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An Experimental Field Protocol for Investigating the Postmortem Interval Using Multidisciplinary Indicators

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ABSTRACT: This article proposes an experimental field protocol for investigating the postmortem interval using specially designed apparatus and human and pig cadavers. We further propose that this goal can only be achieved by a multidisciplinary group, comprised of forensic entomologists, pathologists, and anthropologists. The apparatus and collecting methods described by the authors establish the means by which data can be collected on several fronts simultaneously: the sequential arrival and variety of insects in the decay process, the character and manner of soft tissue decomposition, the sequence and nature of bone exposure and order of disarticulation of skeletal remains, and the influence of climate and season on decay rates and anthropod succession. A central feature of this protocol involves the construction and use of a dual-functioning insect trap that allows separate but simultaneous capture of arriving and emerging populations while successional and decompositional processes of the cadaver are left intact. Results of trap performance tests in an arid climate and preliminary arthropod data collected from field-exposed pig carcasses are presented. The use of this protocol could provide important and badly needed baseline data for both medical investigators and law enforcement personnel, information that is critical to understanding the causes, manner, and time of death, which the law requires to be ascertained.

KEYWORDS: pathology and biology, postmortem interval, entomology, forensic anthropology, immigration-emergence trap, carrion arthropods, insects, cadaver decomposition, decay rates, ecological succession, trap microclimates

One of the most critical questions in the medicolegal investigation of death is "when did the death take place?" Determination of the postmortem interval (PMI) of the deceased most often falls upon the forensic pathologist. In advanced decomposition cases, a forensic anthropologist may be employed to render an estimate, and in rare instances, a forensic entomologist may be consulted. However, a major difficulty faced by both forensic pathologists and anthropologists is that, as the PMI increases, the accuracy of its determination necessarily decreases.

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On the other hand, the use of entomological indicators has been shown to offer reliable estimates of the PMI, even in cases of advanced decomposition [*1*]. Forensic entomology involves the recognition of arthropods (mostly insects), coupled with their sequential arrival times on a corpse and developmental timetables of their offspring, to estimate the time and sometimes cause of death in medicolegal investigations [*2*].

Carrion insects, aside from their use as PMI indicators, have other medicolegal uses. For example, insect larvae found on the deceased have been employed as poison detectors [*3*,*4*]. Moreover, Goff et al. experimentally showed that flesh-fly maggots of *Boettcherisca peregrina* (Robineau-Desvoidy), when reared on tissues containing different levels of cocaine, displayed markedly shorter total development times compared with untreated controls [*5*]. Further study of the effects of cocaine and other drugs on developmental rates of forensically important insects should be equally revealing. Thus, in cases where body fluids and soft tissues are unavailable for pathological or toxicological analysis or where remains are found in advanced stages of decay, insect data may provide a reliable means with which to detect the presence of specific poisons or drugs from the deceased [*4*].

Despite remarkable progress in forensic science over the last several decades, there are few published experimental data describing the sequential appearance of arthropod species on exposed human bodies (but see Refs *6* and *7*). This type of species replacement, called *heterotrophic succession* [*8–11*], is inextricably linked and concurrent with other processes occurring in and on a corpse (for example, soft-tissue putrefaction, skeletal disarticulation, aerobic decay). Therefore, collection of pertinent natural history data on locally occurring arthropod species, such as daily, successional, and seasonal times of activity and development, is a critical first step in providing accurate baseline data for PMI estimation. Considerable field data on carrion-attendant species have been amassed from every continent and major biome of the world [*12–21*]. However, these investigators used non-primate carrion in their experimental designs, and data interpretations have only rarely included medicolegal implications. For forensic entomology to continue as a predictive science, new experimental and quantitative approaches to the study of arthropod succession using unembalmed human cadavers or an appropriate animal model performed in natural settings are needed. Famed British zoologist K. G. V. Smith makes an urgent plea for an experimental approach to this subject in his *Manual of Forensic Entomology*: "The real need for future research from the forensic point of view is to study the faunal succession on intact human corpses in field conditions" (Ref *22*, p. 50). Although difficulties in procurement and ethical and moral practices attendant on the use of human cadavers are many, such issues must be weighed against interpretive errors that might arise when the estimate is based solely on non-primate carrion data. Investigators have successfully capitalized on the many animal-human similarities of decay and arthropod succession; however, the next challenge lies in discovering how much human and animal (nonprimate) bodies differ and why. Until forensic entomologists, pathologists, and anthropologists can demonstrate that the same body of decay and arthropod data are applicable to all animal species, including man, a rationale for increased experimental study of decomposition and arthropod succession in human cadavers is inescapable. Indeed, experiments represent the only way such a demonstration can be made.

Field Protocol and Research Aims

This paper proposes an experimental field protocol for addressing the time-since-death question using human and pig cadavers. Mention is given to pig cadavers because they are purported by some to be the best human model given their similarities in integument, size of thoracic cavity, and internal features; however, it is interesting to note that there are no published pig-human field studies directed specifically to test that assertion. Furthermore, the determination of decompositional status is not well standardized. Among

the methods which have been tried are the SMELLBAD system [*23*], a rating system devised from Arizona [*24*], and another previously used in New Mexico [*25*].

We further propose that the above goals can only be fully achieved by enlisting and integrating expertise from the pertinent disciplines of forensic science, namely, forensic entomology, pathology, and anthropology. Such a multidisciplinary approach to the study of this complex subject could allow data to be collected on several fronts simultaneously, for example, the succession and the variety of roles of insects in the decay process, the character and manner of soft tissue decomposition, the sequence and nature of bone exposure and order of disarticulation from skeletal remains, and the influence of climate and season on decay rates and arthropod successional trends.

A central feature of this protocol involves the construction and use of a trap that captures both arriving and emerging insects while successional and decompositional processes proceed uninterrupted on the cadaver. Therefore, this paper is largely methodological in scope. We present construction details, field procedures, and results of trap microclimate tests. Also reported are preliminary arthropod data from field-exposed pig carcasses in an arid climate collected during summer and fall 1990. Details of the pattern and process of cadaver decay and arthropod succession for this climate will be presented elsewhere.

