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Decay Rates of Human Remains in an Arid Environment

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ABSTRACT: The environment of southern Arizona with mild winters and hot, dry summers produces great variability in decay rates of human remains. Summer temperatures, which range well over 38°C (100°F), induce rapid bloating as a result of the accumulation of decompositional gases. However, in certain circumstances, the aridity can lead to extensive mummification, allowing preservation of remains for hundreds of years.

A retrospective study of 189 cases, concentrating on remains found on the desert floor or in the surrounding mountains and on remains found within closed structures, outlines the time frame and sequences of the decay process. Remains can retain a fresh appearance for a considerable time in the winter, but the onset of marked decomposition is rapid in the summer months. Bloating of the body usually is present two to seven days following death. Following this, within structures, there is frequently rapid decomposition and skeletonization. With outdoor exposure, remains are more likely to pass through a long period of dehydration of outer tissues, mummification, and reduction of desiccated tissue. Exposure of large portions of the skeleton usually does not occur until four to six months after death. Bleaching and exfoliation of bone—the beginning stages of destruction of the skeletal elements—begins at about nine months' exposure.

Insect activity, including that of maggot and beetle varieties, may accelerate decomposition, but this process is greatly affected by location of the body, seasonal weather, and accessibility of the soft tissues. Carnivores and other scavengers also are contributing factors, as are clothing or covering of the body, substrate, elevation, and latitude.

KEYWOODS: pathology and biology, decomposition, aridity

The arid environment of southern Arizona produces a different profile of decay in humans than previously reported [*1-4*]. The large number of decomposing and skeletonized remains recovered in this region requires a means of estimating interval since death.

Many of the earlier studies have relied heavily on the entomological data [*1-3,5*] in assessing both interval since death and seasonality in decomposition. In addition, a number of

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projects have used nonhuman animals to measure decay rates and document the decomposition sequence [*6–10*]. Since the conditions of exposure in the arid Southwest alter these previously researched sequences, the need for investigation of local delay processes has been recognized.

In this retrospective study, autopsy and forensic anthropological reports and photographs are reviewed with the aim of providing guidelines for estimating period since death based on average decay rates in closed structures, in burials, and in the open.

Materials and Methods

The Human Identification Laboratory of the Arizona State Museum, University of Arizona, has acted as consultant for the Office of the Medical Examiner, Pima County, Arizona, for 20 years. During that time, the anthropological team has examined many remains which have been recovered in various stages of decay. From the records of the laboratory, 470 cases were chosen which have the potential to yield information on the rate of decay. All these cases are under the jurisdiction of the Forensic Science Section, Arizona Health Sciences Center, University of Arizona, which administers the Office of the Medical Examiner. Autopsies were performed by the Medical Examiner's Office in all cases.

Of the 470 cases, 189 are found to have both a last-seen-alive date and a found date and to have photographic documentation as part of either the pathological or the anthropological reports. In most cases, this information necessitated the establishment of positive or strong circumstantial identification of the remains. Since comparative records are less likely to be available as the time since death increases and since other circumstantial evidence is lost during this time, identification becomes more difficult and the number of useful cases in the upper ranges of decay is few. Length of exposure is calculated as the difference between the date the individual was last seen alive and the date the remains were recovered. Overestimation of exposure is probable in many cases.

The photographic documentation, dating from 1981, is available at the Forensic Sciences Section. Photographic slides are taken of almost all cases at the time of autopsy or at the time of examination by the anthropological team. Included are basic identification views as well as documentation of lesions, clothing, trace evidence, and identifying marks. In some instances, these are supplemented in the records by photographs made at the scene by law-enforcement personnel. When more than one set of photographs is available, that taken closest to the time of discovery of the remains is used. Similarly, autopsy reports are available from 1981. Cases prior to that date are traced entirely through records and photographs housed at the Human Identification Laboratory.

The remains are classified into five major categories: fresh, early decomposition, advanced decomposition, skeletonization, and decomposition of skeletal material. The first four categories are roughly equivalent to those outlined by Rodriguez and Bass [*3*]. Within each of these classifications, secondary categories, which do not imply a sequence of events, are established (Table 1) which represent the overall condition of the remains. Remains are judged to be *fresh* when there was no visible trace of maggot activity and no discoloration of the body other than those due to lividity. *Early decomposition* includes remains in which discoloration has begun, and continues through bloating and post-bloating stages. *Advanced decomposition* includes both indicators of moist changes such as sagging of tissue and extensive maggot activity, and the processes of mummification and desiccation. Remains are judged to be *skeletonized* when the majority of the bones are exposed. The final phase, *decomposition of the skeletal remains,* includes bleaching, exfoliation, and cortical breakdown.

