this phenomenon are still uncommon.

There is one important reason for this lack of research; it can be difficult to simulate an authentic environment. Water temperature, depth, water chemistry, salinity, and aquatic life are just a few of the numerous variables that would have to be controlled for in an experimental setting. Each of these variables, independent of each other as well as combined, is known to have an effect on the rate of decomposition. In actualistic studies, there is always the possibility that the non-authentic environment could have a causal effect on the outcome.

The research that has been conducted on decomposition and time since death in aqueous environments has had three main foci: adipocere production, insect activity, and taphonomy. While adipocere and insect activity have been emphasized more often in the literature, taphonomy still lacks in abundance. Taphonomic research that has been conducted has centered mostly on data gathered from autopsy reports. This type of research is valuable because it documents actual cases in authentic environments. The variables that occur in these cases can be contributed solely to the environment of which the body came. This is important when interpreting results from a research design. This previous research, focusing on forensic cases, attempts to understand both the process of decomposition in the environments from which the cases come and how it differs from that on land. While much of this research documents the postmortem changes seen in bodies that have decomposed underwater, it does not attempt to estimate the postmortem interval based on these changes.

This study will attempt to correlate the two, postmortem changes and time since death, in order to predict one from the other. If time since death can be predicted by postmortem changes, then an accurate estimation of time since death is possible in situations where a body has been recovered from water. The data contained within this thesis come from autopsy reports of deaths that have occurred in the rivers and lakes of East Tennessee. All the information comes from freshwater cases. This thesis will attempt to answer the following research questions:

1. Can the postmortem changes that occur in aqueous environments be expected to occur in a normal sequence?
2. If the answer to the previous question is yes, can that sequence be assigned to time intervals?
3. Can the postmortem changes that occur in aqueous environments provide an accurate estimate of time since death or time since submergence?
4. What changes in evidence collection at crime scenes and during autopsies could lead to more a more accurate establishment of time since death or time since submergence?

This thesis will attempt to offer an analysis of the timeline of which postmortem changes can be expected to occur in aqueous environments. If a timeline can be produced, these descriptions will be able to be used as criteria in estimating the postmortem interval in future forensic investigations that take place in similar environments.

Chapter 2: Literature Review

Previous research concerning the process of decomposition in aqueous environments has focused on three distinct aspects: adipocere formation, insect succession, and taphonomy. These three foci have been presented in a number of ways using a variety of species. The two most common research designs utilize the domestic pig and humans. Pigs have been used for actualistic studies while humans have been used in descriptive analyses of case studies. This chapter will summarize the range of research published on the decay process associated with aqueous environments.

The formation of adipocere has been documented in the process of decomposition for a very long time. The early papers, published in the mid to late 19th century, were simply case studies written by doctors describing what they thought were "remarkable" or "unusual" findings. These cases were simply physical descriptions of individuals whose bodies have undergone substantial conversion to adipocere during decomposition (Mansfield 1800; Dalton 1859; Gandy 1884).

Following these early descriptive articles, Mant and Furbank (1957) published a paper outlining the history of descriptive analyses of adipocere formation as well as the current understanding of the factors that influence this formation in earth burials. While Mant and Furbank's (1957) descriptions and explanations of adipocere are thorough in their analysis of earth burials, adipocere formation in aqueous environments was not discussed.

Evans (1962) also describes the process by which adipocere forms in dry and mostly dry environments. He states that because his sample size was small, absolute conclusions could not be drawn, but "tentative indications [were] possible." He found that adipocere is more likely to form in females and that it can form during both the warm and cool seasons, although it is less likely to in very cold temperatures. Lastly, Evans (1962) found that the preinhumation period does have an effect on the formation of adipocere; it is more likely to form if the weather between death and inhumation is "foggy and hazy." He did not find a correlation between adipocere formation and age at death or adipocere formation and time elapsed between death and burial (Evans 1962).

In his book, *The Chemistry of Death,* Evans (1963) discusses factors influencing adipocere formation in and out of aquatic environments. He includes the temperature and humidity at the time of death as well as the temperature and humidity during the time between death and burial as important influences (Evans 1963). He also discussed the state of expected adipocere within different types of environments. He says submerged bodies will have soggy adipocere while earth burials will have friable or brittle adipocere (Evans 1963). Again, he found no connection between adipocere formation and age at death or time elapsed between death and burial (Evans 1963).

Adipocere formation was once thought to take at least three months to form. A case study describing an individual found washed up on the beach close to the German and Danish border on the North Sea served to narrow that timeline (Simonsen 1977). The man, whose body had undergone substantial conversion to adipocere, had died only 22 days prior (Simonsen 1977). This unusual rapid transformation is thought to be due to the extreme heat that occurred that summer (Simonsen 1977). Since the postmortem interval could be accurately pinpointed due to the circumstances of the accident (it was a plane crash), the timetable of which adipocere was known to form in marine environments was narrowed to three weeks (Simonsen 1977).

Mellen *et al.* (1993) performed an experiment, submerging human adipose tissue under water in temperature-controlled settings, in order to better understand the characteristics of which adipocere forms under and how temperature and clothing affect the formation Their results were similar to what Evans (1962) had found earlier; adipocere forms in both cold and warm temperatures, but the formation occurs more quickly in warm water. In cold water adipocere can take as long as 12 to 18 months whereas in warm water it can form in as little as two months. They also found that clothing accelerates the conversion to adipocere (Mellen *et al.* 1993).

In a project conducted at the University of Tennessee's Forensic Anthropology Research Facility, O'Brian (1994) looked at adipocere formation in an aquatic environment in order to correlate it to time since death (O'Brian 1994). Using human subjects, he submerged them in water in artificial holes dug in the ground. His results indicated that adipocere formation can occur in just five to six weeks if the ambient temperature or water temperature is "between 70 and 113 degrees Fahrenheit" (O'Brian 1994:vi).

Later, O'Brian (1997) looked at the effects of water currents on bodies. He focused specifically on temperature, taphonomy, and adipocere formation in order to illustrate the taphonomic signatures of a lake setting (O'Brian 1997). He discussed abrasions left on bone by sand through way of water currents, the formation of adipocere, and whether these two factors can aid in the estimation of the postmortem interval (O'Brian 1997). His conclusions indicated that there is still a need for "systematic documentation for both the discovery and the condition of remains in future forensic cases" in order to accurately correlate taphonomy to time since death (O'Brian 1997).

Kahana *et al.* (1999) presented a case study that involved the recovery of a number of individuals at different times from a single accident in order to discuss the timing of the formation of adipocere in marine environments. Over the course of 433 days, 15 bodies were recovered. In addition to adipocere formation, data concerning other postmortem changes were collected. These data included the presence or absence of washerwoman skin, marbling, slippage, discoloration, purge, and the stage of decomposition (Kahana *et al.* 1999).

Two bodies were recovered within the first 48 hours in the fresh state with the presence of washerwoman skin. Three more individuals were recovered within 25 days of death. These bodies had the presence of marbling and slippage and were in the bloat stage of decomposition. After another 13 days, making time since death now 38 days, one more victim was found. This body was also in the bloat stage and had the presence of slippage, discoloration, "focal adipocere," and purge. A month went by before two more victims were found. These bodies had the same postmortem changes, except the formation of adipocere had become more extensive. After 109, days three more bodies were found exhibiting complete conversion to adipocere and were covered by a "thin friable crust." The last four bodies were recovered 433 days after death and were partially skeletonized with a substantial conversion to adipocere described as a "thick friable crust" (Kahana *et al.* 1999).

The results from this research contradict information gathered from other research in marine environments (Kahana *et al.* 1999). In this case, adipocere formation occurred in low temperatures within 38 days, which is relatively short period of time (Kahana *et al.* 1999). The authors discuss this discrepancy by stating further research concerning the "taphonomic clock in marine environments" still needs to be conducted (Kahana *et al.* 1998).

The research concerning the entomology of decaying corpses in aqueous environment has only been conducted for a short time, beginning in the 1970s. These studies describe the succession of insects and other anthropods found in the process of decomposition in aqueous environments. These descriptions aim to understand the correlation between insect succession and the rate of decomposition in order to estimate the time since death or time since submersion.

Payne and King (1972) conducted an experiment with 11 fetal pigs. Using metal tanks as containers, they submerged each of the pigs in water (Payne and King 1972). The data collected included "physical condition, odor, color, and the number and kinds of anthropods on or near the carcass" (Payne and King 1972). The internal temperature, the water temperature, and the ambient air temperature were also noted (Payne and King 1972).

As a result of these experiments, Payne and King (1972) formed a list of insects they found associated with carrion as well as what they found to be an expected model for underwater decomposition. Their model includes six distinct stages (Payne and King 1972). These stages are:

1. ***Submerged Fresh:*** *characterized by initial sinking. One to two days up to two to three weeks (temperature dependent). No insects are present on the remains.*
2. ***Early Floating:*** *the distended abdomen is usually the first part above water. Blowfly eggs were laid immediately and in a higher frequency than recorded on pigs of the same size on the ground. Other insects congregate to feed on eggs. Viscous bubbles on the surface from gasses let out the mouth, nose and anus; odor pronounced; quick discoloration to skin exposed to air.*

3. ***Floating Decay:*** *blowfly eggs hatched and larvae present on the exposed skin. Body orifices under water preventing entrance by the larvae until holes in skin created by other insects feeding on the maggots. During this stage the larvae disappear under the skin. Egg laying ceases and beetles begin to congregate in search of food. They were present mostly at night.*
4. ***Bloated Deterioration:*** *maggot activity increases; as tissue is removed carcass begins to sink; layers of froth cover water. Beetles feed on what maggots are left as carcass sinks.*
5. ***Floating Remains:*** *few anthropods left at this point; this stage is variable in time depending on the frequency of anthropods present. Large number of dead maggots floating in water. Stage ends when remains sink.*
6. ***Sunken Remains:*** *bacteria and fungi complete the process. Only bones and bits of skin remain.*

Insects from four Orders were observed on carrion or feeding on the carrion-eating insects (Payne and King 1972). These include Hemiptera (true bugs), Coleoptera (beetles), Lepidoptera (butterflies and moths), and Diptera (flies) (Payne and King 1972). *Genera* and *species* from these Orders were presented, but are not included here because they differ from region to region.

The rate of decay was found to vary between the 11 carcasses. Although the rate differed, each of the carcasses was observed passing through all of the stages (Payne and King 1972). Due to the difference in timing, only generalizations were made about the actual rate of decay (Payne and King 1972). This research provided the first systematic study of the rate of decomposition and expected insect succession in aqueous environments (Payne and King 1972).