General Trap Features

General trap features follow the immigration-emergence trap of Schoenly [*26*], employed previously in ecological studies on small-animal carrion [*19,27,28*]. The trap was chiefly invented to provide separate but simultaneous capture of arriving and emerging (or emigrating) insects with minimal disruption of normal successional and decompositional processes (Figs. 1–4). The chief advantages of this dual-functioning trap are threefold. First, all individual insects entering the trap, and developing on the cadaver, are eventually captured, thus giving the investigator a total census, not a series of smaller (presumably representative) samples. Second, since arthropods are collected continuously and automatically, the cadaver can be left undisturbed for the full duration of the experimental trial. Third, since the cost of collecting arthropod population data is low, finer resolution of the patterns and processes of decay and succession, as well as greater statistical power for hypothesis testing, are possible.

We now describe the overall features of trap operation. Twenty-four ingress funnels, distributed at two heights and spaced equidistantly along all sides of the trap, collect immigrating arthropods omnidirectionally (Fig. 2). Twelve of the 24 ingress funnels direct immigrating insects to 6 baffle-pitfall assemblies and below-ground killing jars (see Fig. 4), while the remaining 12 ingress funnels give insects unimpeded access to the cadaver inside. Once inside, uncollected (and also emerging) insects eventually exit through a pyramid-shaped collector in the roof and 12 egress funnels and killing jars attached to the exterior wall of the trap (Fig. 1). Since the ingress funnels theoretically capture one half of all arriving individuals and the egress funnels theoretically capture all emerging and emigrating individuals, the total cross-sectional area for immigration is two times larger than the total cross-sectional area for emigration (3174 versus 1587 cm^2). An odorless, ethylene glycol-based solution [*29*], added to each of the 19 collecting jars, serves as a general arthropod killing agent and temporary preservative. Access to the below-ground ingress jars is by a system of 6 underground conduits, each fashioned from a three-piece unit of 15-cm (6-in.)-diameter, low-pressure polyvinyl chloride (PVC) pipe. Between collecting trips, the conduit openings are sealed with a PVC end plug. Consequently, jar replacement and servicing do not require periodic hoisting of the trap. This feature also ensures that the active interface between the cadaver and soil surface remains intact throughout the experimental trial and permits arthropod-assisted processes occurring there to proceed in an uninterrupted fashion.

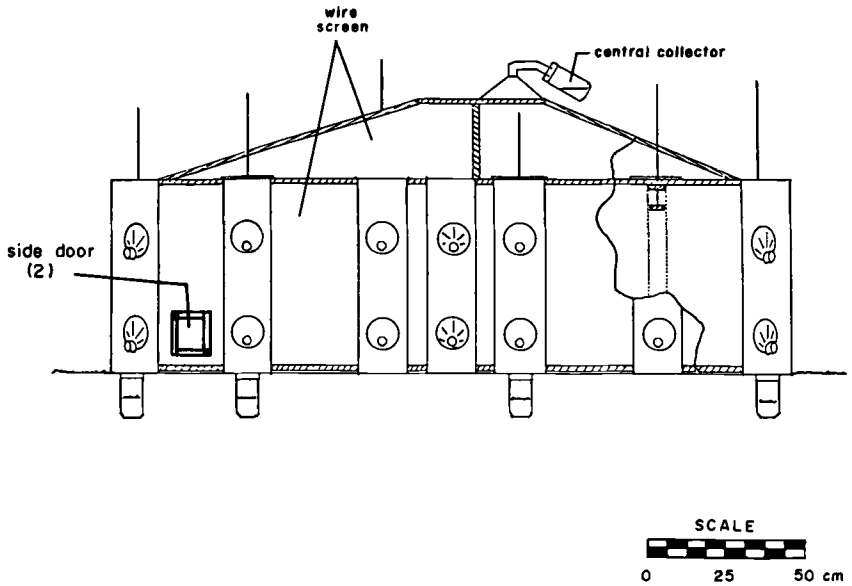

FIG. 1—*Lateral view of the immigration-emergence trap. Cutaway section shows interior details of one of the six ingress funnel-baffle-pitfall units. The twelve emigrant jars and six underground service conduits are not shown.*

Several refinements and additions to the previous trap [*26*] were incorporated in this scaled-up version. These include (*a*) arranging ingress and egress funnels at two heights, ground level and 35 cm (14 in.) high, to ensure more evenhanded capture of surface-active and aerial arthropod species; (*b*) enlarging coverage of metal screening to the sides and top margins of the trap (approximately 60% coverage) to reduce shading effects and to enhance ventilation; (*c*) adding a hinged roof to facilitate access to the trap interior;