In addition to the classification of overall condition, presence/absence data are collected from the photographic evidence of lividity (seen as differential distribution of blood), marbling, skin slippage, maggot activity, Dermestid and other beetle activity, carnivore activity on flesh or bones, and mold on remains or on clothing.

TABLE 1—*Categories and stages of decomposition.*

A. Fresh
   1. Fresh, no discoloration or insect activity
   2. Fresh burned
B. Early decomposition
   1. Pink-white appearance with skin slippage and some hair loss
   2. Gray to green discoloration; some flesh relatively fresh
   3. Discoloration to brownish shades particularly at fingers, nose, and ears; some flesh still relatively fresh
   4. Bloating with green discoloration
   5. Post bloating following rupture of the abdominal gases, with discoloration going from green to dark
   6. Brown to black discoloration of arms and legs; skin having leathery appearance
C. Advanced decomposition
   1. Decomposition of tissues producing sagging of the flesh; caving in of the abdominal cavity, often accompanied by extensive maggot activity
   2. Moist decomposition in which there is bone exposure
   3. Mummification, with some retention of internal structures
   4. Mummification of outer tissues only with internal organs lost through autolysis or insect activity
   5. Mummification with bone exposure of less than one half the skeleton
   6. Adipocere development
D. Skeletonization
   1. Bones with greasy substances and decomposed tissue, sometimes with body fluids still present
   2. Bones with desiccated tissue or mummified tissue covering less than one half the skeleton
   3. Bones largely dry, but still retaining some grease
   4. Dry bone
E. Extreme decomposition
   1. Skeletonization with bleaching
   2. Skeletonization with exfoliation
   3. Skeletonization with metaphyseal loss, with long bones and cancellous exposure of the vertebrae

Autopsy and anthropological reports yield additional information on deposition of the remains. Data are collected on sex, age, and racial affinity of the individual. The latitude and longitude of the location [*11*] of the remains are recorded to the nearest 15′. Elevation is taken to the nearest 500 ft (152 m). Whether the body was fully clothed or covered by other wrappings, partially clothed or unclothed is also recorded. The location of the remains is classed as being within a closed structure, in water, buried (including official cemetery burials with or without embalming), or outside. The final category is subdivided, when possible, into whether the body was in the shade or in the sun.

Because of the retrospective nature of this study, certain errors and inaccuracies must be acknowledged. Since the initial autopsy and anthropological reports were not written with this study in mind, data are frequently missing. Similarly, photographic slides may not be appropriate for full documentation of decay stage. Finally, the slides do not provide information on the extent of internal maggot activity, which is frequently considerable.

Results

Of the 189 cases examined, 23% ($N = 44$) were classified as fresh, 28% ($N = 52$) in early decomposition, 28% ($N = 53$) in advanced decomposition, 15% ($N = 29$) skeletonized, and 6% ($N = 11$) in the final stages of decomposition (Fig. 1). The remains were located within closed structures in 31% ($N = 58$) of the cases, in water 4% ($N = 7$), buried 11% ($N = 21$) (three of which have been embalmed), and in the open air in 51% ($N = 96$) of the cases. In the latter category, 21 could be considered to have been found in shaded areas such as cul-