MacDonell and Anderson (1997) conducted a similar experiment, except they used a natural environment and incorporated clothing into their research design. The authors describe the environments as a lake habitat and stream habitat. Their research also included controlled carcasses that were left undisturbed in addition to the experimental carcasses from which they collected data. Data collection consisted of water chemistry, water temperature, scavenging by invertebrates, and the rate of decomposition (MacDonell and Anderson 1997).

This preliminary research indicated that there was little or no difference between the disturbed and undisturbed remains (MacDonell and Anderson 1997). The rate of aquatic decomposition was found to be slower than that of terrestrial sites described in previous research (MacDonell and Anderson 1997). The authors credit this difference to the lack of a maggot mass and the cooler temperatures of the water (MacDonell and Anderson 1997). They also found that in the stream habitats where the carcass had partial exposure the clothing did not effect scavenging, whereas in the lake habitat, where the carcass was completely submerged, clothing acted to restrict scavenging (MacDonell and Anderson 1997).

Haskell *et al.* (1989) described a number of ways to estimate the submergence interval of a body by interpreting species-specific habits. For example, the midge (Diptera: Chironomidae) is extremely common in freshwater environments and it's previously known life cycle can generate accurate submergence intervals (Haskell *et al.* 1989). Another aquatic insect that helps to establish the submergence interval is the net-spinning caddisfly (Haskell *et al.* 1989). Life history research previously conducted on the caddisfly (Cavanaugh and Tilden 1930 [cited in Haskell *et al.* 1989]) provides a timeline for its structure building, revealing the length of time that the insect has colonized the body (Haskell *et al.* 1989). These results indicate the importance of the use of entomology in determining the submergence interval for a corpse.

Hobischak and Anderson (1999) reviewed coroner cases involving fresh-water death investigations. This research was aimed at establishing the methodology used to determine time since death for local forensic cases and to discover how frequently entomology was utilized in that determination (Hobischak and Anderson 1999). The results of this research indicated that the longer a body was submerged, the less detailed the coroners reports were and that only three out of 23 cases utilized forensic entomology despite the fact that the probability that each case had entomological evidence present was high (Hobischak and Anderson 1999).

Davis and Goff (2000) compared *Decomposition Patterns in Terrestrial and Intertidal Habitats on Oahu Island and Coconut Island,* [in] *Hawaii.* They focused their attention on the relationship of anthropod succession to decomposition in those environments. Their results indicated that while the terrestrial experiment progressed as other studies have done, the intertidal decomposition progressed differently (Davis and Goff 2000). Decomposition at this site was slower, which was thought to be due to the wave activity rather than scavenger activity (Davis and Goff 2000). The initial anthropod occupation was lost when the carcass was submerged (Davis and Goff 2000).

Other research conducted by Hobischak and Anderson (2002) evaluated the utility of looking at different environments to use aquatic insect succession in the determination of time since death or time since submergence. Using pig carcasses, they compared still water pond habitats to that of a flowing stream (Hobischak and Anderson 2002). The succession of insects was similar to what Payne and King (1972) found earlier and the results from the two habitats in this study matched very closely (Hobischak and Anderson 2002). The rate of decomposition was found to be the same between the two sites as well (Hobischak and Anderson 2002).

Additional research conducted on decomposition in aqueous environments focuses primarily on taphonomy. This body of literature contains mostly case studies, which include descriptive analyses of decomposition. These studies ask questions, such as, how does decomposition progress underwater and how does that differ from other types of interments or what activities cause what is known to be signatures of decomposition that has progressed underwater.

Simpson and Knight (1985) discuss the general progression of human decomposition in an aqueous environment. They say that decomposition is slowed in water because the body temperature cools twice as quickly as it does in air (Simpson and Knight 1985). Also, the appearance of cutis anserina or "gooseflesh" can be expected to appear rather quickly because the arectores pilorum muscles contract in response to cold temperatures (Simpson and Knight 1985). Also, since the head sinks lower than the rest of the body, decomposition can be expected to begin there (Simpson and Knight 1985).

They also discuss the onset of postmortem changes found in bodies that have decomposed in water. They say that washerwoman skin appears within ten hours and persists for up to ten days until the skin begins to peel away (Simpson and Knight 1985). It is at this time, they say, that the hair also begins to slip away (Simpson and Knight 1985). Within a month, Simpson and Knight (1985) say that the nails will become loose and following quickly after that, the skeleton will begin to disarticulate. They also address temperature by stating that in the summer months these times may be as short as half of what has been stated (Simpson and Knight 1985).

In 1993, Haglund focused his research on the *Disappearance of Soft Tissue and the Disarticulation of Human Remains in Aqueous Environments.* Using 11 forensic cases, the author was able to design a model of soft tissue removal and an expected sequence of disarticulation (Haglund 1993). In the initial discussion, Haglund (1993) described the various factors that influence the rate of decay and the disarticulation process. First, aqueous environments are highly variable in terms of types of water (fresh or salt), temperature, types of currents, and depth (Haglund 1993). These factors all influence soft tissue removal and disarticulation in different ways (Haglund 1993).

The model for soft tissue removal in aqueous environments is similar to what is found on land (Haglund 1993). Areas on the body with only a thin layer of skin or small amount of tissue covering the bone are the first to be exposed, i.e. "head, hands, anterior tibia" (Haglund 1993). Other factors that have an influence on the rate and placement of soft tissue removal include scavenging and the presence of clothing; scavenging acts to increase the rate of tissue removal while clothing acts to reduce it (Haglund 1993).

His research indicated that the sequence of disarticulation is joint specific (Haglund 1993). More secure joints, such as the vertebral column, endure longer than the more flexible joints, including the wrist, ankle, and arm (Haglund 1993). The general succession of disarticulation in aqueous environments is as follows: the extremities tend to disarticulate from distal to proximal, i.e., first the wrist, then the elbow, followed by the shoulder for the upper extremity (Haglund 1993). The author describes the skull as often the only body part discovered if a body has decomposed in a large body of water (Haglund 1993). The mandible is expected to disarticulate close to the same time as the wrist and the skull similar in time to the elbow (Haglund 1993). Resulting from this research is a model for the expected "pattern of disarticulation of human bodies recovered from aqueous environments" (Haglund 1993).

Rodriguez (1997), like Simpson and Knight (1985), describes what can be expected of a body once it enters the water. He says that decomposition occurs twice as slowly as it does on ground because of the "cooler temperatures and inhibition of insect activity" (Rodriguez 1997). He says once the body has entered the water it can be expected to sink as air seeps out of the lungs (Rodriguez 1997). After all the air has escaped and the body has reached the bottom of its environment, decomposition begins (Rodriguez 1997). Decomposition causes gases and bacteria to accumulate in the gut, which causes the body to begin to rise (Rodriguez 1997). This stage in the process is highly variable because it is temperature dependent; the warmer the water is the quicker this process will occur (Rodriguez 1997). It also depends on the salinity of the water and the bacterial content; salinity slows decomposition while bacteria speeds it up (Rodriguez 1997). Once the body has floated back to the surface, scavengers are attracted to the exposed tissue and begin feeding on the carrion (Rodriguez 1997).

Bassett and Manheim (2002) collected data from forensic cases in order to understand fluvial transport of human remains and in doing so, were able to set up a forensic database of "river victims." Included in their data collection was the stage of decomposition present when the individuals were recovered. They correlated the observed changes with length of time in water and concluded "human remains subjected to fluvial conditions for longer periods of time exhibited more advanced stages of decomposition" (Bassett and Manheim 2002).

Haglund and Sorg (2002) discussed the body of literature that exists pertaining to decomposition in water environments. Their publication concludes that although a significant amount of information about fluvial transport of remains is known, there is a gap in the literature concerning the expected taphonomic signatures in water environments. They stress the importance of future work be concentrated on this aspect through the use of actualistic studies and collection of data from autopsy reports (Haglund and Sorg 2002).

Chapter 3: Materials and Methods

This project involved the use of multiple data collected from forensic autopsy cases. There were two locations of research, each of which provided full access to their forensic cases. These facilities, the Upper East Tennessee Forensic Center at the James H. Quillen College of Medicine in Johnson City, Tennessee and the Hamilton County Forensic Center in the Hamilton County Medical Examiner Office in Chattanooga, Tennessee, provided complete autopsy reports consisting of cases in which individuals had either drowned or whose bodies were recovered from water. The information contained within the reports was used with the intention of understanding the relationship of postmortem changes that have occurred underwater to the postmortem interval.

These two forensic centers were able to provide 69 cases with a known postmortem interval. There were a large number of additional cases included in the original collection, but many of those did not contain a date of death for the individual or a date indicating when the individual was last seen. Without that information, the postmortem interval could not be estimated, resulting in their exclusion from this study. The Johnson City office provided 52 cases with a known postmortem interval and the Chattanooga office was able to provide 17.

Thirty-one variables were collected from each autopsy report. Each variable in this study was actively being recorded by the medical examiners that conducted the autopsies from which the data came. As a result of this, the lack of data regarding any specific variable presented in this text indicates its absence rather than having been overlooked by the medical examiner. With that said, there are a few instances where that logic can be questioned or disputed. For example, odor was sometimes not noted in reports containing a time since death of as many as 720 hours or 30 days. Common sense says that odor must have been present, yet it was not noted by the medical examiner.

A large number of variables were collected, but not all were used in the analysis. For that reason, the data were split into three categories. The first category is made up of informational data; this data consists of demographic information about the victim and the circumstances in which the body was recovered (Table 3.1). The second set of data was collected for use in the analysis, but was later removed for a variety of reasons, which are explained within the data descriptions in table 3.2. The third category of data contains all the variables used in the analysis (Table 3.3).

For the purpose of this research, the data were collected in terms of presence or absence. They were assembled in a binary format where the number one means a trait is present and a number zero means it is absent. This binary format was then used in statistical analyses in order to attempt to answer the research questions previously described. The statistical test chosen was the backward stepwise logistic regression model. The analysis provided by this model correlated the strength of the relationship between the postmortem interval and the presence and/or absence of the variables described above. The statistical program SPSS was used to perform the analyses.

This model is appropriate for data where the independent variable is a dichotomy. In this case the independent variables are the postmortem changes and are scored as either present or absent. The dependent variable is the time since death.