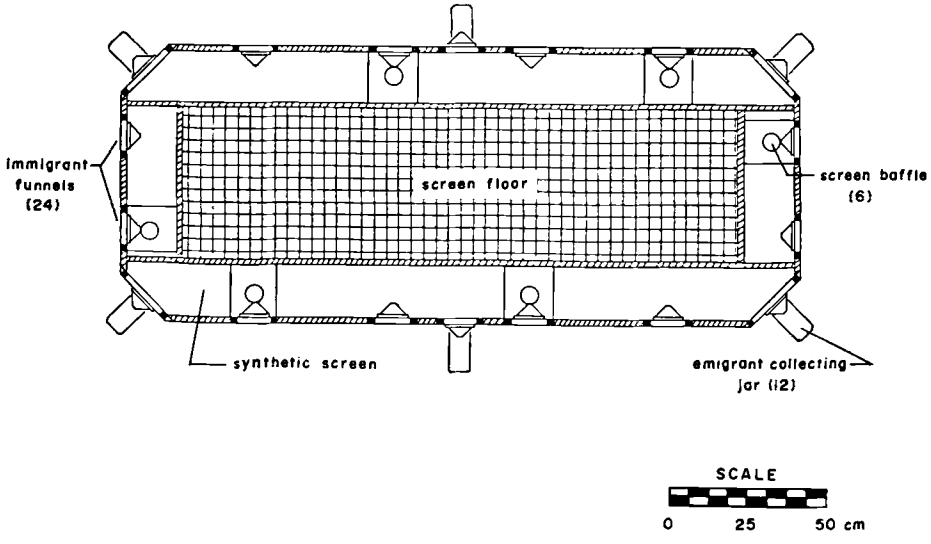

FIG. 2—*Overhead view of trap shown without hinged roof.*

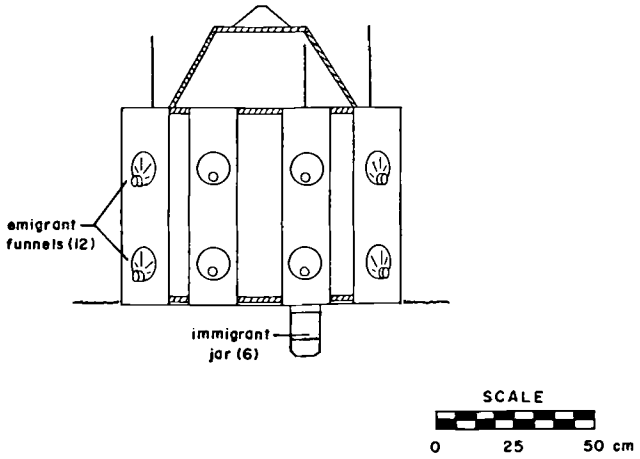

FIG. 3—*End view of trap. Underground conduits and emigrant jars are not shown.*

(*d*) adding a roof-mounted transparent window, 15 by 10 cm (6 by 4 in.), for photographic purposes; (*e*) adding two small side doors, 18 by 18 cm (7.2 by 7.2 in.), for collecting soil and tissue samples and for retrieving meterological instruments; and (*f*) adding a "selectively permeable" trap floor, fashioned from 2.5 cm^2 (1 $in.^2$) galvanized screen, to prevent entry of large vertebrate scavengers. This design, however, does not prevent the entry of small vertebrates, such as the whiptail lizard (genus *Cnemidophorus*).[4]

Details of Trap Construction and Building Specifications

The trap is a framed rectangular box that measures 220 by 90 cm (88 by 36 in.) at its base and stands 60 cm (24 in.) high. A 30-cm (12-in.)-high hinged roof extends the overall height of the trap to 90 cm (36 in.) (Fig. 1). Framing for the trap was constructed of 4.3 by 4.3-cm (1.75 by 1.75 in.) strips ripped from birch or pine two-by-fours. Exterior-grade plywood of 1.25 cm (½ in.) thickness was used for all side, bottom, and roof panels. Following trap frame construction, all wood surfaces were coated with a water-resistant

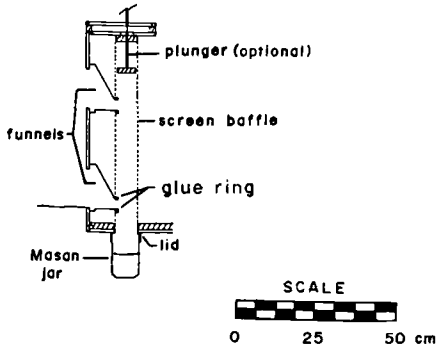

FIG. 4—*Half-section of one of the six funnel-baffle-pitfall units. During collection, an optional plunger is used to purge the baffle of uncaptured insects.*

[4]Schoenly, K. and Smartt, R. A., personal observations, 1990.

varnish or sealant. These dimensions provide ample space for one average-sized human cadaver (approximately 65 kg [145 lb]) or one medium-sized pig (25 to 60 kg [55 to 130 lb]). A list of materials for one fully functioning trap is provided in the Appendix; the cost of materials based on 1988–1989 retail dollars was approximately $600.

Eighteen side panels, measuring 17 by 60 cm (6.8 by 24 in.), were cut from a single plywood sheet. Two 10.5-cm (4.2 in.) holes, spaced 35 cm (14 in.) apart, were drilled into each of the 18 panels for a total of 36 holes. Thirty-six yellow plastic funnels, measuring 11.5 cm (4.6 in.) in diameter, were cemented over the drilled holes with hot glue and stapled. These funnels are of the type with off-center flues, designed to fit snugly over 1-qt motor-oil cans. Yellow funnels were chosen because this color transmits more natural light into the trap, compared with red, green, and blue funnels of the same type, and provide the most muted color against the surrounding landscape. These translucent funnels also stimulate positive phototaxis among emerging flies. Before the funnels were glued to the plywood panels, their flues were oriented to the "six o'clock" position; in the field this orientation gives surface-active arthropods a level surface when entering the trap (Fig. 4). Next, a 6.5-m (20.1-ft) section of 60-cm-wide aluminum window screen was wrapped around the trap wall and stapled in place. Screen was also needed for the roof and top edges of the trap. Twelve of the 18 side panels were fastened to the trap wall with wood screws; 4 of the remaining 6 panels covered the expanded corners of the trap (Figs. 1–3). The 4 corner and 2 center-most panels were fastened with their funnels facing outward (Fig. 1). All joining edges of the 18 panels were sealed to the sidewalls with melted glue.

Details of the funnel-baffle-pitfall assembly are shown in Figs. 4 and 5. A vertical screen baffle, running the entire height of the trap, was fashioned by stapling and gluing together two long edges of a 20 by 60-cm (8 by 24-in.) section of synthetic (Fiberglas) screen. The cylindrical baffle was then turned inside out, and one end was slipped over a 6.5-cm (2.6-in.)-diameter plywood circle and secured with staples and glue. The long axis of the baffle was positioned vertically behind an ingress side panel, and the plywood end of the baffle was then bolted to the top edge of the trap with 2 to 3.8-cm (1.5-in.) machine screws. The other end of the baffle was pushed through a predrilled 6.5-cm (2.6-in.) hole in the trap floor, pulled taut, and fastened to the trap floor with staples and glue. Next, two perpendicular slits were made in the screen where the baffle joined each ingress funnel. A baffle-funnel joint was made with a bead ring of melted glue (Figs. 4 and 5). Entry into the baffle had to be unobstructed and smooth. The pitfall killing jar was a 1.06-L (1 qt) canning jar. Its ringed lid was positioned under one of the baffle openings in the plywood floor and fastened securely with six small finishing nails and hot glue (Fig. 6). An optional plunger, fashioned from a 90-cm (36-in.) section of threaded rod material (0.55 cm in diameter) and a 5.8-cm (2.3-in.)-diameter plywood circle, was inserted into the baffle and tested for ease of movement. The above procedures were repeated for the other five units.