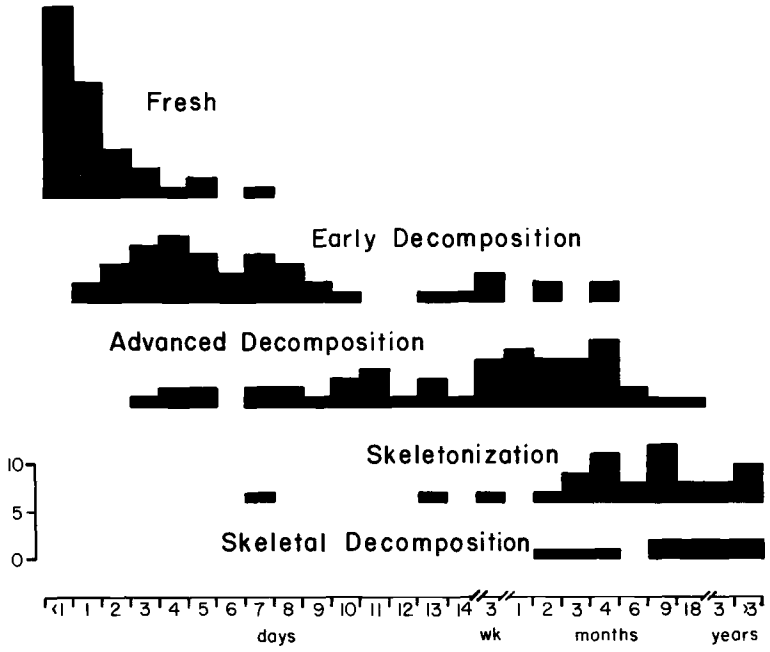

FIG. 1—*Distribution of remains by category and by time.*

verts, in undergrowth, or under rock overhangs. Six cases were found in open, sunny areas. This distinction could not be made in the majority of the open-air cases.

Remains which can be considered fresh, without discoloration or maggot activity, are recorded from the estimated day of death through the seventh day following death. Remains which retain a relatively fresh appearance beyond the day of death are primarily reported during the cooler winter months (November to March). Changes within the fresh category are limited to appearance of lividity. This appears in about half of the cases which were autopsied on the day of death or the day immediately following. By the second day after death, lividity is found in all instances. No insect activity could be detected from the photographs, although deposits of eggs in the nose, eyes, mouth, ears, and genital area, if exposed, have been seen during examination of bodies during this exposure time period.

Early decomposition is first marked by skin slippage and discoloration of the body, either drying of the extremities, marbling, or acquisition of a greenish tint in the abdomen. Earliest reports of this occurs at the first day after death though these first signs of decay may begin as late as the fifth day after death. Maggots tend to appear with the onset of these changes and are noted here by the second day. However, noticeable external maggot activity occurs in only 63% of the cases of early decomposition in which this factor can be assessed. Delay in this stage is again correlated with the time of year, with late fall and winter months producing slower rates of change. Bloating of the abdominal cavity is reported as early as the second day after death and may be accompanied at this point by moderate maggot activity and strong odor. Bloating is generally lost by the seventh day after death, but is recorded as late as the thirteenth day. The final stages of early decomposition are the darkening of the surface and rupture of the abdominal gasses. This stage may occur as early as the third day but are more common after the eighth day following death. In some instances it continues to be found almost two months after death but is only rarely seen after one month. Delay in all these stages may be considerably slowed by burial or submersion in water.

Advanced decomposition begins with the sagging of the tissue and an increase in maggot activity in the thoracic and abdominal cavities as the body fluids drain. This usually appears at the fourth to tenth day following death but may be delayed by temperature. In most cases, this is followed by dehydration of the outer surface of the remains, causing the skin to turn leathery and eventually harden. Despite this surface dehydration, the underlying tissues are frequently moist and may produce a strong odor. Tissue texture changes from one retaining overall structure but which is soft and pliable to one resembling a dark, viscous, adhesive paste. The surface continues to lose moisture until it forms a mummified shell over the skeleton. Maggot and other insect activity continues unabated under this hardened material. Although the onset of this stage can occur as early as the third day following death, it is most frequent between the tenth day and one month. The final stages of this advanced decay are the beginnings of loss of the surface mummification and a marked decrease in maggot activity. Pupal cases are frequently found at this stage, primarily within the body cavities or in surrounding clothing. Molds may appear at the edges of the underlying parts of the body or clothing. This process results in a skeleton with bony exposure of less than half the body. This first appears in the second month following death and may still occur as long as six to nine months following death.

Alternate decay cycles appear to occur in this time period which do not involve mummification. These are mostly found with buried remains and those which are disposed in areas where the humidity is high. In these cases, the onset of advanced decomposition may be rapid, maggot activity extreme, autolysis accelerated, and may quickly lead to skeletonization or adipocere formation.