Other analyses using descriptive statistics were performed in order to illustrate the dispersal of the data. This includes finding the average postmortem interval, the mode of the postmortem intervals, the median of the postmortem intervals, the averages for the

Table 3.1. Demographic Data Descriptions

Variable	Description
Age	This is the biological age. In the few instances when skeletal remains were present, an age at death was estimated using anthropological techniques.
Race	The victims' race was usually presented by the officer on duty and by the medical examiner that performed the autopsy. It is presumed to have been collected by either visual observation or from the positive identification found with the victim. In the few instances when skeletal remains were present, race was estimated using anthropological techniques.
Sex	The victims' sex defined by soft tissue characteristics. In the few instances when skeletal remains were present, anthropological techniques were used to determine the sex.
Estimated Weight	Although a scale was used, the weight is an estimate because the process of decomposition affects weight; bloat increases weight while skeletonization decreases it. Often, the weight was recorded in intervals. This was to account for the estimation.
Length	The length of the victim is measured from the top of the head to the bottom of the heel.
Site Description	This is a description of the location where the body was recovered. In most instances recoveries were made from lakes and rivers.

Table 3.2. Descriptions of Data Collected, But Not Included in Analysis

Variable	Description
Body Temperature	This is the core temperature of the body at the time of recovery. This variable was not used in the analysis because it was never stated in absolute terms; the body was either noted as cold or it was not included at all.
Stage of Decomposition	This was considered noted when a general statement was made in the autopsy report in regards to the overall presentation of the body at the time of autopsy, i.e. bloat, advanced decomposition, skeletal remains, etc. This variable was not used in the analysis because it was not noted consistently.
Rigor Mortis	This is "the stiffening of a dead body, as a result of depletion of adenosine triphosphate in the muscle fibers" (Agnew *et al.* 1965:1326). This variable was not used in the analysis because it is known to occur in less than 48 hours, which is how this data was split.
Livor Mortis	This is the "discoloration appearing on dependent parts of the body after death, as a result of cessation of circulation, stagnation of blood, and settling of the blood by gravity" (Agnew *et al.* 1965:847). This variable was not used in the analysis because it is known to occur in less than 48 hours, which is how this data was split.
Ambient Temperature	This is the air temperature at the location where the body was found. This was not used in the analysis because it was rarely noted. When it was present it was noted in general terms, i.e. warm or hot weather.

Table 3.2. Continued.

Variable	Description
Water Temperature	This is the temperature of the water in the area where the body was recovered. This variable was not used in the analysis because it was only noted 11 times out of the 70 cases.
Entomology	This is the invertebrate scavengers associated with the death scene, i.e. flies and beetles. This variable was not used in the analysis because it was only noted eight times out of the 70 cases.
Vertebrate Scavenging	This is the vertebrate scavengers associated with the death scene, i.e. carnivores. This variable was not used in the analysis because it was only noted three times out of the 70 cases.

Table 3.3. Descriptions of Data Used in the Analysis

Variable	Description
Postmortem Interval	For the purpose of this paper, the postmortem interval is defined as the interval of time beginning at the time that the victim was either last seen alive or the time when death occurred until the time when the body was recovered. The time when death occurred is the preferred variable, but in instances where this was not known, the time the victim was last seen alive was used. This variable was recorded in hours.
Clothing	Clothing was considered present if the victim was wearing at least two pieces, i.e. shorts and a shirt. If the victim was wearing only swim trunks or underwear then the victim was considered unclothed.
Cutis Anserina	This is often referred to as "goose-flesh" or "goose-bumps" and can be defined as the "erection of the papillae of the skin, as from cold or shock" (Agnew *et al.* 1965:371).
Washerwoman Skin	This is the swelling and wrinkling of the skin due to water absorption from a prolonged immersion in water (Spitz and Fisher 1980).
Discoloration	This is "caused by [a] lack of effective cardiac pumping of oxygenated blood" (Clark *et al.* 1997:155). It appears usually as a greenish discoloration.
Marbling	"The state of being veined like a marble" (Agnew *et al.* 1965:874). This is a result of "the outlining of superficial blood vessels by the blue color of deoxyhemoglobin" (Clark *et al.* 1997:154).
Skin Slippage	The "postmortem release of hydrolytic enzymes by cells at the dermal-epidermal junction of the skin results in a loosening of the epidermis from the underlying dermis" (Clark *et al.* 1997:153).
Hair Slippage	This is a product of the same process of skin slippage in the area of the head where the hair grows (Clark *et al.* 1997:153).
Sub-cutaneous Gas	This is gas "situated or accruing beneath the skin" (Agnew *et al.* 1965:1455).

Table 3.3. Continued.

Variable	Description
Purge	This is the "regurgitation of gastric contents" and can typically be found in the nose and the mouth (Clark *et al.* 1997:155).
Odor	This variable was noted upon initial observation during the autopsy and was usually described as foul, putrid, or severe. It is the result of "bacterial overgrowth." These bacteria "produce large quantities of malodorous gases as well as pungent aromatic organic compounds" (Clark *et al.* 1997:155).

presence and absence of the postmortem changes, the averages of the demographical data, and the frequency distributions of the data. This information provided the foundation of which the other statistical analyses were taken.

Next, logistic regression was used to predict the variable by the presence or absence of clothing. If the relationship between the two variables could be correlated then the research sample would have to be split into two samples, one group with clothing and the other without. If the postmortem changes could not be predicted than the sample could be pooled. The tests showed that there was no correlation between the two; time since death could not predict whether the likelihood of the appearance of the postmortem changes increased. Characteristics associated with decomposition that have progressed underwater are just as likely to occur on individuals that were wearing clothes as much as individuals who were not.

Once that test was conducted, two analyses testing the relationship between the postmortem interval and the presence and/or absence of the postmortem changes were conducted. The backward stepwise logistic regression test was used and asked the question of whether postmortem changes can predict time since submersion. One analysis was set up to find which of the postmortem changes could be correlated with either less than or more than the median time of submersion, which was 48 hours, and the other looked at the correlation between less than or more than 24 hours. The median time was chosen as the best fit for this model because of the small sample size. The test focusing on 24 hours was chosen because of the uneven distribution of the data. Much of the data consists of postmortem intervals of under 48 hours. If quartiles would have been used the results would have a higher error rate.

The backward stepwise logistic regression presented seven steps or models. Each step contained a classification table that included the percentage of cases correctly classified. The step with the best classification percentage and least number of variables included identifies the strongest correlations. This test also presents the coefficients for each of the steps, which provides a probability result and an odds ratio.

The coefficients generated by this analysis can then be used in an equation to determine the probability estimate of when the death occurred. The equation provides an answer than ranges between zero and one. Zero represents the earlier end of the time interval and one represents the later end of that interval. If the answer falls in the middle at 0.05, then the probability of a death occurring early or late in the postmortem interval cannot be estimated; it is no better than a guess.

The odds ratio is the odds of an event occurring based on the independent variable. So, in this case, the odds ratios are answering the questions of what are the odds that the characteristics associated with underwater decomposition will occur based on time since submersion and what percentage of the time can the correct association be expected to be obtained. The odds ratios should be used in conjunction with the equation to strengthen an estimate.

Chapter 4: Results

Tables 4.1 and 4.2 contain the raw data used in the statistical analyses. Figures 4.1 through 4.13 illustrate the way in which the data is dispersed. The postmortem changes that were collected in each case are illustrated in figures 4.10 through 4.13. The results are presented here by category.

Demographic Data

The demographic information contained within this section is outlined in table 4.1. It contains each of the following variables and the autopsy case with which it is associated. The ages of the victims ranged from age two to age 79. The largest percentage of them fell between ages 30 and 59 (Figure 4.5). They were mostly male; females only accounted for 12 percent of the group (Figure 4.6). Roughly two percent of the victims were Hispanic and Asian, 14 percent were Black, and 84 percent were White (Figure 4.7). The weight of the victims ranged from 60 pounds at the lightest to 250 pounds at the heaviest, but the average weight was 165 pounds and the median was 169 pounds (Figure 4.8). All but three individuals fell between 60 and 79 inches in length. The others measured 37.5, 53, and 57 inches (Figure 4.9).

Statistical Analysis

The postmortem interval ranged from as little as two hours to as much as 1,440 hours or two months. The modes were two hours (observed 14 times) and 48 hours (observed ten times) and the median time was 48 hours. Forty-six percent of the victims were wearing clothing. Sixty-three percent of them were noted as having cutis anserina

Table 4.1. Demographic Data

Observation	Age	Race	Sex	Weight*	Length**	Site Description
FA-91-17	39	White	Male	170-180	70	Nolichucky River
FA-91-18	28	White	Male	150	69	Nolichucky River
FA-98-106	27	White	Male	200	70	Watauga Lake
FA-98-182	42	White	Male	185	68.5	Creek
FA-93-54	2	White	Male	- - - -	37.5	Beech Creek
FA-95-58	68	White	Male	230-240	70	Holston River
FA-96-128	43	Black	Male	175-180	71.5	Backyard Pond
FA-02-166	19	White	Female	100-110	67	Watauga Lake
FA-03-148	53	White	Male	170	71	Nolichucky River
FA-96-175	31	White	Male	150	70	Holston River
FA-91-43	17	White	Male	165-175	69	Nolichucky River
FA-91-101	79	White	Male	200	69.5	Holston River
FA-91-138	29	White	Male	140	68	Farm Pond
FA-90-174	20	White	Male	135-140	72	Nolichucky River
FA-00-106	18	White	Male	- - - -	- - - -	Boone Lake
FA-01-175	38	White	Male	170	73	Nolichucky River
FA-88-116	41	White	Male	155-165	67.5	Boone Lake
FA-93-134	42	White	Male	150	66	Boone Lake
FA-96-133	18	White	Male	135-140	68	Fort Patrick Henry Lake
FA-00-140	22	Black	Male	191	71	Watauga Lake
FA-92-59	31	White	Male	150-160	67.5	Nolichucky River
FA-90-52	40	White	Male	150	66	Holston River
FA-87-47	56	White	Male	- - - -	- - - -	Creek
FA-89-122	23	Black	Male	200	73.5	Rock Quarry
FA-96-233	34	White	Female	110	60	S. Holston Lake
FA-93-100	27	Black	Male	180	66	Boone Lake
FA-88-89	33	White	Male	180-190	71.5	Boone Lake
00-1025	32	Black	Male	220	73	River
FA-94-94	8	White	Male	60	53	Nolichucky River
FA-01-123	- - -	- - - -	- - - -	178-185	71	Nolichucky River
98-1044	43	White	Female	142	71	Home Bathtub
FA-98-07	38	White	Male	200-210	70	Doe River
FA-01-218	22	White	Male	165-175	72	- - - -
FA-94-126	35	White	Male	180	70	S. Holston Lake
04-473	71	Asian	Female	111	57	Home Bathtub
FA-88-161	29	White	Male	135-145	63.5	Farm Pond
FA-88-67	26	White	Male	175-185	70	Lick Creek
97-1430	65	Black	Male	185	70	Tennessee River
94-865	39	White	Male	150	70	Tennessee River