Six of the 13 emigrant killing jars, also of the 1.06-L size, covered the upper row of egress funnels. Each jar hung from the funnel in a fixed downward position by a cradle (Fig. 7), fashioned from one 5-cm (2-in.) section of 7.5-cm (3-in.)-diameter PVC pipe, one spring-loaded latch, five S-hooks, and assorted hardware (eye bolts, screw eyes, steel chain) (see Appendix). Service to a jar requires unlatching its cradle from the trap wall. Six of the remaining seven emigrant jars covered the lower row of egress funnels. These jars do not require cradles because they are held in place in a fixed downward position with surrounding soil. The last jar was used for the pyramid-shaped collector in the roof. Figure 8 shows the individual components needed for that assembly: one 8-in. (20-cm)-diameter plastic funnel and assorted fittings of 1¼-in.-diameter (3.2 cm) PVC pipe (see Appendix).

Two side doors, measuring 15 by 15 cm (6 by 6 in.), were fashioned from scrap pieces

FIG. 5—*Two of the six funnel-baffle-pitfall units for capturing immigrating insects (the two vertical screen cylinders shown in the right foreground and left background) (compare with Fig. 4). This photo was taken during an early phase of trap construction.*

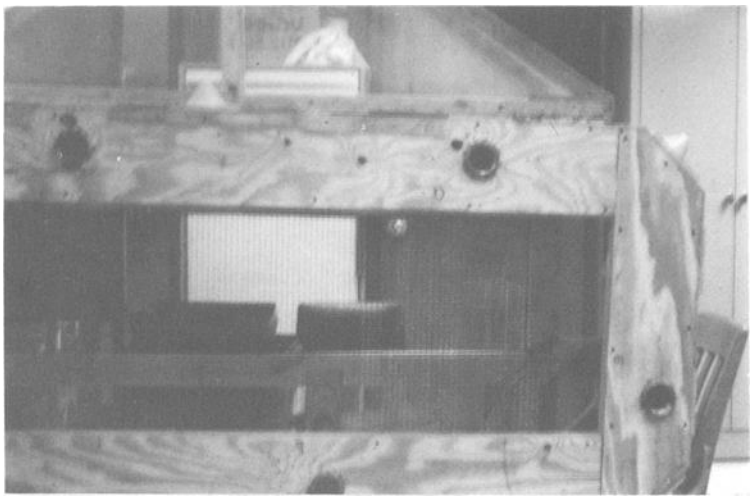

FIG. 6—*Bottom view of trap showing the "selectively permeable" screen floor and jar lids for holding the six pitfall jars (note their staggered arrangement).*

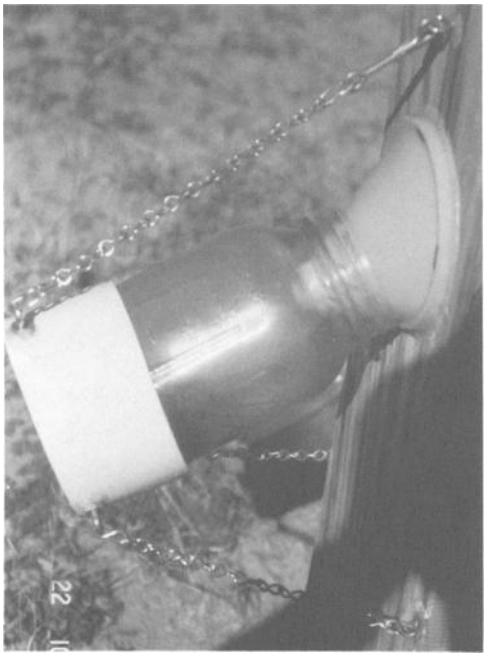

FIG. 7—*Close-up of one of the six cradle units and egress jars for capturing emigrating and emerging insects. The jar is removed by unhooking the top-mounted spring-loaded latch* (upper right corner).

of 4.3 by 4.3-cm (1.7 by 1.7-in.) wood strips, metal screen, and rubber moldings (Figs. 1 and 9). Each door was fastened to the trap by two 6.3-cm (2.5-in.)-long bolts and wing nuts.

Figure 10 shows one of the six underground conduit assemblies. Each unit was fashioned from two 15-cm (6-in.)-diameter PVC pipe fittings: a 45° elbow, and a T-connector. After the elbow was cemented to the middle arm of the T-connector, the two-piece unit was oriented in a vertical, elbow-up position. The top arm of the T-connector was slipped

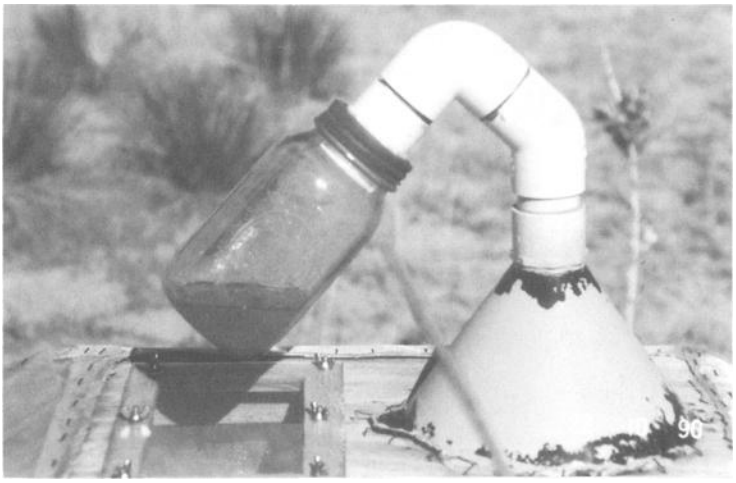

FIG. 8—*Close-up of trap roof showing funnel, egress jar (for capturing emerging/emigrating insects), and window (for photographic access) (compare with Fig. 1).*

over an immigrant jar, rotated until the elbow was aligned with the front of the trap, and secured to the plywood floor using four angle-iron brackets. A loose-fitting end cap with an attached door handle provided an easily removable lid for each conduit (Fig. 10, *lower right corner*). To remove a jar, one reached into the conduit, unscrewed it from the ringed lid, and manuevered it out of the conduit open end first. The reach to the jar was approximately 35 cm (14 in.).