The fourth category considered in this study is skeletonization. This includes all cases in which exposed bone is found in over half of the body but erosion of the skeletal elements has not yet begun. In a single instance in which the remains were recovered from an extremely warm house in late summer, such exposure of skeletal elements was accomplished within seven days following death. The more normal process of decay is loss of mummified material, leaving desiccated material and exposed skeletal elements. The retention of desiccated material is most common at the points of muscle and ligament attachment, such as along the spine and at the articular ends of the long bones. At this time, evidence of carnivore and other animal scavenging on the bone appears to increase sharply. This stage begins after two months of exposure and is not found in this sample after one year. The most common time period for this stage is two to nine months following death. The final stages of this category are reduction of the remains to bone, with or without some greasy appearance. Although this may appear in some instances as early as the third week, it normally requires over six months exposure. Under protected conditions such as burial or dry shade, this stage can last for many years.

The last stage of decay is reported for remains found outside in unprotected environments. This is the erosion of the skeletal elements, beginning with bleaching, then exfoliation of the outer cortical surface, loss of metaphyseal areas of the long bones and exposure of cancellous bone in the vertebrae, and, finally, reduction of the bones to small fragments. Bleaching first appears in the second month, but becomes more common by the sixth month. Because remains may be moved or uncovered during exposure, the upper limit is not well-documented. The last case reported in this sample is at two and one-half years following death. Exfoliation is reported as early as the fourth month, but may be more likely to begin at around one year to eighteen months. Metaphyseal loss is reported in only one case from this sample, and that occurred after five and one-half years of exposure.

Discussion

Research on decay rates in dog and cat carcasses has been done within the Tucson area [*8*]. A seasonal rotation of blow fly species was noted, with *Pharmia regina* being found during the winter months; the most common summer blow fly was *Cochliomyia macellaria*,

and in the spring, the predominant form was *Phaenicia sericata.* Flesh flies *(Hystricocemina plinthopyga), Calliphora spp.,* and *Sarcophaga cessator* were also reported. A succession of flies was noted beginning with *H. plinthopyga,* which was succeeded by *P. regina* and the other blow fly species. Eggs hatched in about two days and larval stages completed in four to seven days. The larvae required about five days to pupate.

This study also noted the difficulty of insects to infest remains. The sarcophagids, in particular, are greatly influenced by temperature and sunlight, so that a succession of cloudy days prevents egg-laying. After this time, the carcass is often too dried to be accessible. In summer, the eggs must be laid in the shade to ensure viability of the young. In the winter, the warmth of the sun aided the development process. Decomposition rates during the winter were slowed since larvae were only seen to be active during the day. Reduction to skeletal elements was accomplished in one fifth the time during the summer as compared with the winter.

Insect activity is one of the numerous complicating factors which must be recognized in the present study. Unless the insects can lay eggs in the initial stages of decay, much of the surface will dry and become inhospitable to the larval stages, which need both moisture and accessibility to air. This is the most probable reason for the high percentage of cases in early decomposition which do not exhibit external maggot activity. Maggot activity may begin later on the more internal tissues as these become accessible through autolysis.

The primary insect types in southern Arizona are the species of blow flies and flesh flies. Less frequently, larvae of *Piophila casei,* commonly known as "cheeseskippers," are encountered. These are most often found with remains from cooler areas such as northern Arizona or with remains recovered at higher elevations.

Later decomposition is enhanced by the activities of the Dermestid beetles, their larvae, and other beetle forms. These perforate the mummified skin and desiccated tissue. This allows easier separation of the remains by body segment.

Carnivores are another natural factor which can accelerate decomposition of the remains. Most carnivore activity appears to occur during advanced decomposition and initial mummification. Coyotes are the most abundant natural scavenger in the Southwest, but bear, javelina, and packrat also transport bone. In two instances, bear was the suspected scavenger, and, in both cases, the portions of the body were consumed while already well into decomposition. Discovery of isolated elements is common, and careful searches of the surrounding area often yields little, if any, other remains. Coyotes, in particular, are known to transport desiccated body segments to dens or other such locations for consumption. All of these animals will gnaw on bones, which increases the rate at which these elements are lost. Household pets are also a contributing factor to the loss of flesh, especially in remains found within closed structures.

The moisture and temperature to which remains have been exposed is a major area of complication in the estimation of decay rates. As noted in the above results, the time of year at which death occurred must be considered. Southern Arizona enjoys a relatively arid, hot climate with intense summer "monsoon" rains, mild winters with short, relatively gentle rains [*12*]. The nighttime temperatures during the summer remain high, whereas, in the winter, the nights are often close to freezing following a rapid drop from daytime highs. Average high and low temperatures for the Tucson area along with average annual precipitation by month are shown in Fig. 2. Flooding occurs mostly in the summer, but although the waters may rise very rapidly, they recede within one to three days. Large bodies of water are not plentiful except along the Colorado River.