Table 4.1. Continued

Observation	Age	Race	Sex	Weight*	Length**	Site Description
94-866	53	White	Male	169	70	Tennessee River
FA-94-20	28	White	Male	150	66	Rural
FA-96-214	50	White	Male	240-250	67	S. Holston Lake
92-1104	26	Hispanic	Male	192	68	Tennessee River
FA-96-91	77	White	Female	150-155	69	Nolichucky River
FA-97-46	20	White	Male	190	72	Laurel Falls
03-962	36	White	Male	186.5	73	Tennessee River
FA-96-108	37	Black	Male	200	69	Cherokee Lake
FA-94-102	40	White	Male	140	69	Boone Lake
92-1234	35	White	Male	175	- - - -	Tennessee River
FA-97-112	52	White	Male	160	69	Nolichucky River
FA-01-188	35	White	Female	- - - -	- - - -	- - - -
FA-00-241	38	White	Male	168	68	- - - -
FA-99-175	32	White	Male	165	69	- - - -
FA-91-135	31	White	Male	190-200	71	Watauga River
FA-88-124	43	White	Male	165-175	70	Holston River
FA-92-109	26	White	Male	175-180	69.5	Watauga River
94-1540	23	Black	Female	151	62.5	Tennessee River
01-604	43	White	Male	191.5	73.5	Chattanooga Creek
FA-00-24	55	White	Female	115-125	61.5	Fort Patrick Henry Lake
FA-90-05	32	White	Male	150	68	Lick Creek
FA-89-108	53	- - - -	- - - -	160-170	67	Reedy Creek
FA-00-219	36	White	Female	137	64	Boone Lake
FA-90-99	14	Amer-asian	Male	- - - -	69	Holston River
04-606	31	Black	Female	110	62	Tennessee River
93-631	77	White	Male	145	71	Tennessee River
02-1413	34	White	Female	134	70	Tennessee River
92-39	45	White	Male	106	61	- - - -
99-440	35-40	White	Female	- - - -	- - - -	Chattanooga Creek
FA-03-120	50	White	Male	245	71	Watauga River

* Weight in pounds
** Length in inches
- - - Data not included in autopsy report

Table 4.2. Data Used in the Analysis

Observation	PMI	*1	*2	*3	*4	*5	*6	*7	*8	*9	*10
FA-91-17	2	1	1	1	0	0	0	0	0	0	0
FA-91-18	2	1	1	1	0	0	0	0	0	1	0
FA-98-106	2	1	1	1	0	0	0	0	0	1	0
FA-98-182	2	1	0	1	0	0	0	0	0	0	0
FA-93-54	2	0	0	0	1	0	0	0	0	0	0
FA-95-58	2	0	1	1	0	0	0	0	0	1	0
FA-96-128	2	0	1	0	0	0	0	0	0	0	0
FA-02-166	2	0	1	1	0	0	0	0	0	0	0
FA-03-148	2	0	0	1	0	0	0	0	0	1	0
FA-96-175	2	0	1	1	0	0	0	0	0	0	0
FA-91-43	2	0	1	1	0	0	0	0	0	0	0
FA-91-101	2	0	1	0	0	0	0	0	0	0	0
FA-91-138	2	0	1	0	0	0	0	0	0	0	0
FA-90-174	2	0	0	0	0	0	0	0	0	1	0
FA-00-106	3	0	1	1	0	0	0	0	0	0	0
FA-01-175	3.5	1	1	1	0	1	0	0	0	0	0
FA-88-116	5	1	0	0	0	0	0	0	0	1	0
FA-93-134	10	0	0	0	0	0	0	0	0	1	0
FA-96-133	12	0	1	0	0	0	0	0	0	0	0
FA-00-140	12	1	1	1	0	1	0	0	0	1	0
FA-92-59	15	0	0	1	0	0	0	0	0	0	0
FA-90-52	16	0	1	1	0	0	0	0	0	0	0
FA-87-47	19	1	1	1	0	0	0	0	0	0	0
FA-89-122	24	1	0	1	0	0	0	0	0	1	0
FA-96-233	24	0	1	0	0	0	0	0	0	1	0
FA-93-100	24	0	1	0	0	0	0	0	0	1	0
FA-88-89	24	0	0	0	0	0	0	0	0	1	0
00-1025	36	1	0	1	1	0	1	0	1	1	0
FA-94-94	36	0	1	1	0	0	0	0	0	0	0
FA-01-123	36	0	1	1	0	0	1	0	0	0	0
98-1044	36	0	0	1	1	1	1	0	0	0	0
FA-98-07	48	0	1	1	0	0	0	0	0	0	0
FA-01-218	48	0	1	1	0	0	0	0	0	1	0
FA-94-126	48	0	1	1	1	1	0	0	0	1	1
04-473	48	0	0	1	0	0	0	0	0	0	0
FA-88-161	48	1	1	1	0	0	0	0	0	0	0
FA-88-67	48	1	1	1	0	0	0	0	0	0	0
97-1430	48	1	0	1	1	1	1	1	1	0	1
94-865	48	1	0	1	1	1	1	0	1	1	0
94-866	48	1	0	0	0	1	1	0	1	0	0

Table 4.2. Continued.

Observation	PMI	*1	*2	*3	*4	*5	*6	*7	*8	*9	*10
FA-94-20	48	1	1	1	0	0	0	0	0	0	0
FA-96-214	60	0	0	0	0	0	0	0	1	0	0
92-1104	72	0	0	1	1	1	1	0	1	0	0
FA-96-91	72	0	1	0	0	0	0	0	0	0	0
FA-97-46	72	0	1	1	0	0	0	0	0	0	0
03-962	72	0	0	1	0	0	0	0	0	0	0
FA-96-108	72	0	1	1	0	1	1	1	1	0	1
FA-94-102	72	0	1	1	1	1	1	1	0	0	0
92-1234	84	1	0	1	1	1	0	0	0	1	0
FA-97-112	96	0	1	0	1	1	1	1	1	0	0
FA-01-188	96	0	1	1	1	1	0	0	0	0	0
FA-00-241	96	0	1	1	0	1	1	0	1	1	0
FA-99-175	110	0	1	1	1	1	1	0	0	0	0
FA-91-135	110	0	1	1	1	0	0	0	0	0	0
FA-88-124	110	0	1	0	0	1	1	0	1	1	1
FA-92-109	134	0	1	1	1	1	1	1	1	1	0
94-1540	134	1	1	0	0	0	0	0	0	0	0
01-604	158	0	0	0	1	0	1	1	1	1	0
FA-00-24	158	0	1	1	0	1	0	0	0	0	0
FA-90-05	158	0	1	1	0	0	0	0	0	0	0
FA-89-108	170	0	1	0	0	1	1	1	1	0	1
FA-00-219	182	0	1	1	0	1	1	0	1	1	0
FA-90-99	206	0	1	1	0	1	0	0	1	0	1
04-606	206	1	0	0	1	0	1	1	0	0	0
93-631	230	1	0	0	1	1	1	0	0	0	0
02-1413	480	1	0	0	0	0	0	0	0	0	0
92-39	504	1	0	1	1	0	1	1	0	0	0
99-440	720	1	0	0	1	0	1	1	0	0	0
FA-03-120	1440	0	1	0	1	1	1	1	1	1	1

*1: Clothing
*2: Cutis Anserina
*3: Washerwoman Skin
*4: Discoloration
*5: Marbling
*6: Skin Slippage
*7: Hair Slippage
*8: Sub-cutaneous Gas
*9: Purge
*10: Odor

PMI: Postmortem interval is recorded in hours.