Trap Placement and Operation

When selecting a potential study site, one should avoid areas of high human activity not only because they lack security but also because a large fraction of the local arthropod fauna is synanthropic (that is, associated with man), which can mask normal successional patterns. If long-term studies are planned, individual traps could be enclosed by chain-link cages [*6*], each measuring no less than 4 m long by 2 m wide by 2 m high (13.3 by 6.7 by 6.7 ft). Installation of a lockable gate and remote security system should also be considered, even if only pig carcasses are employed. For baseline studies, the trap should rest on level ground on well-drained soil. If more than one trap is used and replicates are desired, replicate traps should be placed in microhabitats that share similar ground cover, proximity to large vegetation or physical landmarks, and exposure to sunlight or shade. Traps should also be spaced at least 100 m apart[5] to minimize possible habituation effects [*30*].

A 4.5 m^2 plot, measuring 3 by 1½ m (5.4 yd^2, 3.3 by 1.3 yd), was cleared for trap placement. After the plot was smoothed, the trap was placed in position, and the locations of soil impressions left by the six conduits were noted. The trap was then removed from the marked plot, and excavation began on the six holes (Fig. 11). Proper installation also required that we dig a 25-cm (10-in.)-wide by 3-cm (1.2-in.)-deep trench, corresponding to the plywood-enclosed area of the trap floor. Care was taken not to disturb the smaller rectangular plot bounded by the soil trench because this was where the cadaver would be placed. Excavation was complete when the bottom rims of all ground level funnels were flush with the surrounding soil and when the screen floor rested atop the soil surface of the undisturbed plot (Fig. 12). Also, because immature flies and beetles of many

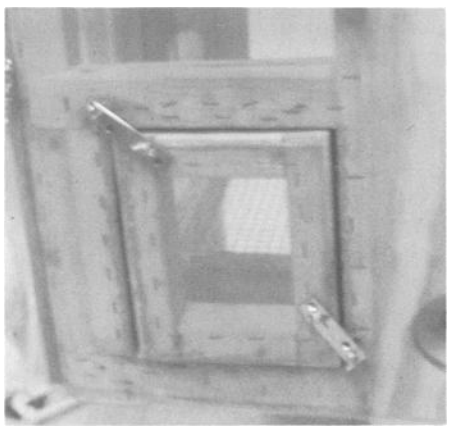

FIG. 9—*Close-up of one of the two side doors (15 by 15 cm) for collecting soil and tissue samples and retrieving meterological instruments (compare with Fig. 1). Each door is fastened to the trap wall with two removable wing nuts.*

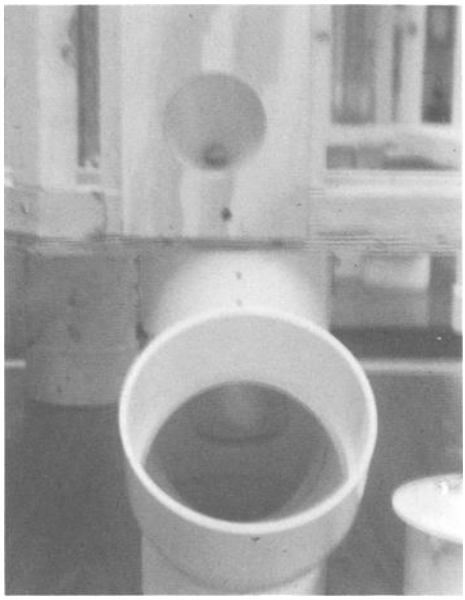

FIG. 10—*Close-up of one of the six conduits for removing and servicing ingress jars; the end plug for this unit is shown in the lower right corner.*

carrion-associated species burrow into the surrounding soil to complete development, the plywood floor should be covered with native soil to extend the area of pupation and emergence around the cadaver. Soil was also built up around the trap to give surface-active species unbroken access to ground-level funnels. This procedure also minimizes losses of arthropods under the trap floor. The trap should settle for at least one week before experiments begin to minimize "digging-in-effects" [*31*].

After the cadaver was positioned on the galvanized screen floor, the trap was closed and locked. Final preparations included checking seals on the two side doors and roof and securing all plungers to their "up" position (that is the piston end of each plunger must be situated above the upper row funnel). Conduit lids were fitted loosely into elbows, and each unit was covered with native soil (Fig. 13).

Collecting jars were filled one-third full with either a 50:50 mixture of glycerol and water or Leech's solution [*29*], a mixture containing 600 mL water, 400 mL ethylene glycol (antifreeze coolant), and 1 mL detergent. When added to pitfall traps, these solutions continue to kill and preserve specimens for up to seven days before requiring recharging [*32*], and each carries no noticeable odor, at least to human senses. Because rates of evaporation are much lower for these two solutions than ethanol-based agents, both are well suited for use in arid climates.

Frequency of Collections and Data Collection Procedures

It has become routine practice in summer and spring carrion studies to monitor cadavers at least once daily for the first two to five weeks (for example, Refs *13*, *18–20*, *33*, and

[5]Goff, M. L., personal communication, Feb. 1989.

FIG. 11—*Field plot shown after excavation of the six conduit holes. These holes guide excavation of the 25-cm-wide by 3-cm-deep trench. The inside rectangular plot (bounded by the trench) is left undisturbed for cadaver placement.*

FIG. 12—*Final field placement should insure that the bottom rims of all ground level funnels are flush with the surrounding soil. No gap should exist between the screen floor and the undisturbed plot inside. The perforations in the screen floor (see square holes) allow the investigator to collect soil samples from the trap interior.*