Seasonal differences are seen in the present data. When death is estimated to have occurred during the winter months, the remains retain a fresh appearance for up to a week, and bloating may not occur until about ten days following death if the body has not been within a heated structure. However, despite these differences, the process of dehydration usually ensues so that the sequence of events is virtually identical.

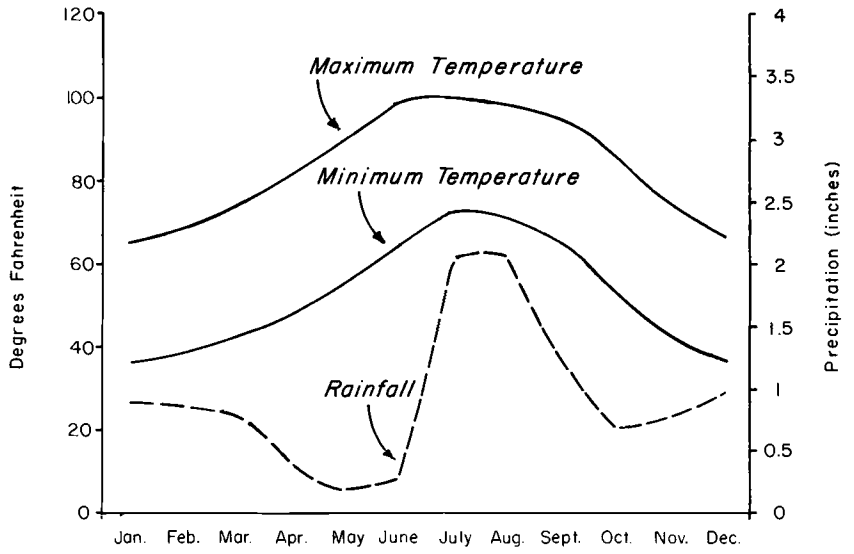

FIG. 2—*Temperature and precipitation ranges for southern Arizona, based on data [12] from the University of Arizona, Tucson.*

At higher latitudes there appears to be a delayed decomposition. However, these results are complicated since these areas are frequently also at higher elevations. They will tend to have cooler temperatures, snowfall, and freezing weather during the winter months and more rain throughout the year. These conditions tend to inhibit dehydration of the soft tissues and decrease insect activity. Carnivore activity may be altered due to a shift in species frequencies at higher elevations and latitudes.

Location of the remains is a prime determinant of exposure to insects [*13*], carnivores, and moisture. Too few cases in this study have been found in water to assess this fully as a medium of decay, so it will not be discussed further. The major location types in this study are open air, closed structure, and burial. Exposure on the desert floor (150- to 1000-m [500- to 3000-ft] elevation) in an unprotected area results in rapid bloating of the remains primarily between the second and fifth day after death (Fig. 3*a*). There is then a transition toward dehydration of the upper surfaces and beginnings of mummification, which is noticeable in most cases by the eleventh day following death and may last until one month. At this point there is gradual loss of the mummified skin which takes about eight months, leaving only skeletal elements. Bleaching and exfoliation of remains begin at about this time and continue until the skeletal elements are greatly reduced. These stages are not mutually exclusive, and there is usually retention of the articular cartilage and adherence of the intervertebral discs even as some bone surfaces are undergoing bleaching and cortical loss. Odor at this point is usually slight.

Confinement within a closed structure presents a different pattern of decay since these circumstances may prevent onset of mummification and accelerate decomposition (Fig. 3*b*). Bodies found with houses, trailers, and other such buildings often show a slower onset of early decomposition. Bodies may retain a fresh appearance for three days following death. Bloating appears usually during the third day following death and is still frequently found at seven days. However, the retention of moisture most often quickly leads to exposure of the skeletal elements. This is usually found by the fourth month after death, but may occur much sooner. In some circumstances in which there is drainage of body fluids or in which air