0: Characteristic not present
1: Characteristic present

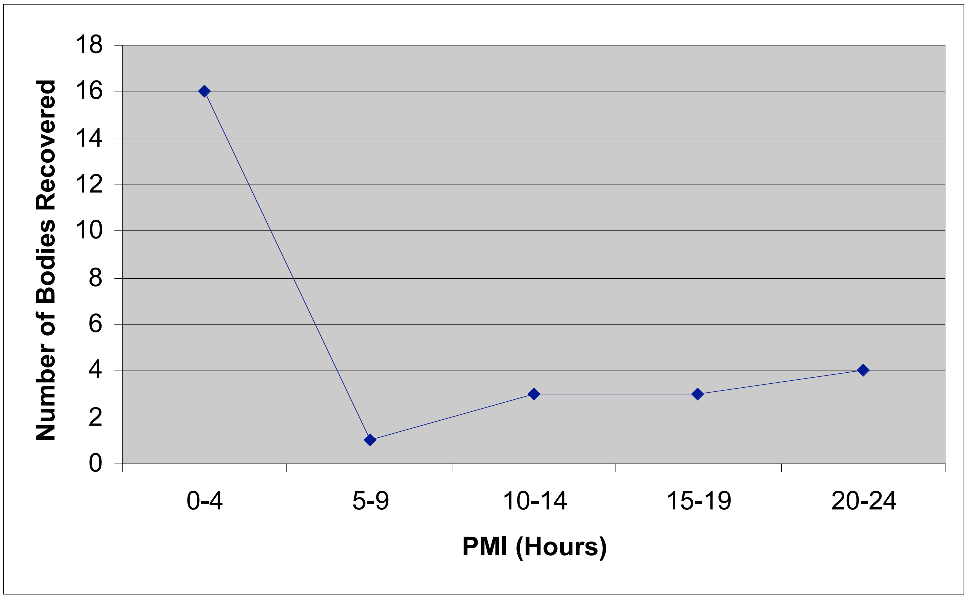


Figure 4.1. Body Recovery Within 24 Hours

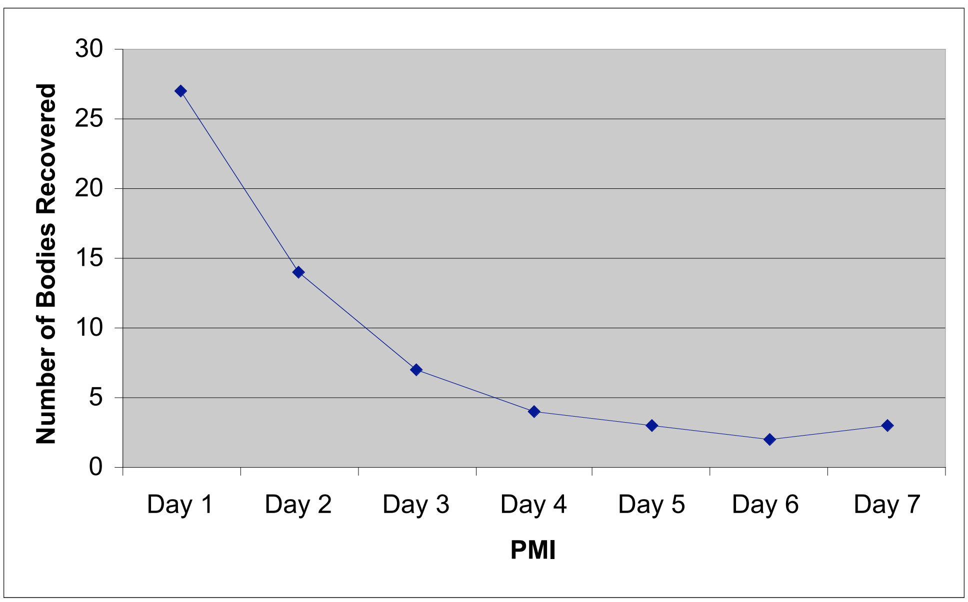


Figure 4.2. Body Recovery Within One Week

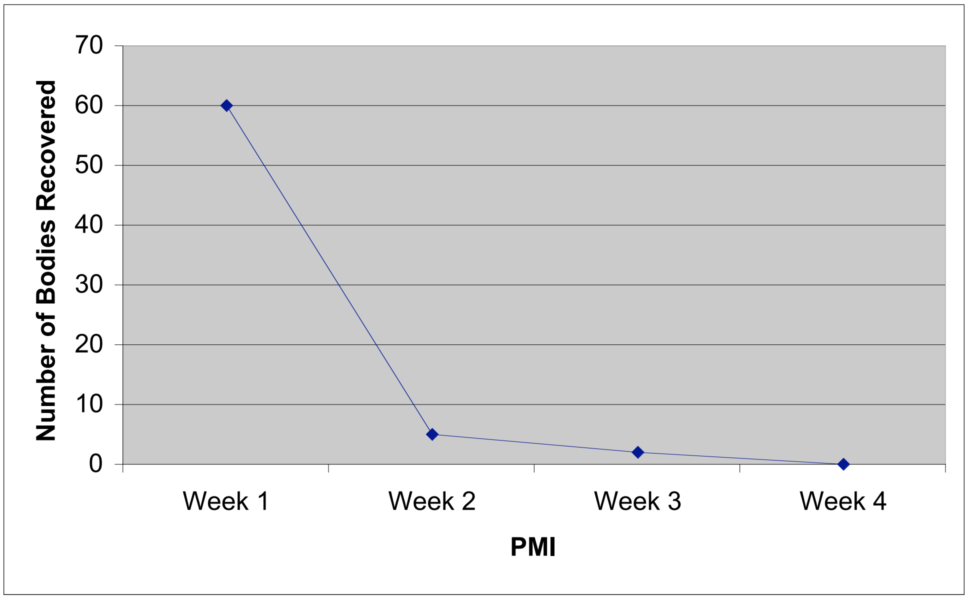


Figure 4.3. Body Recovery Within One Month

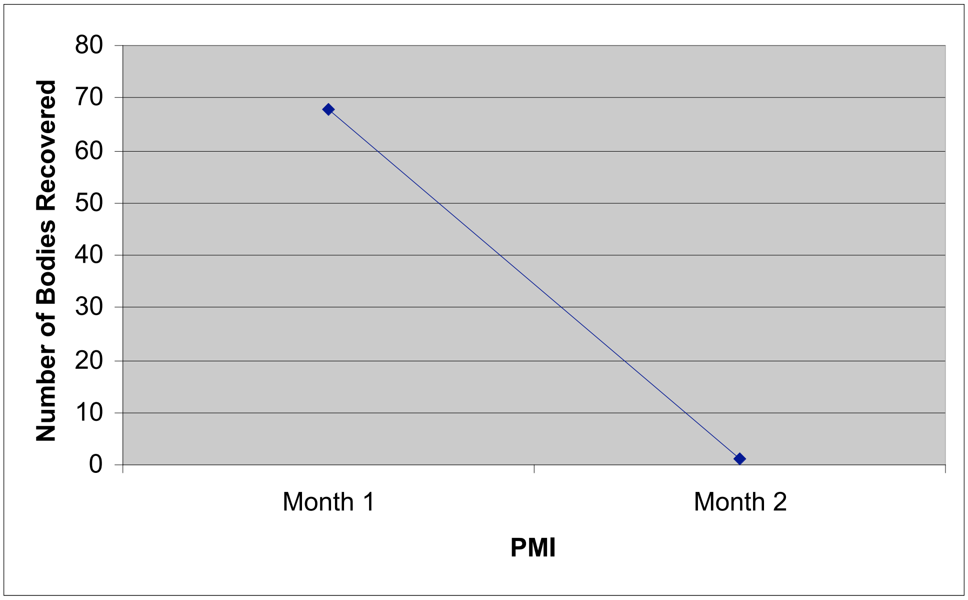


Figure 4.4. Body Recovery Within Two Months

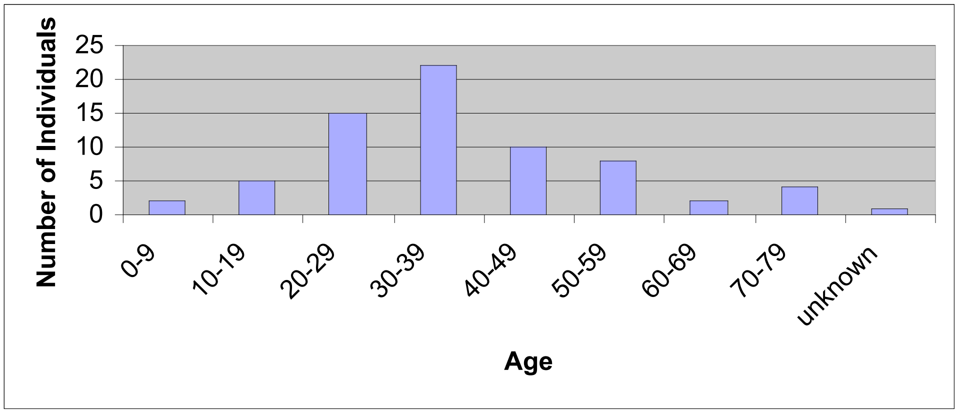


Figure 4.5. Age Cohorts

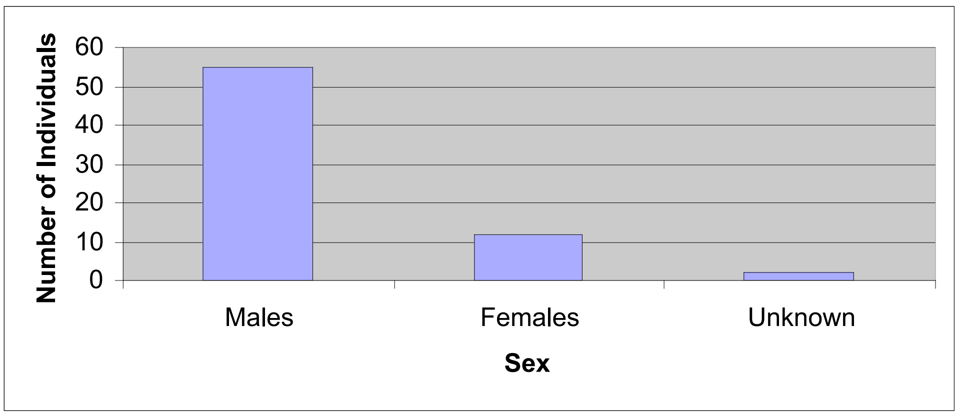


Figure 4.6. Sex Cohorts

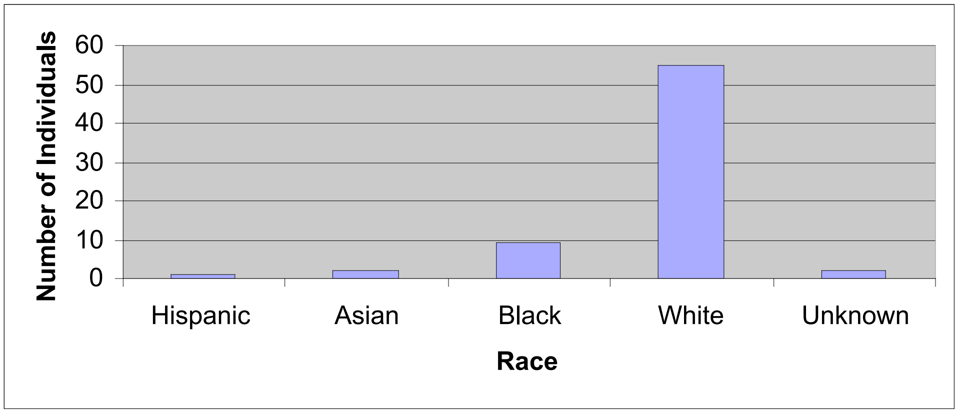


Figure 4.7. Race Cohorts

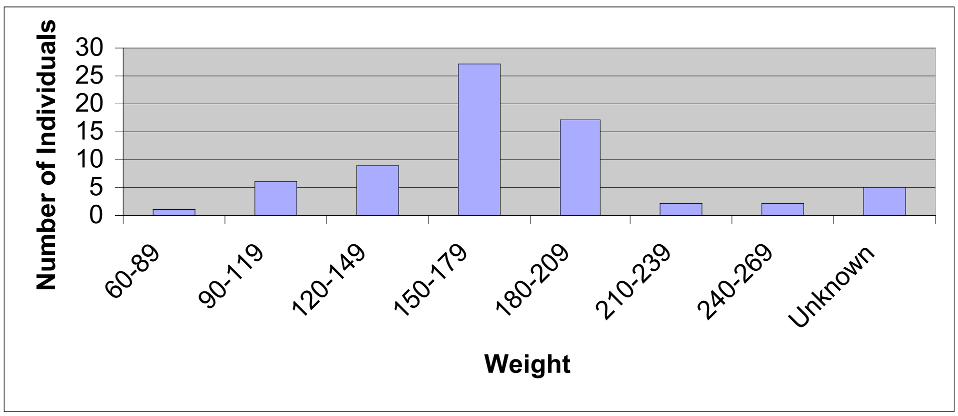


Figure 4.8. Weight Cohorts

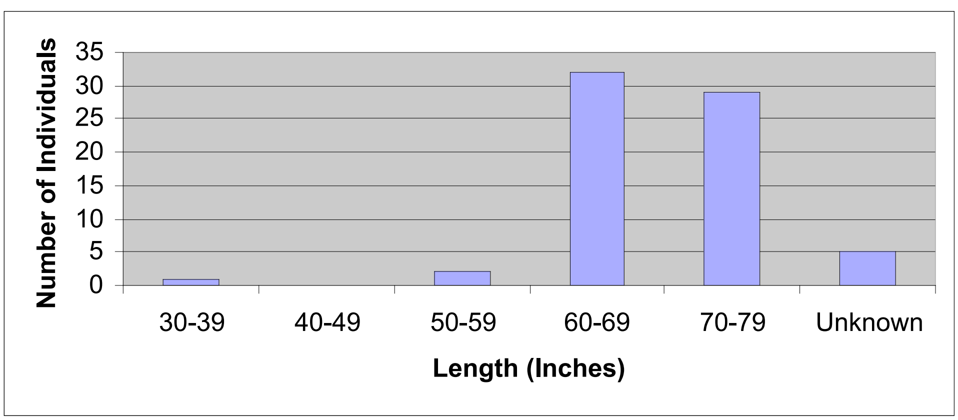
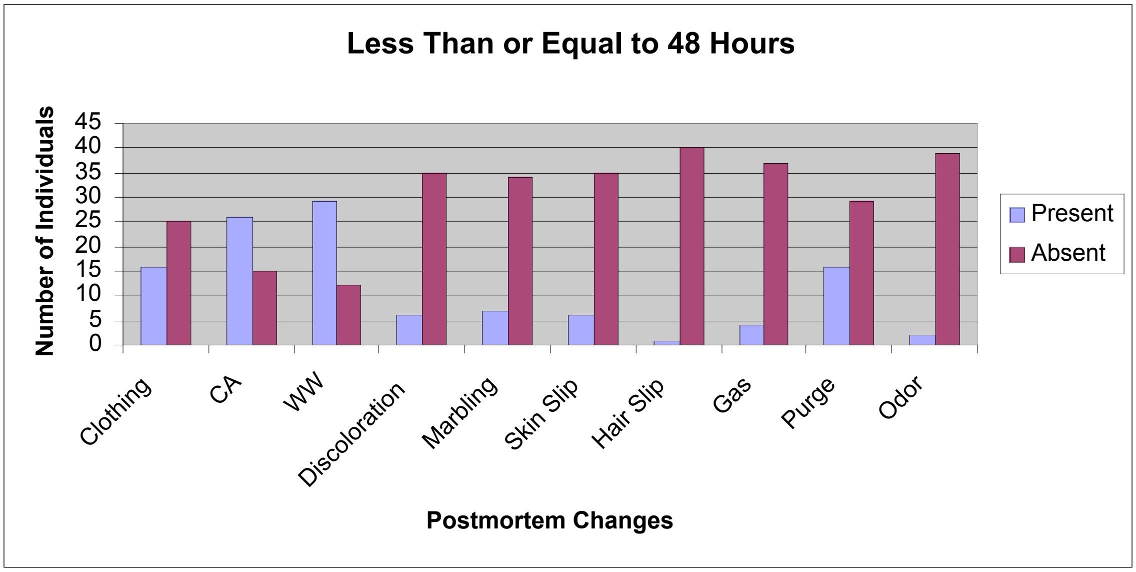
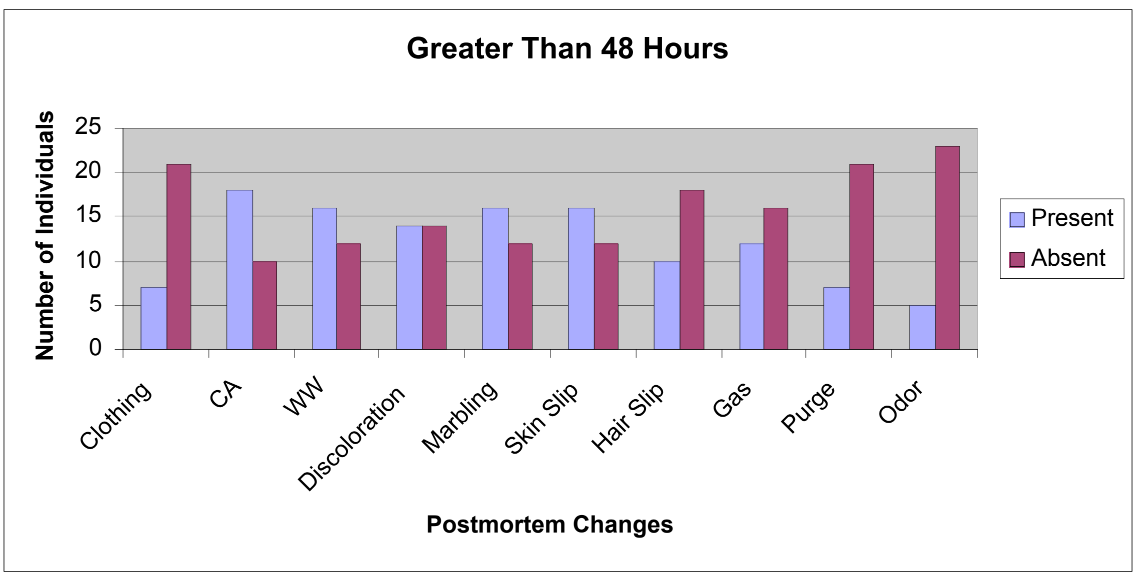


Figure 4.9. Length Cohorts



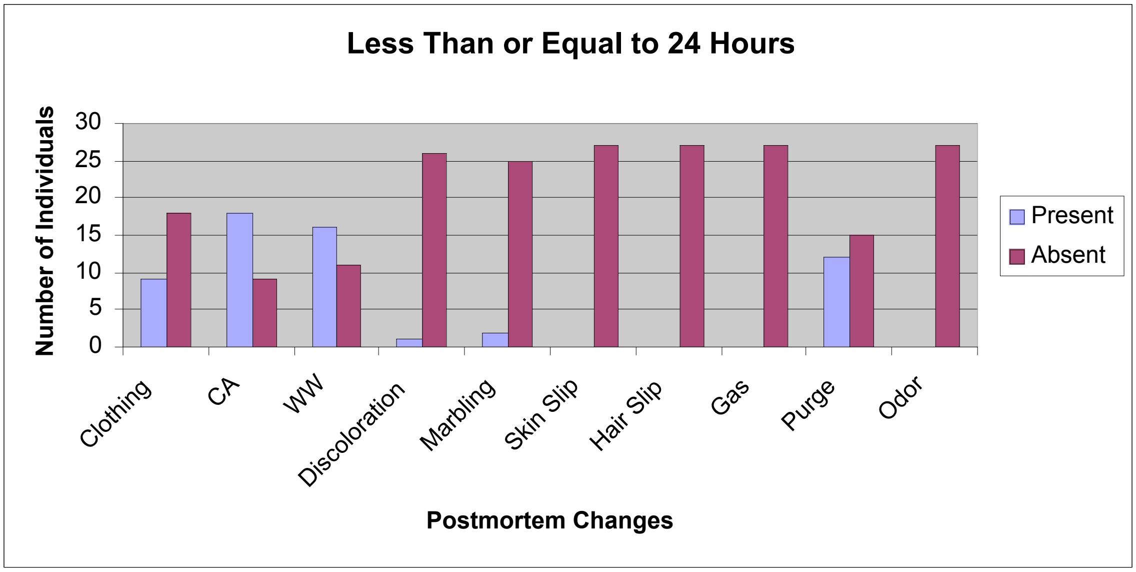
* CA: Cutis Anserina, WW: Washerwoman Skin

Figure 4.10. Postmortem Changes Occurring in Less Than or Equal to 48 Hours