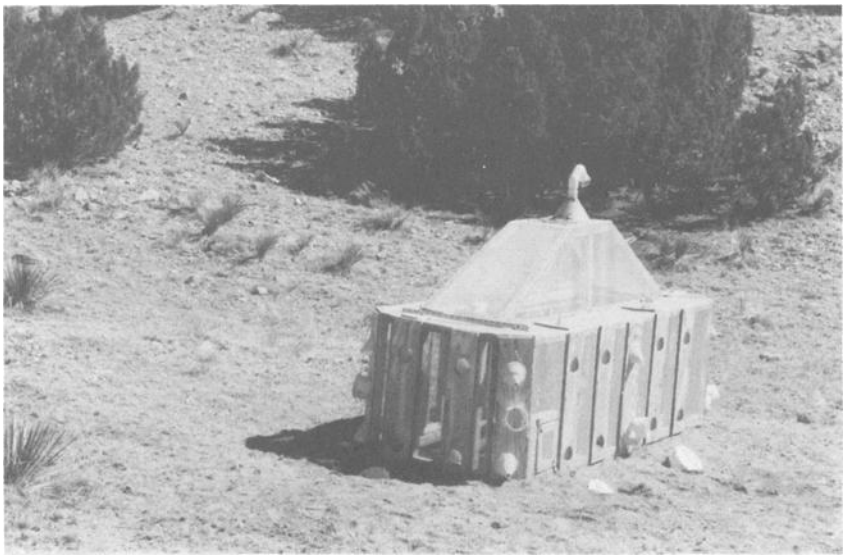

FIG. 13—*Trap in place in the field. The trap should settle for at least one week before experiments begin to minimize digging-in effects caused by the excavation.*

34], and generally once thereafter every few days until observations are terminated [*18*, *20*]. Examination of 23 summer carrion studies reveals that, on the average, researchers make 20 daily site visits per experimental trial.[6] During late autumn and winter carrion trials, much of the captured fauna may be comprised of incidental or accidental species, species that use the carcass for shelter. However, some researchers have found a specialized winter fauna [*35*,*36*] composed of the larvae of carrion-feeding winter gnats (Diptera: Trichoceridae).

During each trap visit, jars were emptied and recharged using fresh or recycled solution. Before immigrant jars were removed, plungers were lowered to ground level to purge baffles of uncollected arthropods. This step insures a contemporaneous collection.

To study the effects of carrion decay on the soil fauna, soil samples taken beneath and adjacent to the carcass can be collected at a depth of 2 to 3 cm using a soil corer or trowel [*2*,*37*]. Extraction of arthropods from soil samples can be performed using modified Berlese or Tullgren funnels [*38*]. It is important to note that, long after remains disappear on the surface, succession continues underground. Therefore, traps used in previous field trials should be moved to a new site several metres away before the next field trial begins. This procedure ensures natural synchrony between the faunas living on the carcass and those in the soil.

Several workers have reported that internal carcass temperatures rise during periods of active decay due to the combined actions of putrefaction processes and maggot masses [*2*,*14*,*19*,*20*]. Penetration thermometers inserted into natural cadaveral orifices and maggot masses, and contact thermometers affixed to the skin surfaces of cadavers, can be used to monitor internal and surface carcass temperatures, respectively.

Both pathologists and anthropologists have critical questions about the rates of decomposition and skeletonization as a guide to determination of time since death. Consequently, both pathology and anthropology should be involved in monitoring the process through direct examination supplemented with a photographic record.

[6]Schoenly, K., unpublished data, 1991.

A weather station should be established at the study site to provide a diary of local weather changes. Recording hygrothermographs and barographs are ideal for monitoring changes in relative humidity, ambient air temperature, and atmospheric pressure because these instruments record data continuously over extended periods. Instruments to record soil temperature, rainfall/snowfall, and wind speed/direction should also be locally installed.

Preliminary Capture Results and Decay Rates in New Mexico

A checklist of arthropod families found on carrion at five different locations in the southwestern United States is given in Table 1. The carrion taxa listed for Budaghers, New Mexico,[7] and El Paso, Texas, were collected from rabbit or pig carcasses using immigration-emergence traps [*19*,*26*,*27*]. Arthropods listed for the Hueco Mountains, Aden Crater, and White Sands sites were collected from rabbit carcasses [*18*] using conventional hand-sorting techniques [*2*,*37*].

The number of arthropod taxa (number of families) recorded from the five sites varied widely, from 12 for Aden Crater to 28 for the Hueco Mountains. Interestingly, the more taxonomically dissimilar Aden Crater and Hueco Mountains sites are only 85 km apart, compared with the greater between-site distances for the more faunistically similar El Paso, Budaghers, and White Sands sites. Comparison of the five sites also reveals a high degree of between-site similarity in shared taxa: histerids, tenebrionids, trogids, calliphorids, sarcophagids, and ants were found at each of the five sites. Most importantly, this similarity holds regardless of whether traps were used or not. Picture-winged flies (Family Otitidae) were collected by McKinnerney at each of her three sites, but were absent from the trap-based collections at El Paso (examination of the Budaghers fauna has not yet uncovered otitid flies). Nevertheless, it is sufficient to say that the numbers of different kinds of arthropod taxa recovered from immigration-emergence traps fell neatly within the range of taxa collected using more conventional approaches (15 and 21 taxa versus 12 to 28 taxa) (Table 1). In the future, it would be valuable to compare conventional and trap-assisted catches in the same location. This procedure would allow a more conclusive test of possible cage effects and the role large vertebrate scavengers play in carcass reduction, and would provide badly needed quantitative data on relative and absolute abundances of locally occurring, forensically important species.

Experience in the central region of New Mexico has shown that complete skeletonization of human bodies can be reached in six months, while if initial exposure is late in the year and the body is sheltered, more than two years could be required to reach the same level [*25*]. In other regions of the state, the process can be accelerated or retarded, depending upon the elevation and climatic regime. Clearly, local conditions greatly affect the rates of decomposition and skeletonization, but a reliable database for a single area is a necessary step before reasonable generalizations can be made about other areas.

Trap Microclimate Tests

Peterson noted that entomologists have traditionally assumed that climatic conditions inside experimental cages are generally similar to outside environmental conditions [*39*]. Such an assumption runs the serious risk of underestimating the impact cage effects may play on extrapolation of experimentally derived results. The well-known positive correlation between air temperature and maggot development rate is one example where serious miscalculation could result if cage effects went unchecked. For instance, Reiter showed that *Calliphora vicina* maggots required development times of 1 to 16 days for

[7]Schoenly, K. and Griest, K., unpublished data, 1990.