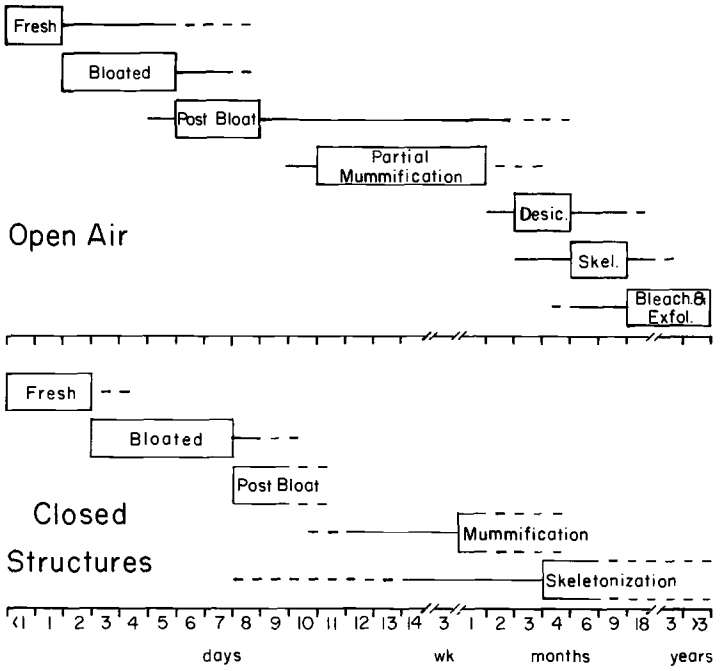

FIG. 3—*Stages of decomposition by time: remains found in open air* (top) *and in closed structure* (bottom).

circulation evaporates much of the moisture, mummification may occur but may require about two weeks longer than if the body had been exposed outside.

Remains interred directly in the soil frequently show signs of very moist decomposition. Skin slippage and fungus development are common. Various stages of adipocere development have been observed even in shallow graves. These remains eventually show loss of all soft tissue, including those at the articular ends of long bones. Frequently there is also loss of much of the "greasy" appearance of the bone and loss of the brain tissues. At this time, decomposition odors are markedly absent. The bones do not show bleaching or exfoliation unless the body was protected from direct contact with the soil. Protected internments usually exhibit adhering pupae cases and may have dehydrated, flaking, dark tissue attached to the bones. This should not be confused with the dehydrated, strongly adherent tissues found with surface exposure. Exposure of shallow burials is common, producing differential decay.

Clothing, bedding, and other coverings also affect the rate of loss. Frequently, clothing is displaced during the bloating stages, exposing the chest and abdomen. However, in those cases in which clothing covered the body, decomposition appeared to be retarded, particularly in the stage of advanced decomposition.

The presence of major defects such as blunt force trauma and gunshot wounds also may contribute to the decomposition of the body. These provide access to the moist portions of the body for the insect forms while also maintaining air contact. However, Burger's study [*8*] suggests that blow flies were less attracted to postmortem incisions than to the natural body openings. This was attributed to the competition for air which would occur under these conditions. This may explain why, in some instances, indications of sharp force trauma are preserved in mummified skin and are not lost to insect activity.

Other factors must be acknowledged to affect the decay process but which could not be assessed due to the limited scope of this study. These include body size and composition, quantity and types of coverings (natural versus synthetic), and changes in the location of the body during exposure.

The detailed research of the University of Tennessee decay facility has provided the medicolegal community with an excellent guideline against which to compare local decay processes and rates. The categories used in the present study correspond roughly with those provided by Rodriguez and Bass [*3*] and allow some comparison of timing and sequence between the locales. Remains exposed to insect activity but protected from rodents and carnivores remained fresh longer in the Tennessee experiment and had a longer period of bloating and greater seasonal variability in these earlier stages than seen in the Southwest. However, the combined decay and dry stages appear to be of shorter duration, probably as a result of the inhibition of insect activity by dehydration seen in the arid areas. Decomposition changes were slowed during the winter months to a greater extent than in the present study. Comparison of decay rates on buried individuals [*4*] is more limited since burial depth data are frequently lacking from the Arizona records. The Tennessee study demonstrated the importance of burial depth in accessibility of the body to insects and carnivores and for significant changes in temperature and alkalinity.

Summary

This retrospective study provides guidelines for estimation of the interval since death based on the decay process in the arid Southwest. The environmental conditions are seen to alter the previously reported sequence and timing of events during decomposition. Exposure outside, with high temperatures and low humidity, accelerates the early decomposition and results in surface dehydration/mummification within two weeks. Insect and carnivore activity gradually reduce these remains to the skeletal elements in four to six months, and bleaching of the bone begins at about nine months. Remains in closed structures show prolongation of the early decay stages but rapid progression to skeletonization by about three to four months following moist decomposition.

Acknowledgments

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