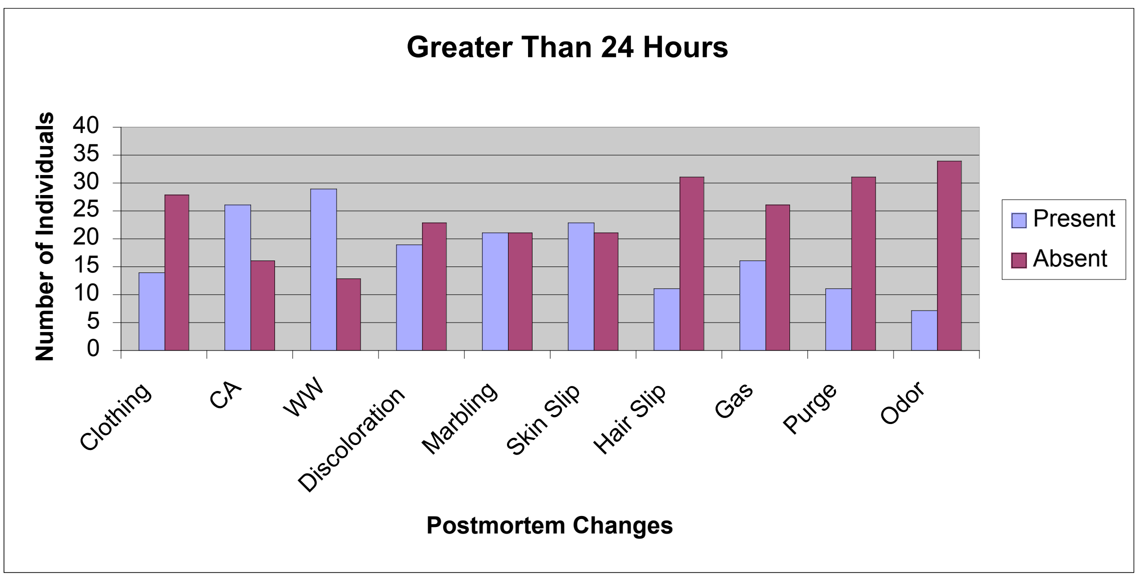
* CA: Cutis Anserina, WW: Washerwoman Skin

Figure 4.11. Postmortem Changes Occurring in Greater Than 48 Hours



* CA: Cutis Anserina, WW: Washerwoman Skin

Figure 4.12. Postmortem Changes Occurring in Less Than or Equal to 24 Hours



* CA: Cutis Anserina, WW: Washerwoman Skin

Figure 4.13. Postmortem Changes Occurring in Greater Than 24 Hours

and 64 percent of them were noted as having washerwoman skin. Only 29 percent of the victims were noted as having discoloration and 23 percent exhibited marbling. Thirty-one percent of the victims were noted as having skin slippage and 16 percent had hair slippage. Twenty-three percent of the victims were noted as having sub-cutaneous gas. Twenty-three percent of the victims were also noted as having purge present in the nose and mouth. Only 11 percent of the victims were noted as having an odor. These data can be seen illustrated in table 4.2 and figures 4.10 – 4.13.