TABLE 1—*Inventory of arthropod orders and families collected on various sizes and types of mammal carrion from different locations in the Chihuahuan Desert: only families known to participate in the carrion decay process (that is, necrophagous, predaceous, and omnivorous taxa) are included; minor or incidental taxa are not included.*

Taxon	Budaghers, NM[a,b]	El Paso, TX[b,c]	Hueco Mountains, TX[d]	Aden Crater, NM[d]	White Sands, NM[d]
Orthoptera (grasshoppers)					
Acrididae (short-horned grasshoppers)	X		X		
Hemiptera (true bugs)					
Reduviidae (assassin bugs)			X		
Coleoptera (beetles)					
Carabidae (ground beetles)	X			X	
Cleridae (checkered beetles)	X		X	X	X
Dermestidae (skin beetles)	X	X	X		X
Histeridae (hister beetles)	X	X	X	X	X
Nitidulidae (sap beetles)			X		
Scarabaeidae (tumblebugs)	X	X		X	
Silphidae (carrion beetles)	X	X	X		X
Staphylinidae (rove beetles)	X	X	X		
Tenebrionidae (darkling beetles)	X	X	X	X	X
Trogidae (trogid beetles)	X	X	X	X	X
Lepidoptera (moths)					
Geometridae (geometrid moths)			X		
Noctuidae (noctuid moths)	X		X		

Diptera (true flies)					
Anthomyiidae (anthomyiids)					X
Asilidae (robber flies)	X		X		
Calliphoridae (blowflies)	X	X	X	X	X
Muscidae (muscid flies)	X	X	X		
Otitidae (picture-winged flies)			X	X	X
Piophilidae (skipper flies)			X		
Sarcophagidae (flesh flies)	X	X	X	X	X
Tachinidae (tachinid flies)			X	X	
Tephritidae (fruit flies)			X		
Hymenoptera (ants, wasps, bees)					
Andrenidae (panurgid bees)			X		
Apidae (honey bees)			X		
Braconidae (braconid wasps)	X		X	X	X
Formicidae (ants)	X	X	X	X	X
Halictidae (halicitid bees)			X		
Pompilidae (spider wasps)		X			
Vespidae (potter wasps)	X	X	X		
Phalangida (harvestmen)					
Opilionidae (daddy longlegs)	X		X		
Araneida (spiders)	X	X	X		X
Solpugida (sun-scorpions)	X	X			
Total taxa	21	15	28	12	13

[a]This study (from collections examined through October 1990).
[b]Based on catches from immigration-emergence traps.
[c]From Schoenly and Reid [*19*] and Schoenly [*26,28*].
[d]From McKinnerney [*18*].

maggots to reach 10 mm in body length when reared at temperatures ranging from 7 to 35°C (Ref *40*, estimated from Fig. 45 in Ref *22*). Thus, before field trials began, we monitored meterological conditions inside and outside an empty trap to determine differences in air and soil surface temperatures, humidity, evaporation, and light.

Ambient air and soil surface temperatures, recorded inside and outside an empty trap, are shown in Fig. 14. Ten sets of readings were taken over a 22-h period on 18 to 19 Aug. 1989 at a desert site near Socorro, New Mexico (approximately 40 miles south of Albuquerque, New Mexico). Air temperatures were recorded using a pair of maximum-minimum thermometers. Soil surface temperatures were recorded using two penetration-type dial thermometers inserted into the soil at a depth of 1 cm [*28*]. To simulate operational conditions of the trap, 300 mL of Leech's solution [*29*] was added to each of the 19 trap jars prior to taking the first set of readings.

The temperature curves in each pair-wise test manifested similar shapes and spanned similar ranges (Fig. 14). However, air temperatures inside the trap were approximately 8°C cooler, on average, than surrounding air temperatures (24.7 versus 32.2°C) with the largest difference (10°C) noted during mid-morning (Fig. 14). Similarly, soil surface temperatures, on average, were lower inside the trap than surrounding soil temperatures (27.5 versus 36.6°C), but the largest difference of 12°C occurred during early evening (1900 h). Most of the smaller differences in air and soil surface temperatures for each pair of readings occurred at late evening (2050 h) and at high noon (1200 h), when shading effects were less pronounced. These results clearly indicate the presence of an appreciable cage effect, at least with regard to air and soil surface temperatures. Repeating these trap tests with a carcass should yield smaller differences between inside and outside air temperatures because rising carcass temperatures, generated by maggot masses and internal anaerobic processes, would warm the inside trap temperatures, at least during active decay periods. Indeed, Schoenly found that both surface and interior core temperatures of two rabbit carcasses undergoing active decay in a desert climate were consistently warmer than outside air temperatures during summer [*28*]. These test results

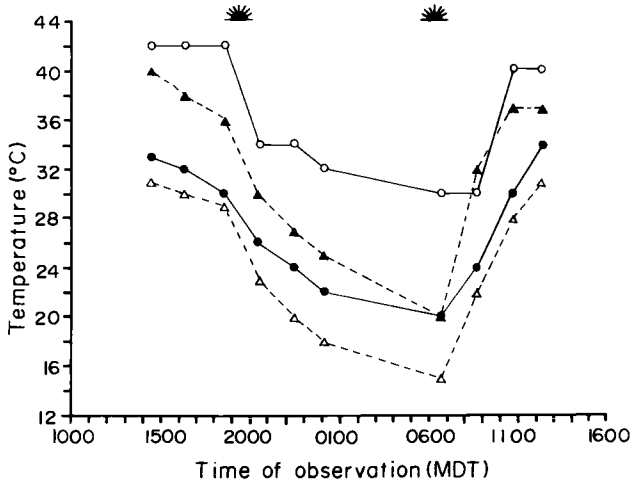

FIG. 14—*Soil and ambient air temperatures inside and outside an empty trap recorded over a 22-h period (1440 to 1220 h) on 18–19 Aug. 1989 near Socorro, New Mexico. Open symbols indicate trap air* (triangles), *and outside soil surface* (circles) *temperatures; closed symbols indicate outside air* (triangles), *and trap soil surface* (circles) *temperatures. Partial sun symbols show approximate periods of sunset and sunrise (MDT).*

underscore the need to record air and soil surface temperatures both inside and outside the experimental enclosures.

In addition to temperature, pair-wise readings of relative humidity were collected at the same site and time using a wet-dry bulb sling psychrometer. On average, relative humidity was only slightly lower inside the trap (54.6%) than outside (57.8%), with the largest differences occurring at early evening (1855 h) and early morning (0650 h). The range of humidities was smaller inside the trap (36 to 78%) than outside (32 to 88%), suggesting that the trap provided a buffering effect against a more variable environment outside.