Table 4.3 contains the results from the logistical regression analysis performed in order to understand the relationship between the presence or absence of clothing and the presence or absence of the postmortem changes. This analysis tested if clothing could predict if the postmortem changes would either be present or absent. It concluded that clothing is not a good predictor of any of the postmortem changes except for cutis anserina. Cutis anserina is 3.968 times more likely to be present when clothing is not present.

The first backward stepwise logistic regression test performed provided seven steps analyzing the data on the basis of the median time of 48 hours. Step four had the highest classification rating and therefore was the best model for this data set. The results of this test are presented in tables 4.4 and 4.5. Step four had the best overall percentage score of 81.2 percent. However, the percentage correct was far better on scoring the correlation when looking at postmortem intervals of less than or equal to 48 hours. One can be expected to correctly classify an individual as having been dead for 48 hours or less 92.7 percent of the time. Once an individual has been dead longer, the percentage drops to 64.3 percent.

Table 4.3. Clothing as a Predictor of [the variable].

Variable	Omnibus Test	P - Value	Wald Test	P - Value
Cutis Anserina	6.954	0.008	6.68	0.010*
Washerwoman Skin	0.091	0.763	0.09	0.764
Discoloration	0.400	0.527	0.404	0.525
Marbling	0.228	.633	0.225	0.635
Skin Slippage	0.061	0.805	0.061	0.804
Hair Slippage	0.025	.875	0.025	0.874
Sub-cutaneous Gas	0.825	0.364	0.782	0.377
Purge	0.004	0.951	0.004	0.951
Odor	0.362	0.547	0.340	0.560

*Significant at alpha </= 0.05

**Cutis Anserina is the only postmortem characteristic that can be predicted by the presence of clothing.

B	Wald Test	P – Value	Exp(B)
-1.378	6.68	0.010*	.252

*Exp^B = Odds Ratio = .252 = 1/.252 = 3.968

Table 4.4. Classification Table (48-Hour Split)

Observed		Predicted		
		Time Median		Percentage Correct
		</= 48 Hours	> 48 Hours	
Step 1	**</= 48 Hours**	34	7	82.9
	> 48 Hours	7	21	75.0
Overall Percentage				**79.7**
Step 2	**</= 48 Hours**	37	4	90.2
	> 48 Hours	10	18	64.3
Overall Percentage				**79.7**
Step 3	**</= 48 Hours**	37	4	90.2
	> 48 Hours	9	19	67.9
Overall Percentage				**81.2**
Step 4	**</= 48 Hours**	38	3	92.7
	> 48 Hours	10	18	64.3
Overall Percentage				**81.2**
Step 5	**</= 48 Hours**	38	3	92.7
	> 48 Hours	11	17	60.7
Overall Percentage				**79.7**
Step 6	**</= 48 Hours**	38	3	92.7
	> 48 Hours	11	17	60.7
Overall Percentage				**79.7**
Step 7	**</= 48 Hours**	38	3	92.7
	> 48 Hours	12	16	57.1
Overall Percentage				**78.3**

Table 4.5. Coefficients (48-Hour Split)

Step	Postmortem Changes	B	P - Value	Exp(B)
1	Odor	-2.341	0.143	0.096
	Clothing w/cutis anserina	-1.742	0.175	0.175
	Constant	-1.348	0.132	0.260
2	Cutis anserina	1.317	0.151	3.734
	Washerwoman Skin	-0.957	0.187	0.384
	Discoloration	0.837	0.413	2.308
	Marbling	1.763	0.068(*)	5.828
	Hair Slippage	2.331	0.091	10.287
	Sub-cutaneous Gas	1.329	0.204	3.779
	Purge	-1.274	0.112	0.280
	Odor	-1.812	0.210	0.163
	Clothing w/cutis anserina	-1.548	0.205	0.213
	Constant	-1.361	0.128	0.256
3	Cutis anserina	0.995	0.203	2.705
	Washerwoman Skin	-0.876	0.221	0.416
	Marbling	2.127	0.016*	8.390
	Hair Slippage	2.821	0.025*	16.792
	Sub-cutaneous Gas	1.108	0.282	3.028
	Purge	-1.248	0.114	0.287
	Odor	-1.929	0.197	0.145
	Clothing w/cutis anserina	-1.755	0.152	0.173
	Constant	-1.054	0.175	0.349
4	Cutis anserina	0.875	0.246	2.398
	Washerwoman Skin	-0.928	0.193	0.395
	Marbling	2.487	0.003*	12.023
	Hair Slippage	2.989	0.016*	19.859
	Purge	-1.067	0.142	0.344
	Odor	-1.519	0.259	0.219
	Clothing w/cutis anserina	-1.947	0.117	0.143
	Constant	-0.905	0.225	0.405
5	Cutis anserina	0.614	0.378	1.848
	Washerwoman Skin	-0.819	0.241	0.441
	Marbling	2.084	0.004*	8.035
	Hair Slippage	2.709	0.026*	15.012
	Purge	-1.138	0.113	0.321
	Clothing w/cutis anserina	-1.713	0.151	0.180
	Constant	-0.768	0.277	0.464

Table 4.5. Continued.

6	Washerwoman Skin	-0.728	0.291	0.483
	Marbling	2.073	0.004*	7.946
	Hair Slippage	2.485	0.032*	11.999
	Purge	-1.179	0.096	0.308
	Clothing w/cutis anserina	-1.509	0.198	0.221
	Constant	-0.421	0.466	0.656
7	Marbling	1.872	0.005*	6.503
	Hair Slippage	2.680	0.020*	14.580
	Purge	-1.093	0.117	0.335
	Clothing w/cutis anserina	-1.656	0.152	0.191
	Constant	-0.855	0.043*	0.425

*Significant at alpha </= 0.05
(*)Close to being significant

Within this analysis only two of the postmortem changes were found to be significant (alpha = 0.05) (Table 4.5). These were marbling (0.003) and hair slippage (0.016). The odds ratios are as follows: marbling is 12.023 times more likely to be present if the individual has been dead longer than 48 hours and hair slippage is 19.859 times more likely to be present if the individual has been dead longer than 48 hours.

The second backward stepwise logistic regression test performed also provided seven steps analyzing the data on the basis of time. In this analysis the data was split to look at less than or equal to 24 hours and greater than 24 hours. The results of this test are presented in tables 4.6 and 4.7. Each step in this analysis had the same overall classification score of 78.3 percent. Step five was chosen as the best model for this analysis. Although step six has the same classification rating and fewer variables present, it did not have any significant variables. Step five, however, has one significant variable. The percentage one can expect to be correct was far better when scoring above 24 hours. One can be expected to correctly classify an individual as having been dead for less than 24 hours only 59.3 percent of the time. Once an individual has been dead longer, the percentage of time one can expect to classify correctly increases to 90.5 percent.

Within this model, one postmortem change was found to be significant (Table 4.7). The significant variable is purge (0.048). The odds ratio for purge is 0.166 which means that purge is 6.024 times more likely to be present if the individual has been dead either 24 hours or less.

Table 4.6. Classification Table (24-Hour Split)

Observed		Predicted: Time Median </= 24 Hours	Predicted: Time Median > 24 Hours	Predicted: Percentage Correct
Step 1	**</= 24 Hours**	18	9	66.7
	> 24 Hours	6	36	85.7
Overall Percentage				**78.3**
Step 2	**</= 24 Hours**	18	9	66.7
	> 24 Hours	6	36	85.7
Overall Percentage				**78.3**
Step 3	**</= 24 Hours**	18	9	66.7
	> 24 Hours	6	36	85.7
Overall Percentage				**78.3**
Step 4	**</= 24 Hours**	16	11	59.3
	> 24 Hours	4	38	90.5
Overall Percentage				**78.3**
Step 5	**</= 24 Hours**	16	11	59.3
	> 24 Hours	4	38	90.5
Overall Percentage				**78.3**
Step 6	**</= 24 Hours**	16	11	59.3
	> 24 Hours	4	38	90.5
Overall Percentage				**78.3**
Step 7	**</= 24 Hours**	26	1	96.3
	> 24 Hours	14	28	66.7
Overall Percentage				**78.3**

Table 4.7. Coefficients (24-Hour Split)

Step	Postmortem Changes	B	P - Value	Exp(B)
1	Odor	18.263	0.999	85378990
	Clothing w/cutis anserina	-0.042	0.962	0.959
	Constant	-0.998	.321	0.369
2	Cutis Anserina	0.102	0.911	1.107
	Washerwoman Skin	0.995	0.242	2.705
	Discoloration	1.656	0.252	5.236
	Marbling	0.522	0.675	1.685
	Skin Slippage	18.714	0.998	1E+008
	Sub-cutaneous Gas	18.845	0.998	2E+008
	Purge	-1.844	0.057(*)	0.158
	Odor	18.240	0.999	83461777
	Clothing w/cutis anserina	-0.42	0.962	0.959
	Constant	-0.998	0.321	0.369
3	Cutis Anserina	0.089	0.918	1.093
	Washerwoman Skin	0.990	0.240	2.690
	Discoloration	1.664	0.246	5.282
	Marbling	0.514	0.676	1.672
	Skin Slippage	18.714	0.998	1E+008
	Sub-cutaneous Gas	18.840	0.998	2E+008
	Purge	-1.848	0.055(*)	0.157
	Odor	18.258	0.999	84976299
	Constant	-0.994	0.321	.370
4	Washerwoman Skin	0.993	0.238	2.700
	Discoloration	1.620	0.234	5.054
	Marbling	0.533	0.661	1.704
	Skin Slippage	18.706	0.998	1E+008
	Sub-cutaneous Gas	18.770	0.998	1E+008
	Purge	-1.871	0.046*	0.154
	Odor	18.319	0.999	90369057
	Constant	-0.925	0.213	0.397
5	Washerwoman Skin	1.082	0.187	2.951
	Discoloration	1.839	0.153	6.293
	Skin Slippage	18.693	0.998	1E+008
	Sub-cutaneous Gas	18.603	0.998	1E+008
	Purge	-1.798	0.048*	0.166
	Odor	18.514	0.999	1E+008
	Constant	-0.961	0.196	0.382

Table 4.7. Continued.

6	Washerwoman Skin	1.146	0.166	3.147
	Discoloration	2.238	0.065(*)	10.259
	Skin Slippage	18.462	0.998	1E+008
	Sub-cutaneous Gas	19.236	0.998	2E+008
	Purge	-1.645	0.059(*)	0.193
	Constant	-1.037	0.166	0.354
7	Discoloration	2.456	0.058(*)	11.653
	Skin Slippage	18.390	0.998	96936298
	Sub-cutaneous Gas	18.810	0.998	1E+008
	Purge	-1.699	0.046*	0.183
	Constant	-0.181	0.635	0.834

*Significant at alpha </= 0.05
(*)Close to being significant

Chapter 5: Discussion

The data presented in this thesis is a direct representation of the types of forensic cases that are associated with aqueous environments that occur in the East Tennessee region. Cases in which bodies have been submerged in water can expect the recovery to occur in less than 48 hours and more likely within the first two hours of death. One possible explanation for the quick recovery time may be associated with the manner and cause of death. Most often, bodies recovered from water have been products of accidental drowning and the circumstances of which the individual drowned are usually cases in which they were swimming with others. The others witness the drowning and are able to call the authorities quickly and identify the area in which to search. This quick reaction time results in a quick recovery time.

With that being said, there are a number of cases included in this paper in which recovery did not occur within the first 48 hours and sometimes did not occur for a total of two months. This longer postmortem interval makes the estimate of time since death more difficult. In any circumstances, the longer an individual has been dead the more difficult it is to estimate the postmortem interval.

Initially this data was split into two categories: individuals with clothes and individuals without clothes. It was thought that clothing might be associated with the presence or absence of the postmortem changes collected in this paper. Through the use of logistic regression, this was shown to not be the case. Only one of those changes, cutis anserina, could be correlated with the absence of clothing. One possible explanation for the correlation is that the presence of clothing acts to prohibit the rapid chilling effect on the skin required for this physical response from the arrectores pilorum muscles to occur.

This result indicates the presence or absence of clothing should not have a bearing on the estimation of the postmortem interval of bodies that have been submerged in water.

The backward stepwise logistic regression that was performed on the median time split of 48 hours revealed the high accuracy that can be expected when a estimating a time since death of less than 48 hours. Using the two most significant postmortem changes as indicators of time since death, if hair slippage and marbling are not present then the individual has probably been dead less than 48 hours. However, if hair slippage and marbling is present, then one can only say with much less accuracy that the individual has been dead longer than 48 hours. The odds ratios are helpful in this analysis in that they illustrate the relative strength of each of these postmortem changes. Since hair slippage is 19 times more likely to appear when an individual has been dead more than 48 hours rather than less than 48 hours and marbling is 12 times more likely to be present on bodies with a postmortem interval of greater than 48 hours then hair slippage is a better indicator of the postmortem interval. However, the presence of both of these postmortem changes can provide a more accurate estimate than if either one was only present by itself.

The next analysis, using backward stepwise logistic regression, split the time interval into less than or equal to 24 hours and greater than 24 hours. The narrower split in the early hours of the postmortem interval was conducted because of the uneven distribution of the data. Much of the data present lies in the time interval of two to 24 hours. The results from this analysis showed that estimating the time since death based on the postmortem changes collected is more difficult if the individual has been dead 24 hours or less than if the individual has been dead 48 hours or less. Estimating a time since death of more than 24 hours, however, becomes significantly easier. This can be attributed to two things. First, the postmortem changes collected in this paper are relatively late changes. In this sense relatively late means simply that they are known to occur after the first 24 hours. Second, the interval between 25 hours and 2,880 hours is quite large and the statistical chance of missing that interval is slim, thus making a time since death estimate of greater than 24 hours very accurate.

The only statistically significant postmortem change within this second backward stepwise logistic analysis was purge. Purge is six times more likely to be present on a body that has been dead 24 hours or less than a body that has been dead for longer. An explanation for this can probably be attributed to the watery environment. Over time purge can be expected to be washed away; therefore, if purge is present in the nose or mouth of an individual who has been submerged in water, the chances of that person having only been in the water for a short period of time are high. The longer an individual stays under water the less likely that individual will have purge present.

An equation can be used to determine the probability of a death having occurred in either the 48-hour time split or the 24-hour time split. The equation is as follows:

Step 1:

$$Z = \text{constant} + B_1\,(0,1^*) + B_2\,(0,1^*) + \ldots B_i\,(0,1^*),$$

*where B is the coefficient for each variable, 0 = an absent variable and 1 = a present variable.

Step 2:

$$\text{Probability} = \frac{1}{1 + E^{-(Z^*)}}$$

*where Z = the answer to the equation is step 1.

The following is an example of how to use this equation. The following data comes from case FA 94-102. The victim had the following variables present: cutis anserina, washerwoman skin, discoloration, marbling, skin slippage, and hair slippage. Clothing, sub-cutaneous gas, purge, and odor were all noted as having been absent. In order to determine the probability that the individual had either been dead for either less than or equal to 24 hours or greater than 24 hours, the following equation must be calculated. The coefficients used within this equation come from step five of the backward stepwise logistic regression analysis conducted on the 24-hour split.

$$Z = -0.961 + 1.082\ (\text{washerwoman skin}) + 1.839\ (\text{discoloration}) + 18.693\ (\text{skin slippage}) + 18.603\ (\text{sub-cutaneous gas}) + (-1.798)\ (\text{purge}) + 18.514\ (\text{odor})$$

$$Z = -0.961 + 1.082\ (1) + 1.839\ (1) + 18.693\ (1) + 18.603\ (0) + (-1.798)\ (0) + 18.514\ (0)$$

$$Z = -0.961 + 1.082 + 1.839 + 18.693$$

$$Z = 20.693$$

$$\text{Probability} = \frac{1}{1 + E^{-(Z^*)}} \quad \text{*where } Z = 20.693$$

$$\text{Probability} = \frac{1}{1 + 0.000000001} = \frac{1}{1.000000001} = 0.999999999$$

This equation provides a probability estimation of .999999999, which means that the likelihood that this individual has been dead for greater than 24 hours is very high.

The postmortem changes collected in this paper, but not found to be significant in the estimation of the time since death are many. Odor, for example, should be correlated with longer periods of time. It is common sense to know that a body that has been dead for longer will have an odor. It is that common sense that may help to explain its non-significance in the analysis. First, the concept of odor and odor strength is difficult to report objectively. What smells strong to one individual may not smell so strong to another. If medical examiners smell strong putrid odors on a daily basis then they may not be as apt to be sensitive to it or as apt to record it. So, it is possible that only the very putrid smelling remains were recorded as having an odor or that on some days the olfactory sense of the medical examiner was more sensitive and it was on those days that odor was recorded.

It is possible that the other postmortem changes either bear no significance on the postmortem interval or that they were confounded during the statistical analyses. The way in which the data was collected did not allow for a correlation between the variables to be measured or for the changes to be measured against real time. If the data could have been measured in a continuous rather than discrete manner a more accurate estimation of time since death may have been able to be made. This change in data collection would, however, rely on the way in which medical examiners collect their data.

Chapter 6: Conclusions

While these data do not illustrate a statistically predictable pattern of events associated with the process of decay in aqueous environments, they do, however answer some useful questions.

Can the postmortem changes that occur in aqueous environments be expected to occur in a normal sequence?

The answer to this question is both yes and no. First, no, the changes cannot be expected to occur in a completely predictable fashion such as insect succession on carrion. That would entail the presence of each of these changes at a given time, regardless of environment and that is not the case. Second, yes, because certain postmortem changes can be expected to occur early on in the postmortem interval and others later. The results from these analyses provide vague expectations of when some of these changes can be expected to occur, thus providing a sort of sequence.

If the answer to the previous question is yes, can that sequence be assigned to time intervals?

The answer to this question is yes, but only if two factors regarding data collection are changed. First, more data would need to be collected. It would need to represent a broader and more complete timeline. In an ideal situation the timeline representing the postmortem interval would represent a normal distribution. Second, the data themselves would need to be continuous rather than discreet. This would enable the data to be correlated with actual time. The discrete nature of the way in which this data is collected makes a real time correlation to the postmortem changes very difficult.

Can the postmortem changes that occur in aqueous environments provide an estimate of time since death or time since submergence?

The answer to this question is yes, but emphasis should be placed on the word estimation. All research estimating time since death is just that, an *estimation*. This research provides loose estimations of a postmortem interval. It allows an investigator to say, sometimes with as much as 90 percent accuracy, that a body has been in the water for less than or more than 48 hours. It also provides an estimate based on 24 hours. It does not, however, provide a narrower interval or a real time estimate.

What changes in evidence collection at crime scenes and during autopsies could lead to more a more accurate establishment of time since death or time since submergence?

There are a number of data currently not collected by both medical examiners and responding police officers that, if collected, could lead to a better basis of which to perform research. The first and most ideal change that could occur would be an established set of guidelines of what information must be collected and how it should be recorded. This would lead to a uniform set of information present in autopsy reports. Second, more information should be included in police reports. The areas for which this information should be written is present on the crime scene reports, but are often left blank. These data include the air temperature, the body temperature, and the climate. Additional data not accounted for on the crime scene report forms, but are just as important are water temperature and the identification of scavengers, if present. Stage of decomposition, even if fresh, should also be recorded either by the responding officer or by the medical examiner. These data have the potential to greatly influence future research and to provide a better foundation from which to conduct statistical analyses.

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Vita

Billie Seet was born in Fort Bragg, North Carolina to her mother Candice S. Harmon. Her mother and her adoptive father, Ray P. Seet, raised her in the San Francisco Bay Area. Billie graduated from Novato High School in June of 1993 and attended many different colleges and studied many different things before deciding on Anthropology and settling into the academic life. She finally received her Bachelor of Arts degree in May of 2003 from San Francisco State University. She then moved to Knoxville, Tennessee to attend graduate school. Billie received her Master of Arts degree in August of 2005 from the University of Tennessee, Knoxville. Ms. Seet is currently seeking employment in any "blue state," but is planning on living in Boston, Massachusetts.