Evaporation rates were estimated by placing identical plastic bowls containing 250 mL of water on comparable soil inside and outside the trap for 20 h. The amount of water lost through evaporation was estimated using a graduated cylinder. Losses of 70 and 50 mL were recorded from the outside and inside bowls, respectively, yielding average hourly losses of 3.5 mL outside and 2.5 mL inside. Such values are comparable given the wide swings in air and soil temperatures recorded above (Fig. 14).

Light-penetration tests revealed that the screen mesh surrounding the trap reduced light intensity to an average of 48% of outside readings. That estimate is rough, however, given the mosaic of light and dark patches made by different trap materials. Although small mesh metal screen makes an excellent insect-proof covering, it is more opaque to light than white nylon or 16 by 20-gauge cotton gauze; only glass or clear plastic permits greater than 75% light penetration [*39*]. Smith reports that some blowfly species (for example, *Phaenicia* spp.) are positively heliotropic, preferring open sunlight to shade [*22*]. Greenberg, however, reported nocturnal oviposition activity in three blowfly species, *Phaenicia sericata* (Meigen), *Phormia regina* (Meigen), and *Calliphora vicina* (Robinson-Desvoidy) [*41*]. During summer and fall field trials, we found maggot masses on trap-enclosed pig carcasses[8]; therefore, subdued light conditions in the trap interior did not prevent successful oviposition and larviposition by carrion-breeding flies. The general relevance of Smith and Greenberg's claims to these results will become more apparent when more data on trap-assisted collections are gathered and when other experiments on blowfly oviposition behavior become available.

Prospects and Recommendations for Future Research

This study presents an experimental field protocol for investigating the postmortem interval and offers preliminary field data on desert climatic factors and carrion arthropod activity. A detailed comparison of soft and hard-tissue degradation and arthropod invasion sequences in xeric, mesic, arctic, and tropical environments is sorely needed. The combination of entomological, pathological, and anthropological indicators in such studies should open new avenues for discovery of important and little-known facts about the pattern and process of decay in human bodies for medicolegal purposes. It is hoped that, when sufficient data are gathered in each knowledge area, one could fix the PMI using one set of indicators, and use the other indicators as a way of verifying and narrowing the margin.

Finally, we propose that future researchers make it a routine practice to use freshly acquired carcasses, instead of frozen carcasses, in their studies of cadaver decomposition and arthropod succession. In a study of postmorten changes in freeze-thawed and fresh-killed rat carcasses, Micozzi observed markedly higher rates of external decay and disarticulation in freeze-thawed animals than in freshly killed, untreated controls [*42*]. Increased mechanical injury in the tissues of previously frozen animals coincided with the known destructive actions of freeze-thawing. Although Micozzi concluded that the skel-

[8]Schoenly, K. and Griest, K., personal observations, 1990.

etal disarticulation sequence was not demonstrably different in the two treatments, it remains to be seen if PMI estimates or carrion arthropod invasion sequences differ between fresh-killed and freeze-thawed animals. Unless freeze-thawing is a variable under study in an investigation, we join Micozzi in urging the use of fresh carcasses, whenever possible, over previously frozen carrion in future field investigations.

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APPENDIX—Materials List for Immigration-Emergence Trap

Item, Description, and Purpose	Quantity
A. Lumber	
1. Two-by-fours, each ripped into two 2 by 2-in. strips (for trap frame and roof, side doors)	85 linear ft
2. Plywood, 4 by 8-ft sheets, ½-in. thick, exterior grade (for side and top panels, floor, roof, and baffles)	2
B. Window screen/hardware cloth	
1. Aluminum window screen, 26-in. roll (for sides, top edge, and roof)	35 ft
2. Fiberglass window screen, 26-in. roll (for ingress baffles)	4 ft
3. Hardware cloth, 1-in.^{2} mesh (for selectively permeable trap floor)	12 ft^2
C. Plastic funnels	
1. Yellow funnels, 4-in. diameter, with off-center flues (for ingress and egress funnel assemblies)	36 count
2. Funnel, 8-in. diameter (for pyramid-shaped collector in roof)	1 count

APPENDIX—(*Continued*)

Item, Description, and Purpose	Quantity
D. Glassware/other plastic items	
1. Canning jars with rings and lids, 1-qt size (ingress and egress collecting jars)	19 count
2. Transparent acrylic sheet, ¼-in. thick, 6 by 6 in. (for roof window)	1 count
3. Low pressure, 6-in.-diameter PVC pipe fittings: T-unit, 45° elbow, end cap (parts for underground conduit)	6 each
4. Low pressure, 3-in.-diameter PVC pipe (for 6 egress jar holders)	1 ft
5. Low pressure, 1¼-in.-diameter PVC pipe fittings: 90° elbow, 45° elbow, 2 end couplers (parts for roof-mounted egress jar)	1 each
6. Low pressure, 1¼-in.-diameter PVC pipe (for roof-mounted egress jar)	1 ft
E. Hardware	
1. Steel rod material, ¼-in.-diameter (part for baffle plungers)	16 ft
2. Steel hinges, heavy duty, 6 in. (for hinged roof)	1 pair
3. Drywall screws, 3 in. long (chief fasteners for trap frame)	500 count
4. Finishing nails, 1-in. long (secondary fasteners)	500 count
5. Steel staples, 5/16-in., staple gun variety (for attaching screen to cage frame)	3000 count
6. Steel chain (part for egress jar cradles)	7 ft
7. Screw eyes and eyebolts (parts for egress jar cradles)	36 count
8. S-hooks (part for egress jar cradles)	30 count
9. Spring-loaded gate latches (for egress jar cradles)	6 count
10. Assorted machine screws (for assembling ingress baffles, underground conduits, side doors, etc.)	150 count
11. Angle iron brackets (for anchoring underground conduits to trap floor)	24 count
F. Sealants and adhesives	
1. Marine varnish/waterseal (for sealing wood surfaces)	1 gal
2. Glue sticks (general adhesive)	48 count
3. Wood glue (wood adhesive)	1 qt
G. Arthropod killing and preserving agents	
1. Antifreeze coolant (arthropod killing agent)	5 gal/trial
2. Glycerol (arthropod killing agent)	5 gal/trial
3. Ethanol, 95% (arthropod preservative)	10 gal/trial

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